Proceedings of the Asia Design and Innovation Conference (ADIC) 2024

Asia Chapter of the Design Society

Hosted by

College of Design and Innovation, Tongji University

December 5 - 6, 2024

Shanghai, China

Editors

Yong Se Kim

Yutaka Nomaguchi

Chun-Hsien Chen

Xiangyang Xin

Linna Hu

Meng Wang

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同济大学设计创意学院

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Foreword

Asia Design and Innovation Conference 2024

The Asia Design and Innovation Conference (ADIC) was held on December 5 and 6, 2024, in Shanghai, China, as the event of the Asia Chapter of the Design Society. The local host is the College of Design and Innovation, Tongji University.

ADIC is an expanded continuation of the Asia Design Engineering Workshops (A-DEWS), held in 2014, 2015, 2016 and 2017 as the events of the Asia Chapter of the Design Society (DS). The DS Asia Chapter has started in 2014 with the mission to foster collaboration in design research, education and practices in Asia while connecting to the other active communities of design research and education.

The theme of ADIC 2024 is Design and Innovation for Sustainable Economy addressing both basic and fundamental design and innovation research and education issues and new breakthrough research and education topics including design for circular and digital economy. ADIC 2024 program included keynote speeches, invited theme speeches and discussions, presentations of full papers and presentation-only papers, and networking with the conference dinner, farewell reception, lunch and coffee breaks. While ADIC is the event of the Asia Chapter, paper presentations and participations from other regions than Asia made ADIC 2024 support the mission of the Asia Chapter and DS very well.

After peer review process of the full papers, 53 papers were selected from more than 90 submissions to be included in the ADIC 2024 proceedings. ADIC 2024 papers encompass the following areas:

Design Process and Theory, Design Methods and Tools
Design Thinking, Design for Innovation
Human Behavior in Design, Design Creativity, Design Cognition
Design Learning and Education
AI in Design, Design Informatics, Data-Driven Design
Sustainable Design, Design for Circular Economy
Product-Service Systems Design, Service Design
Experience Design, Interaction Design
Design for Architecture and Cultural Issues.

In addition to those published full papers, the conference presented excellent keynote speeches by vice president Yongqi Lou of Tongji University, dean Juyoung Chang of school of design at Dongseo University, and professor Jarmo Suominen at the college of design and innovation at Tongji University. A discussion session was also held with invited theme speeches by professor Cees de Bont, the head of the industrial design division, National Univ. of Singapore, professor Jianxi Luo of City University of Hong Kong, and professor Tobias Larsson of Blekinge Institute of Technology. Nine presentation only talks were also given in the conference.

Acknowledgements

I would like to thank Dean Fei Hu of the College of Design and Innovation (D&I) at Tongji University for fullest support at the college-level to host ADIC 2024. The local organizing committee composed of D&I faculty and staff colleagues as well as a few Shanghai local colleagues made this conference possible with excellent organization and operation with effort to improve conference experience values of participants and other stakeholders.

From the inception of the idea of holding a conference of the Asia Chapter in 2024 after some years of low chapter activity over the past several years, the co-chairs of the conference, Yutaka Nomaguchi of Osaka University, Chun-Hsien Chen of Nanyang Tech. University and Xiangyang Xin of Tongji University, made wonderful collaboration with timely suggestions and enthusiastic encouragements. I am sure they will lead the chapter in the coming years with further collaboration with active members of the Chapter. Big thanks to co-chairs of ADIC 2024. I also would like to thank the member of the Program Committee composed of design research and education leaders in Asia and in Europe in promoting the call for papers with excellent recommendations on the program of the conference. International reviewers made great contribution in keeping the quality of the conference very high with their invaluable contributions in thorough and fast reviews with remarkable comments. I am proud that our review process was really superb matching the qualities of journal reviews.

Foremost, the biggest thanks go to the authors and speakers of the conference as well as active participants. A critical value of academic conferences like ADIC is active discussions among participants sparked by presentations of contributed papers and keynote and invited speeches.

Finally I would like to mention that Linna Hu and Meng Wang, young professors at Tongji D&I, made continued contributions, from the very initial stage all the way to final publication, in both organizing part and technical program part.

Professor Yong Se KIM
College of Design and Innovation
Tongji University

December 2024

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a worldwide community

The Design Society is an international non-governmental, non-profit making organization whose members share a common interest in design. It strives to contribute to a broad and established understanding of all aspects of design and to promote the use of results and knowledge for the good of humanity.

The Design Society was founded in 2000, taking on the previous activities and responsibilities of the Workshop Design Konstruction (WDK) Society, especially the organization of the International Conference on Engineering Design (ICED) series of conferences, which had been running since 1981. Since 2000 the Society has organized ICED conferences in Stockholm in 2003, Melbourne in 2005, Paris in 2007, Stanford in 2009, Copenhagen in 2011, and Seoul in 2013 with its continuation in Milan, Vancouver, Delft, Gothenburg, Bordeaux, and Dallas.

The Society has members from over forty countries and it organizes diverse events including conference with regional chapters and special interest groups. The Society is very active in publishing papers and proceedings on design topics.

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- Creating and evolving a formal body of knowledge about design
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- Promoting publications and their dissemination
- Organising international and national conferences and workshops
- Establishing Special Interest Groups and other specialist activities
- Co-operating with other bodies with complementary areas of interest

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DESIGNING A METHOD FOR IMPROVED (DISTRIBUTED) CULTURAL UNDERSTANDING – THE CULTURAL DIMENSIONS THINKING CAPS

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ABSTRACT

Designing a method, that assists culturally diverse and distributed development teams in better understanding each other's perspectives and, therefore, improving their creative output and collaboration is the goal of this contribution. To do so, the research on cultural theories and different creativity methods that engage communication have been analyzed. Thereafter, a method has been designed combining interactive elements that engage creativity with the content of what lies behind cultural differences. The method uses Hofstede's Cultural Dimensions as a theoretical basis and De Bono's six thinking hats as a practical basis to reach its goal and therefore successfully support multicultural distributed development teams in solving problems creatively.

Keywords: creative problem-solving, creativity method, distributed product development, method design, supporting culturally diverse teams

1 INTRODUCTION

As businesses expand globally, the prevalence of distributed teams in product development has increased. The increased complexity of products requires a variety of skills and disciplines to meet the demands of these future products [1, 2]. Product development is a creative act leading to the creation of innovative products. Creativity in this context is defined by originality and appropriateness [3]. With team members spread across different regions and countries, the cultural impact on creativity has become a critical factor. Culture influences how individuals think, communicate, and solve problems, all of which can affect the creativity of distributed teams [4–10].

One significant way culture impacts creativity is through communication. While some cultures emphasize direct and assertive communication, others favor indirect and implicit styles. These differences can cause misunderstandings and hinder creativity when team members from diverse cultural backgrounds work together. For instance, a team member from a culture that values direct communication may become frustrated with a colleague who communicates indirectly, leading to collaboration difficulties and a reduction of creative ideas. On the other hand, a colleague who is used to indirect communication might be hurt by direct criticism and might not be able to see it objectively even if it was meant that way. This emotional involvement might again lead to emotions getting in the way of being creative. [4–6, 9, 11]

This circumstance calls for a specific support combining these aspects: designing a method that improves cultural understanding and works in a distributed setting. Developing such a method is the overarching goal of this contribution.

2 STATE OF THE ART

2.1 Distributed Product Development

Even though product development is a widely studied and relevant topic, there is no uniform definition in the literature; Many different definitions and approaches exist. Blessing and Chakrabarti [12] state that product development is a complex, multifaceted, and dynamic phenomenon in an organization's micro and macro context. This phenomenon involves people, a product under development, related processes, knowledge, methods, and tools. Furthermore, Albers and Gausemeier [13] complement the definition of product development by stating that it can be seen as a stage within a broader context, including activities such as product creation, strategic planning, production system planning, and production of the finished product. Bavendiek et al. [14] note that the development of increasingly complex products requires the collaboration of experts, some of whom might be available only in different locations [15]. The definition of distributed product development in this contribution includes three aspects: the spatial separation (organizational or temporal) of at least one team member, the need to use communication technologies, and collaboration that takes place either synchronously or asynchronously [16–18].

2.2 Influences on Creativity in Distributed Product Development

Creativity and collaboration are two elements that enable teams to successfully work together and achieve their goals [19]. Creativity refers to a process either in the brain or shared that results in something that can be considered new and useful in some point of time [20]. This importance extends beyond teams working in a distributed setting; collaboration and creativity pose unique challenges for distributed teams. Research indicates that working together tends to be more seamless when teams are in the same physical space than when not [21]. In particular, creative processes may be perceived as challenging in virtual teams [22]. Brucks and Levav also examined the influence of different modes of communication (virtual or face-to-face) on creativity [23]. They concluded that face-to-face meetings lead to better idea generation, indicating that communication and personal human interaction significantly influence creativity. Nevertheless, the quality of the ideas and the decision of which idea to pursue may be independent of the mode of collaboration, whether face-to-face or distributed [23]. This finding is attributed to differences in the amount of information conveyed through screens compared to face-to-face communication and a narrowed visual focus that makes branching out and generating new ideas more challenging in a virtual setting. The necessity for support of creativity is further substantiated by Dühr [17], who asserts that creative teamwork, an essential component of the product development process, requires specific assistance in a distributed setting.

2.3 Cultural Influence on Creativity in Distributed Product Development

Culturally diverse teams possess a unique ability to generate innovative and high-quality solutions due to the range of perspectives, experiences, and approaches they contribute. This blend of different viewpoints frequently results in fresh insights and creative problem-solving strategies. However, it is essential to acknowledge that these teams are also more likely to encounter challenges in collaboration. Cultural norms, communication styles, and implicit assumptions can cause misunderstandings or friction within the team. Thus, while the potential for enhanced creativity and quality is significant, culturally diverse teams must implement strategies for effective communication, mutual understanding, and collaborative synergy to fully realize their collective potential [24].

In essence, culture functions both to integrate and differentiate. Individuals within a particular cultural background find a sense of identity and purpose through cultural norms that offer behavioral guidelines and a framework for interaction. Conversely, those outside this cultural framework might find certain attributes unfamiliar or requiring adaptation. These attributes can be limiting if they do not align with their cultural concept, potentially leading to disengagement from a system with unshared or divergent cultural distinctions [25].

Creativity can be supported through many methods, one of them being the Six-Thinking-Hats by De Bono [26]. This method is introduced in more detail since it is used as basis in the method design. This method facilitates switching the point of view to analyze a problem from multiple perspectives. Participants adopt a specific perspective represented by a hat in a specific color to collaboratively generate ideas before transitioning to a different viewpoint with the next hat [27]. As a decision-making and creativity method, each “hat” symbolizes a distinct perspective or cognitive style: white for objective facts and information, red for emotions and feelings, black for critical analysis and identifying potential issues, yellow for optimism and benefits, green for creativity and innovation, and blue for overseeing the thinking process [26].

To understand culture in more detail Hofstede’s cultural dimensions can be used. Since Hofstede’s theory still has the broadest data baseline up until today and is widely accepted and used his theory is used as another basis for the method design in this contribution and therefore introduced in more detail here [28–31]. The model has five cultural dimensions: Power Distance Index, Individualism vs.

Collectivism, Masculinity vs. Femininity, Uncertainty Avoidance Index, and Long-Term vs. Short-Term Orientation. Subsequently, Michael Minkov introduced a sixth dimension, Indulgence vs. Restraint [32]. This model's goal is to help understand cultural differences, enhance intercultural communication, and design communication strategies. It is used for managing culturally diverse teams and understanding the influence of culture on work dynamics and business practices. Additionally, it provides a foundation for academic research, facilitating empirical studies and intercultural training programs [28–31]. Each dimension offers insights into specific aspects of a culture's value system. The Power Distance Index measures the level to which less powerful members of a team accept and expect unequal power distribution [33]. Individualism vs. Collectivism evaluates whether individuals prefer a loose social framework, where they are expected to care for their closest family, or a tighter framework, where individuals look out for a broader circle of people [34]. Masculinity vs. Femininity reflects the distribution of gender roles, with masculine societies focused on competition and success, whereas feminine societies prioritize caring for others and enjoying a quality life. The Uncertainty Avoidance Index measures the tolerance for uncertainty and ambiguity, indicating how comfortable one feels in unstructured situations. Long-Term vs. Short-Term Orientation relates to the focus of people's efforts, whether on future benefits (long-term) or current benefits (short-term). Indulgence vs. Restraint assesses the degree to which free gratification of basic and natural human desires related to enjoying life and having fun is granted, as opposed to suppressing gratification and regulating it through strict social norms [29, 32].

3 METHODOLOGICAL APPROACH

The subordinate goal of this contribution is to design a method, that assists culturally diverse and distributed teams in better understanding each other's perspectives and, therefore, improving their creative output and collaboration.

To do so, the research on cultural theories and different creativity methods that engage communication have been analyzed. With this knowledge at hand, a method has been designed combining interactive elements that engage creativity with the content of what lies behind cultural differences. To accomplish this, the following research questions have been raised:

- RQ1: How can the knowledge of cultural differences be communicated without exposing oneself?
- RQ2: Which creativity method can be used to build the basis for creative discussions but can still be applied in an acceptable way for different cultures?
- RQ3: How can a method be designed that integrates changing cultural perspectives and engaging in creative discussions in a culturally appropriate way?
- RQ4: How can such a method be visually supported to assist the team in the application process?

4 RESULTS

The Cultural Dimensions Thinking Caps Method is designed to facilitate a shift in perspectives among team members. It seeks to transcend the limitation of individual viewpoints by encouraging members to consider issues from their standpoint and adopt and understand the perspectives of their peers. The method consists of three blocks: Cultural Dimensions (based on [29]); the Cultural Dimensions Thinking Caps (based on [29] and the Six Thinking Hats by [26]); and Discussion and Consolidation of the Cultural Dimensions Thinking Caps, two explanation activities and a discussion activity, respectively. The recommended duration of the whole method is 50 minutes or more to gain an understanding of Hofstede's Cultural Dimensions and the introduced Cultural Dimensions Thinking Caps and then properly discuss a chosen topic on the team's collaboration (fundamental topics like "communication within the team" or "punctuality in the team") from different perspectives. The duration depends on the team's size and the number of cultural dimensions represented by the team members.

4.1 Design of the Method

First, the Cultural Dimension Thinking Caps starts by introducing the six cultural dimensions defined by Hofstede [29]. Flexibility is provided here by only introducing the dimensions that should be used for discussion in the next step. The moderator can select dimensions that are specifically relevant based on the cultures represented by the team members or based on observation of the team prior to the workshop. If hierarchical structures concern the team, looking at the dimension of masculinity versus

femininity could be most relevant. This explanatory block and the following one form the foundational section of the method, which is essential for understanding and successfully applying it.
To avoid overgeneralization and the potential for stereotyping, the approach strategically avoids focusing on specific cultures identified by region or nation. Instead, the method is structured around Hofstede's Cultural Dimensions [29, 32, 35], a model recognized and respected in academic and applied settings [36]. Hofstede's framework was chosen for its clarity and ease of understanding, making it accessible to a broad audience [36]. To ensure clarity for those unfamiliar with Hofstede's work, the term Cultural Dimensions is used predominantly, with a reference to Hofstede provided at the beginning of the block.
Each cultural dimension is described clearly and concisely for quick and efficient learning. The use of colors and pictograms to represent the extremes of each dimension enhances the overall comprehensibility for the user. It allows dimensions to be more easily identified in the method application, especially if used as part of the entirety of the Cultural Synergy Spectrum method. This section concludes with an overview that includes descriptions of each cultural dimension, its extremes, and an explanation of the colors and pictograms chosen.
Table 1 illustrates the detailed description of each cultural dimension, along with its extremes, their descriptions, the chosen color, and the pictogram.

Table 1. Detailed description of the cultural dimensions Power Distance and Individualism vs. Collectivism based on [32]

Cultural Dimension	Power Distance		Individualism vs. Collectivism	
Description	This dimension is about how people view power and authority. In some cultures, it is normal for bosses to have much power and for everyone else to follow orders. In other cultures, people like everyone to have a say and be more equal.		This dimension is about whether people think doing things independently or as a group is more important. In some places, people focus on their own goals, while group or family goals are more important in others.	
Extremes	High	Low	Individualistic	Collectivistic
Description Extremes	People accept a hierarchical order without much question.	People prefer equality and challenge authority more readily.	Individualistic societies prioritize individual goals and rights.	Collectivistic societies emphasize group cohesion, loyalty, and collective well-being.
Color	Royal blue represents dignity, intelligence, and authority.	Light blue symbolizes openness, tranquility, and equality.	Red is a color of strength, passion, and boldness.	Green denotes community, growth, and harmony.
Pictogram	Crown	Handshake	Single Person	Two People

Table 2. Detailed description of the cultural dimensions Masculinity vs. Femininity and Uncertainty Avoidance based on [32]

Cultural Dimension	Masculinity vs. Femininity		Uncertainty Avoidance	
Description	This dimension is not about men and women but what a culture thinks is important. Some places value being the best and winning, while others care more about everyone getting along and being happy.		How comfortable people feel with uncertain or unknown things. Some cultures do not like surprises and prefer clear rules, while others are okay with taking things as they come and being more flexible.	
Extremes	Masculinity	Femininity	High	Low

Description Extremes	Societies with masculine values prefer achievement, heroism, assertiveness, and material rewards for success.	Societies with feminine values prefer cooperation, modesty, caring for the weak, and quality of life.	High Uncertainty Avoidance cultures try to minimize such situations by strict laws and rules.	Low Uncertainty Avoidance cultures accept differing thoughts or ideas more.
Color	Black conveys power, sophistication, and formality.	Light Purple represents care, compassion, and empathy.	Dark Grey symbolizes caution and formality.	Light Blue, suggesting calmness and flexibility.
Pictogram	Flexed Biceps	Tulip	Lock	Wave

Table 3. Detailed description of the cultural dimensions Long-/Short-Term Orientation and Indulgence vs. Restraint based on [32]

Cultural Dimension	Long-/Short-Term Orientation		Indulgence vs. Restraint	
Description	People's attitude toward the future or the present. Some cultures often plan for the long term and think about the future, while others focus more on the present and keep traditions.		This dimension is about whether people in a culture like to enjoy life and have fun freely or think it is better to control and limit these things. Some places are more about having fun and relaxing, while others believe in being stricter and more controlled.	
Extremes	Long-Term	Short-Term	Indulgence	Restraint
Description Extremes	Cultures with a long-term orientation are more pragmatic, modest, and future-oriented.	Cultures with a short-term orientation are more normative, respect traditions, and focus on quick results.	Cultures classified under indulgence generally allow relatively free gratification of basic and natural human desires related to enjoying life and having fun.	A society that suppresses gratification of needs and regulates it using strict social norms.
Color	Yellow indicates optimism and enlightenment.	Light Brown denotes practicality and reliability.	Bright Orange is vibrant and energetic.	Cool Blue reflects self-control and responsibility
Pictogram	Star	Hourglass	Party Popper	Person in Lotus Position

4.2 Application

After the theoretical segment of this method, users engage in a perspective-shifting activity block. The primary objective of this block is to facilitate a dynamic exchange of viewpoints, enabling users to articulate their perspectives and to understand and engage with the perspectives of other team members. The structure of this block is as follows: First, users select the Cultural Dimension Caps that reflect the diverse composition of the team. This selection sets the stage for a multifaceted discussion on a single topic central to team collaboration. A pre-selection of caps can increase efficiency in time management, especially when time is of the essence.

The range of potential discussion topics includes but is not limited to, strategies for meeting deadlines, effective teamwork and task delegation, setting and achieving goals, maintaining morale, and methods for resolving misunderstandings or conflicts.
A unique feature of this discussion is its structured format. The discussion begins from the perspective of the first Cap selected and continues for a predetermined period of time. At the end of this period, the discussion transitions seamlessly to the perspective of the next Cap. This process is repeated until all perspectives represented by the selected Caps have been explored. After discussing each perspective, there is a consolidation phase where users document their learnings and insights from each perspective in the space provided in the template. This methodical approach ensures a comprehensive understanding and integration of different perspectives within the team.

4.3 Visualization

The Cultural Dimensions Thinking Caps method was implemented in Miro [37] as the interactive whiteboard makes the operationalization of all three blocks possible. The information needed to be displayed for the first block, the Cultural Dimensions (based on [29, 35]); the information needed to be displayed for the Cultural Dimensions Thinking Caps (based on Hofstede [29, 35] and the Six Thinking Hats by De Bono [26]) as well as the possibility to take notes for each participant in this second block; and the possibility to collect everybody's insights in Discussion and Consolidation of the Cultural Dimensions Thinking Caps. Figure 1 shows an excerpt of the visualization for the first block, the Cultural Dimensions.

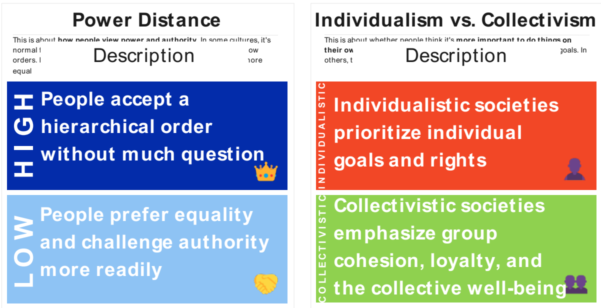

Figure 1. Excerpt from Hofstede's Cultural Dimensions - visualization of the first block within the Cultural Dimensions Thinking Caps

Figure 2 shows an excerpt of the visualization of the second block of the Cultural Dimensions Thinking Caps. The second block incorporates the information for each Cap; the excerpt shows the Caps for the two dimensions represented in Figure 1.

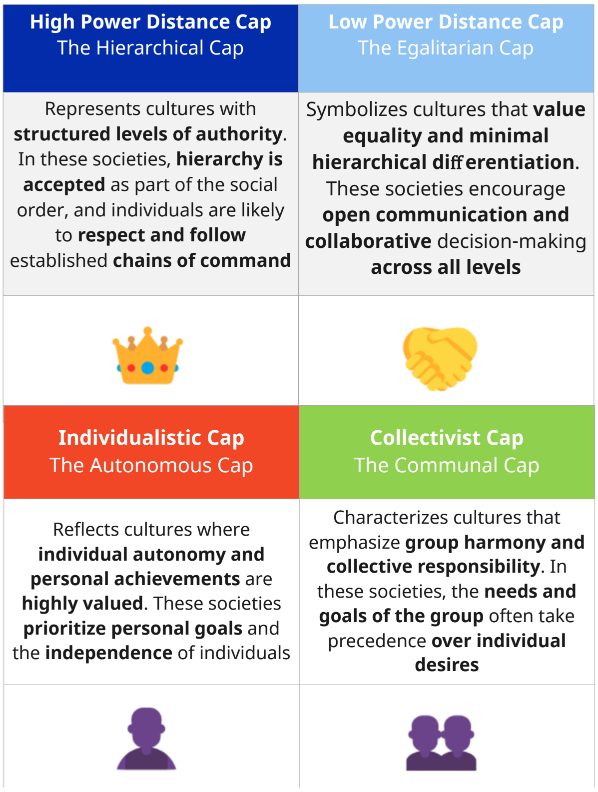

Figure 2. Excerpt from the Cultural Dimensions Thinking Caps - visualization of the second block within the Cultural Dimensions Thinking Caps

Furthermore, this second block provides the possibility to take notes. Sticky notes can be taken from the so-called "Sticky note parking lot" at any time and used either anonymously or with name.
The visualization of the third block is again divided into the different Caps (see Figure 3). Insights and learnings generated when discussing in the viewpoint of a certain Cap can be directly noted in the respective card. The discussion takes place in smaller groups first, with different groups using different Caps. Afterward, the insights are collected by the entire group.

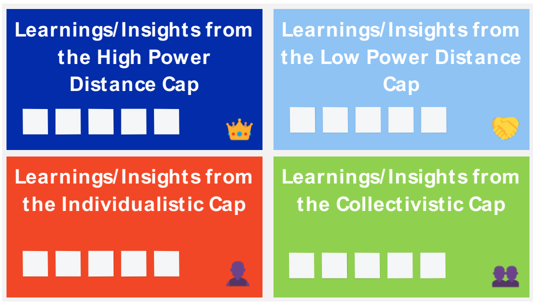

Figure 3. Excerpt from the discussion and consolidation - visualization of the third block within the Cultural Dimensions Thinking Caps

5 DISCUSSION AND CONCLUSION

An initial validation was carried out while using the Cultural Dimensions Thinking Caps as part of the Cultural Synergy Spectrum Method [38]. Thus, the Cultural Dimensions Thinking Caps Method should be also validated individually. When the method is carried out within approximately 40 minutes of a method application workshop that is 120 minutes long, the feedback given is not only focused on the Cultural Dimensions Thinking Caps but on a lot more impressions. Therefore, applying only the Cultural Dimensions Thinking Caps and asking the participants for feedback directly on this method separately will help get more detailed impressions from the participants. An individual application is planned as a next step and is supposed to give insight into further improvement potential. Furthermore, there are other options for communication about culture than using the Cultural Dimensions by Hofstede [29]. It has been used as the basis for this contribution and the developed method because it is widely used and based on the broadest explorative study on cultural differences. Other creativity methods could have also been used to engage the team in creative exchange.

The use of Miro as the tool to assist in the method execution might also not be optimal for every team. It is to be validated again in different settings to see if this tool is suitable for a multitude of teams or if it might be restricted to users who are familiar with such digital tools.

The first research question, how to communicate cultural differences, was answered by implementing Hofstede's six cultural dimensions in their opposing characterization as perspectives to be taken when discussing a problem. The resulting twelve options are formulated in the thinking Caps. A fundamental topic such as "communication within the team" or "punctuality in the team" can be discussed using the different Caps. The participants are divided into groups, and each group takes one of the twelve Thinking Caps and discusses the problem from that perspective. The findings are then consolidated. The way the discussion is led is based on De Bono's [26] Six Thinking Hats, which answers the second research question. The group is divided into different sub-groups that "wear" pre-selected Cultural Thinking Caps. A facilitator can make the selection in advance. To accommodate different communication styles, ideas for the Cap's perspective on the fundamental topic can first be written down silently and anonymously. Those who wish to participate in a discussion from their perspective can then do so. At the end of the discussion, the sub-group takes a different Cap, i.e., a different characterization of a cultural dimension, and starts again with the silent generation of ideas on the fundamental topic from this perspective. The time needed for this activity can be adjusted by changing the size of the sub-groups and the number of Caps each subgroup takes. The whole group then collect the insights gathered on the fundamental topic from the different perspectives.

The third research question is answered by systematically combining the elements of the first two research questions. And finally, one way to visually support the method is to use the Miro whiteboard which worked well in this initial validation but has been critically discussed for future applications.

Since the method has only been validated in the context of applying a broader method, the next step is to validate the Cultural Dimensions Thinking Caps individually with different culturally diverse and distributed teams.

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USING AI TO GENERATE SHORT VIDEOS AS STIMULI FOR SUPPORTING DESIGN CREATIVITY

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ABSTRACT
Current computational idea generation support tools, especially Artificial Intelligence (AI)-driven ones, mainly produce textual and/or pictorial stimuli to support design creativity at the early stages of design. However, the impact of using AI-generated videos as creative design stimuli remains underexplored. With the advancement in computational power and AI models, generating videos to support design creativity is possible. This paper explores using state-of-the-art AI models to generate short videos as stimuli for supporting creative idea generation. A qualitative case study is conducted, involving design experts comparing the effects of textual, pictorial and video stimuli to support the generation of a flying car concept. The case study indicates that design experts prefer video stimuli generated using AI models as they offer dynamic motion and mechanism information that provides more inspiration. Although the current AI-generated video stimuli have limitations, such as lacking technical details, this paper highlights the great potential of using video to prompt design creativity.

Keywords: Design Creativity, Idea Generation, AI in Design, Design Stimuli, AI-generated Video

1 INTRODUCTION

Creativity, which is defined as "the process by which something so judged (to be creative) is produced" [1], is an integral part of product design and development. It is a significant process during the early stages of design that underpins the generation of innovative ideas for breakthrough products [2, 3]. Although consumers and end-users might not explicitly indicate creativity as a design requirement, creativity is considered a fundamental element for product innovation ultimately leading to product success [2, 4]. Studies have revealed that creative products are more likely to succeed in crowdfunding campaigns [5] and design competition awards [6]. Therefore, it is often a requirement for designers to come up with creative design ideas for informing the development of innovative products. However, coming up with ideas, especially creative ones, is a challenging task.

Generic tools such as Brainstorming [7], mind mapping [8], and Six Thinking Hats [9], were often employed by designers to support the generation of creative design ideas. To better support idea generation in the design context, design-focused tools and methods were developed, including TRIZ [10], design-by-analogy and WordTree [11], the Creativity Diamond Framework [12], the three-driven combinational creativity approach [13], and the 77 design heuristics [14]. These tools or methods help users remove mental blocks and expand design search spaces, but require the users to possess sufficient knowledge and experience to master. In recent years, computational means have been increasingly explored to support designers in generating creative ideas. These new computational approaches or tools often generate stimuli in textual and/or pictorial forms as sources of inspiration or information to support designers in creative idea generation [15]. With the advancement of computational power and Artificial Intelligence (AI) algorithms, AI-generated videos are becoming possible and affordable. However, few studies have explored employing AI algorithms for generating videos to prompt designers in creative idea generation. It also remains unclear whether videos could be used as an effective means to trigger designers' creative minds.

This paper is aimed at exploring the use of state-of-the-art AI models and algorithms to generate short videos as stimuli to support designers in generating creative design ideas. An AI tool, the IdeaMotion, is developed capable of generating short videos based on textual design descriptions. A qualitative case study is conducted to gain insights into using AI-generated videos as stimuli from the perspectives of designers. The following section reviews the related studies on computational and AI tools for supporting design creativity. Section 3 presents the details of the proposed AI video generation tool, and Section 4 showcases a case study with designers. The discussion and conclusions of the paper are presented in Sections 5 and 6, respectively.

2 RELATED WORKS

Employing computational means for supporting design creativity could be traced back to the 1990s. For example, Qian and Gero [16] developed one of the earliest computational systems for supporting design creativity finding analogical mappings through structure and behavior. Bhatta and Goel [17] proposed an autonomous design system IDeAL to support analogical designs by employing the structure–behavior–function model. Chakrabarti *et al.* [18] explored the use of text databases hierarchically by topic to aid design. Bryant *et al.* [19] presented a computational conceptual generation tool utilizingFunctional Basis and existing design knowledge to produce viable design variants. These pioneer studies laid the foundation for subsequent research and development in supporting design creativity utilising computational techniques.

Over the last decade, a number of sophisticated computational tools and approaches, leveraging AI, machine learning, natural language processing, and image processing techniques, have been developed to better support design creativity. Some of these tools provide or produce textual stimuli only to support designers. For example, Georgiev *et al.* [20] proposed a computational approach to produce new scenes through synthesizing existing scenes by thematic relations, for example, "microwave, bake, chestnut" is produced by synthesizing "fireside, roast, chestnut" and "microwave, bake, fish" as "roast" and "bake" are similar thematic relations. B-Link [21, 22] is a data-driven design support tool that helps designers discover and associate textual knowledge, which is underpinned by a large knowledge base created using academic publications. InnoGPS [23, 24] provides a text-based interactive map, which contains a technology space knowledge base created based on the US patent database, to allow designers to explore new design opportunities and directions. TechNet [25], which is a technology semantic network based on paten data, has been used to facilitate the generation of ideas [26] and representation of designs [27]. Pro-Exlpora [28] employs the Markovian model and machine learning to explore new design problems in text forms to inspire designers. Recently, with the rapid advancement of Large Language Models (LLMs), several LLM-based approaches have been proposed to support generating creative design ideas [29]. Zhu *et al.* [30] proposed a generative design approach to automatically generate bio-inspired design in the form of natural language by retrieving and mapping biological analogies using LLM. For instance, generating a piece of natural language text describing a new flying car design inspired by pterosaurs. Chen *et al.* [31] proposed an LLM-based tool to retrieve textual knowledge from a bio-inspired knowledge base and map the knowledge to support divergent thinking. Chen *et al.* [32] leveraged the Function–Behavior–Structure ontology to decompose conceptual design tasks and guide LLMs to generate high-quality textual concepts to stimulate designers.

In addition to textual stimuli, several tools and approaches have also employed images and pictures as stimuli to stimulate designers. For example, the Combinator [33, 34] simulates human combinational creativity and produces combinations of design phrases, such as "kettle cup" and "spider silk violin", with corresponding merged or overlapped images, to prompt designers. The Retriever [35] employs aspects of analogical reasoning to produce new ontologies of a desired design accompanied by an image mood board to support creative design idea generation. Generative Adversarial Network (GAN), a generative AI framework, has been investigated to produce synthesized images of two items to prompt design creativity [36]. GAN has also been used to learn a specific design style and apply the style to a target product such as producing an image of a streamlining style chair [37], as well as fusing the design features of two objects such as a horse and a bike [38], to stimulate humans in creative idea generation which has gained positive impacts. DALL·E, an AI system for creating images from natural language descriptions, has been employed to generate pictorial ideas based on textual descriptions of combinational designs such as "an avocado chair", which achieved a similar creativity level to novice designers [39]. Chen *et al.* [40] leveraged the reasoning capability of LLMs to generate design concepts employing the 5W1H method, Function–Behavior–Structure model and Kansei Engineering, and convert the textual concepts into images using text-to-image models for supporting human designers.

Producing textual (such as texts, keywords and phrases) and/or pictorial (such as images and pictures) stimuli to inspire and trigger designers' creative minds is one of the most often used methods. Such conventional formats of stimuli have been proven to have positive effects on enhancing designers' creativity. While recent advancements in computational power and AI algorithms enabled the generation of videos, explorations on AI-generated video stimuli for supporting design creativity are needed.

3 USING AI FOR GENERATING VIDEO STIMULI

An AI tool, the IdeaMotion, is thereby developed to produce short videos based on the descriptions of designs in natural language to support designers in creative idea generation. An overview of the tool is depicted in Figure 1. The designer would need to generate a piece of design description in text forms or utilize an existing design description as the input of the IdeaMotion. The tool will then extract text features from the input design description. Bidirectional Encoder Representations from Transformers (BERT), a pre-trained machine-learning model for natural language processing, is employed to capture the semantic information from the input. An attention mechanism is introduced to help the tool focus on the key semantic information relevant to video generation.

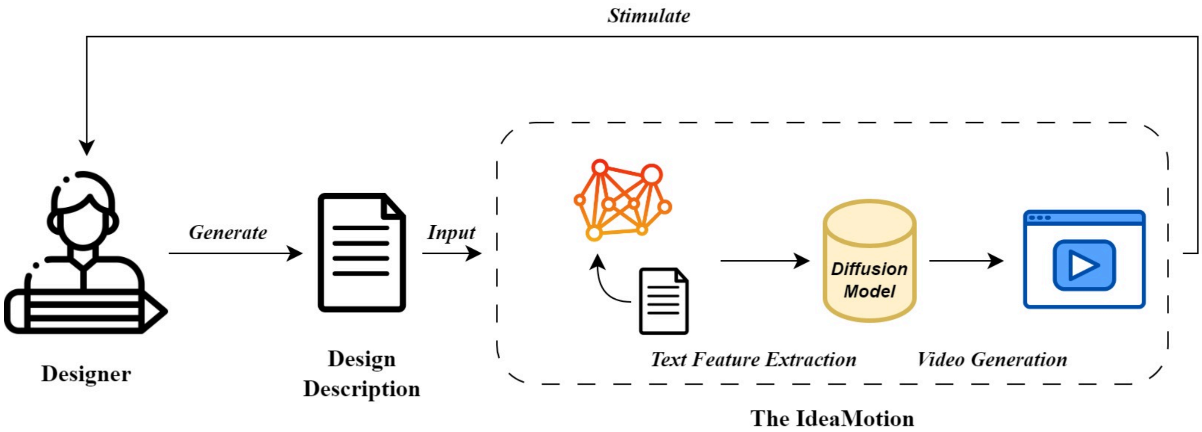


Figure 1. An Overview of the IdeaMotion

Once the key semantic features are obtained, the features are mapped to the video latent space. A readily available diffusion model based on the Unet3D structure [41] is employed to ensure the diversity and complexity of texts in the latent space are captured. The representation of the video latent space is then mapped to the video visual space to produce a video interpreting the input design description. Unet3D is a three-dimensional convolutional neural network-based structure for processing video data that can capture the spatiotemporal relationship in the video. It has an encoder for extracting high-level features and a decoder for restoring these features, which are used for video denoising and generating respectively. The IdeaMotion is packed as a web-based tool with simple user interfaces, as shown in Figure 2 and Figure 3, of which Figure 2 shows the user input interface asking the user to describe the desired design in text and Figure 3 shows the output interface playing the video generated. Due to the limitations of the models used and computational power, the generated video length has been limited to 2 seconds.

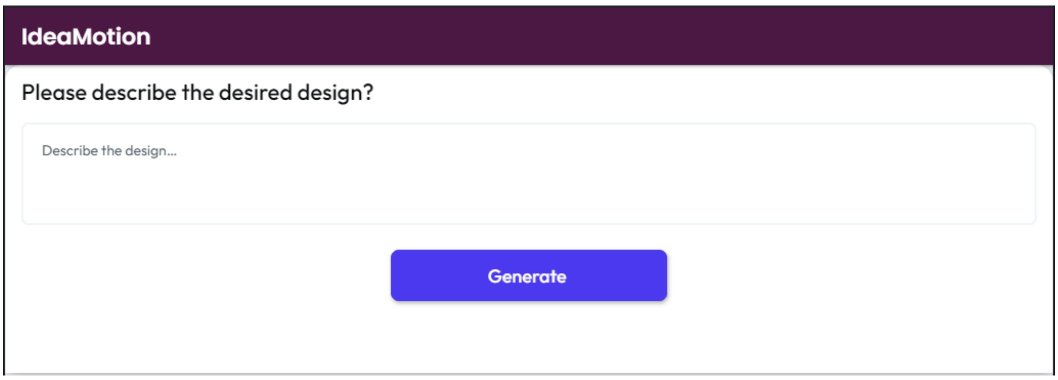


Figure 2. The User Interface of the IdeaMotion – User Input

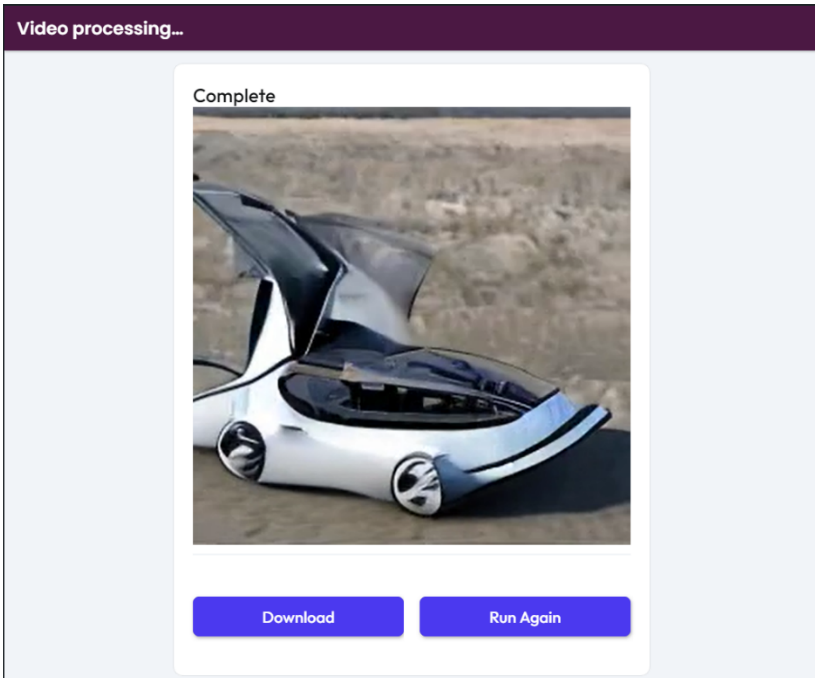
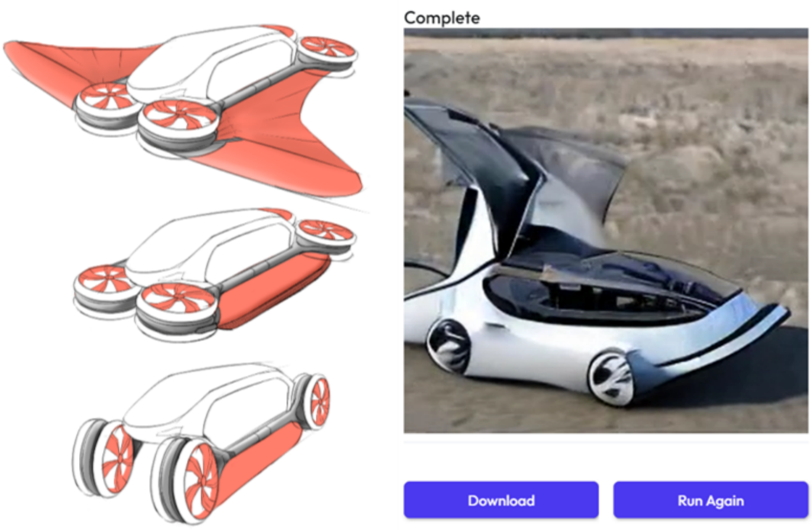


Figure 3. The User Interface of the IdeaMotion – Video Output

4 CASE STUDY

To gain insights into how video stimuli generated by the IdeaMotion support design creativity and compare with conventional textual and pictorial stimuli, a case study has been conducted involving two design engineering experts with over ten years of experience. In the case study, producing a concept of a flying car, which has often been used in design research, is adopted as the design task. Three stimuli of a "flying car" are employed and provided to the design experts, as shown in Figure 4. Figure 4(a) presents a textual stimulus describing a flying car design inspired by pterosaurs (adopted from [30]), Figure 4(b) is a pictorial stimulus created by a human designer that depicts the flying car design according to the textual description in Figure 4(a) (adapted from [30]), and Figure 4(c) is a video stimulus produced by the IdeaMotion using the textual description in Figure 4(a) as the user input.

The flying car has a body that is similar in shape to pterodactyls, with a body designed to control drag, lift, and thrust. It also has a lightweight hull and a propeller to generate thrust. The vehicle's hull is constructed of high-performance carbon fiber, inspired by the lightweight skeletons of pterosaurs. The propeller is mounted on a pivoting arm that is controlled by a joystick. The entire assembly weighs approximately 35 pounds and looks similar to a parasail. The propeller is 16 inches in diameter and is powered by a 930cc marine engine.



(a). Textual (from [30]) ***(b). Pictorial (Adapted from [30])*** ***(c). Video***

Figure 4. Textual, Pictorial, and Video Stimuli of "Flying Car"

To better showcase the video stimulus of the flying car in this paper, six time frames of images of the video with 0.4 seconds apart are presented in Figure 5. As shown in the figure, the flying car has the shape of a pterosaur with a pair of wings at the rear of the car. From 0.0 seconds to 2.0 seconds of the time frames, the fast-running car is gradually opening and extending its wings outward preparing for takeoff, which shows the progress of transforming from ground mode into flight mode.

Figure 5. The Short Video of "Flying Car" in Time Frames

Semi-structured interviews have been conducted with the two experts (Expert 1 and Expert 2) to investigate their viewpoints towards using the three types of design stimuli provided for supporting them in completing the concept generation task, as well as their perspectives on using AI-generated videos for supporting design creativity. The first question asked was "Do you use design stimuli for supporting idea generation? Which type of stimuli do you use?" Both Experts 1 and 2 indicated that they often employ stimuli to support them in idea generation. Expert 1 said "*I give priority to video, but also go for pictures sometimes. Video is kind of dynamic and shifts my attention to make me think differently rather than looking at a static image.*" Expert 2 mentioned that "*I mainly use images, sometimes use videos, but I rarely use texts*". The second question asked was "Have you used AI-generated stimuli for helping you with idea generation?" Expert 1 indicated that "*I have recently used AI-generated images, but have not used AI-generated videos.*" However, Expert 2 said that "*I rarely use AI-generated stimuli, as the quality of generated contents is not very good and sometimes might not be relevant to what I want to see*."

The design task "to produce a concept of a flying car" was then given to the experts. The three stimuli, as shown in Figure 4, were provided to the experts following the sequence of textual, pictorial, and then video stimuli to explore their views if they use such stimuli to support them in the design task. The third question "What are your thoughts on the three stimuli in helping you with the concept generation task?" For the textual stimulus, Expert 1 indicated that "*The textual stimuli will make me think but not really in a particular direction. It would take time to read the text again and again to make me think or inspire me.*" Expert 2 said "*I already have some ideas or images of a flying car in my mind by reading the text. It is good to see 'quantification' in the text such as the weight, size, material and engine model. However, I would need to spend time to generate a visualisation to showcase the design concept.*" Regarding the pictorial stimulus, Expert 1 said "*The image provides a direction. It is not really that I am going to produce something like this, but provides me with a clue or guide.*" Expert 2 said "*This is definitely better than the text, which is more tangible and inspiring. It is almost identical to what I had in mind. But, in a way, it limits imagination, such as the shape is already fixed, and lacks technical details.*" For the video stimulus, Expert 1 said "*This is the most inspiring one for me, as it involves a lot of things which I can interpret, such as the motion, the look and appearance, the loop and the mechanics, and even the environment. There is more divergent thinking looking at this, making me think in different directions.*" Expert 2 said "*It helps me visualise the motion of the design and move on to the engineering side, thinking how each component moves and joined together. But it misses the details of propellers.*" The experts were then asked "Which stimulus do you prefer?" Expert 1 indicated that the video stimulus is the first choice, followed by the pictorial and then textual stimuli. Expert 2 mentioned that the video and pictorial stimuli are the first choices rather than the textual stimulus.

Lastly, the experts were asked to express their views towards AI-generated video stimuli on design creativity in general. Expert 1 said "*Using AI-generated video stimuli is more inspiring which prompts you into different aspects of thinking and see things from different perspectives. Such a project or research in this direction would be of great benefit to design engineers.*" Expert 2 said "*Having something like this to work from at the idea generation stage is useful, especially if the generated video* *is longer. However, I think AI-generated content, like 3D images or animations, should not be considered the final form and designers should always go to further develop or revise. I believe there is a huge potential if AI can generate editable or configurable models or contents. This will further spark creativity.*"

5 DISCUSSION

Prior to showing the experts the stimuli in Figure 4, questions were asked to explore whether the experts use stimuli in idea generation. Both design experts suggested that they often use stimuli in idea generation to help them enhance their design creativity, while they both prefer pictorial and video stimuli rather than textual stimuli. Neither of the designers has previously used AI-generated video as stimuli, while one of them has previously used AI-generated images. To use the design stimuli in Figure 4 to come up with ideas to address the design task, both Experts 1 and 2 agreed that the video stimulus, which was generated by the IdeaMotion, would be their first choice. They both indicated that the video provided allowed them to visualize the motion and the mechanisms of the design. This is something that is very challenging for textual and pictorial stimuli to achieve. Both experts also agreed that the textual stimulus is the least useful one for supporting them in idea generation, and it would be quite time-consuming for them to produce or visualize a concept inspired by the text. Furthermore, Expert 2 pointed out that the video and pictorial stimuli are missing some technical details, while the textual stimulus contains useful quantifications of technical details. Considering the use of AI-generated videos as stimuli for supporting creative idea generation in general, both experts agreed such a format is useful and further research on exploring AI-generated video for supporting design creativity is promising. One of the experts indicated that the generation of editable models by AI would be a potential direction.

Therefore, concerning the case study conducted, video stimuli have significant potential to enhance creativity during idea generation. Although the current AI-generated video produced by IdeaMotion using the diffusion model lacks technical details, the video's dynamic and visual nature can inspire new ways of thinking in comparison to conventional textual and pictorial stimuli. Current AI-driven idea generation support tools mainly generate textual stimuli (e.g. [30], [31], and [32]) and pictorial stimuli (e.g. [34], [36], [37], [38], and [40]), while these textual and pictorial outputs could be potentially converted into videos by adopting AI models for video generation to provide additional inspiration enhancing design creativity. With more powerful AI models, such as Sora [42], becoming available, there is great potential to translate those quantitative technical details from text into videos providing more useful information. There are also some initial works (e.g. Text-to-CAD [43]) on generating simple CAD models, such as a plate or a gear, through text prompts. Most of these tools can only produce OBJ, STEP or STL format CAD files, while such formats only contain information regarding the shape or 3D geometry of a model limiting the capability of using the CAD model for complex tasks such as supporting video or animation. Thereby, further AI research studies are needed to explore the creation of CAD models capable of supporting video generation.

The current research has certain limitations. Firstly, the AI video generation tool, the IdeaMotion, developed in this research uses a diffusion model which limits the length of the videos generated. This limits the amount of information that could be conveyed in the video. Secondly, only a few samples and experts were involved in the study limiting the insights discovered.

6 CONCLUSIONS

This paper explores the use of AI models and algorithms for generating videos based on textual input, and implements this into a tool named the IdeaMotion. The tool uses BERT to capture semantic information from textual input and employs a Unet3D structure-based diffusion model to produce videos. A qualitative case study was conducted by interviewing two design experts to gain insights into using AI-generated videos as stimuli for supporting creative idea generation. The case study shows that video stimuli are preferred by design experts compared with pictorial and especially textual stimuli, as video stimuli provide additional information regarding the motions and mechanisms. This paper has contributed to the body of knowledge in research on design creativity and AI, which provides useful insights on AI-generated videos as stimuli for supporting design creativity. In future studies, more samples of a larger variety of objects including both dynamic and static ones will be explored by interviewing more design experts. A quantitative case study focusing on exploring how the use of AI-generated video stimuli affects the creativity level, including novelty and usefulness, of idea generation outputs in comparison with using pictorial and textual stimuli will be conducted.

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MEANING GENERATION THEORY: A BAYSEIAN APPROACHI TO SIGN × CONTEXT = MEANING

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ABSTRACT
This study proposes the "Sign × Context = Meaning (Meaningful Value)" theory for ideation in design engineering. By integrating abduction and Bayesian inference, the framework generates new meanings by shifting the contexts of signs. Case studies conducted with NEW STANDARD, Inc., validated its application in 10 product and customer experience (CX) development. While the framework demonstrates reproducible innovation, its effectiveness is influenced by cultural and contextual factors. Future research should explore AI-driven tools to enhance meaning generation across diverse contexts.

Keywords: Idea generation theory, Bayesian Inference, Product Development, Innovation of Meaning

1 INTRODUCTION

In recent years, the needs of consumers and users in the fields of design engineering and innovation have shifted beyond mere functionality to include emotional and experiential aspects [1], [2]. This shift underscores the need to delve into the socio-cultural meanings that users associate with products. Interpretive methodologies provide a valuable lens for this exploration. Schutz [3] emphasizes that individuals' daily experiences are imbued with subjective meanings shaped by their social worlds, suggesting that the meanings users attach to products are deeply embedded in their cultural and social contexts. Furthermore, hermeneutics [4] and phenomenology [5] argue that such meanings are not inherent to the objects themselves but emerge through the interaction between individuals and their cultural, emotional, and social environments. For example, a coffee cup can hold various meanings depending on the context. It might serve as a functional tool for drinking coffee, symbolize mindfulness in a quiet morning routine, represent energy and focus for work, or even act as a status symbol in specific social settings. These perspectives collectively highlight the importance of understanding products not merely as functional items but as vessels of socio-cultural significance. Therefore, in design, this suggests that consumers and users engage with products not merely as functional items but also as objects through which they express and interpret their identities and values. Notably, "innovation of meaning," one of the four categorized approaches within design thinking, has gained attention as consumers and users increasingly find special emotional and socio-cultural significance in products [6], [7]. To achieve innovation of meaning, the potential for recognizable and reproducible methodologies in design-driven research has been suggested [8]. Verganti has long emphasized an inside-out approach using design discourse [9] and a hermeneutic framework based on interpretive methodologies [10], though these concepts remain primarily theoretical, with limited empirical validation. Accordingly, we proposed and conducted empirical testing on new design-driven approaches for creating and delivering meaningful value [11].

The development of products and services has two critical aspects: first, the generation of ideas, and second, the process of realizing them. Idea-generation methods focus on creating new combinations of existing knowledge and elements through reasoning [12]. Various methodologies, such as brainstorming, the KJ method, and TRIZ, have been developed to support this process. However, methods specifically designed to generate ideas centered on meaning creation have yet to be fully established. Developing methods specifically for meaning generation would allow products and services within design engineering to evolve with more flexible, culturally and socially adaptable meanings. This, in turn, fosters the “semantic turn” [13], which enhances the experiential and affective value that consumers seek, strengthening the competitive edge of products and services.

This study proposes a theory, “Sign × Context = Meaning,” rooted in meaning generation and addressing ideation through abduction from the perspectives of design engineering and consumers’ and users’ needs. As demonstrated by the case studies of Kartell and Luceplan by Dell’Era et al. [14], this framework aims to balance meaning generation with consistency and flexibility through the interplay between technology and design. Additionally, the framework theoretically supports context-based meaning generation by explaining how the interpretation of signs changes based on context through Bayesian inference. In the future, probabilistic changes in meaning based on context can be anticipated through Bayesian reasoning, enabling a systematic approach to flexible generation of meaningful value. This framework allows for the creation of meaningful value aligned with the observed context, enhancing adaptability to diverse consumers’ and users’ needs without relying solely on implicit sense-making. In this study, we adopt a design science framework to validate the effectiveness of the “Sign × Context = Meaning” theory in achieving contextual meaning interpretation by integrating design science with practical application. Specifically, in collaboration with NEW STANDARD Inc., we evaluated how this framework could accommodate meaning generation across diverse cultural backgrounds and contexts in product design and customer and user experience (CX) development through case studies. Furthermore, through empirical research on ten product development projects, we demonstrate that this framework provides a recognizable and reproducible methodology for “innovation of meaning” in the design process.

2 METHODOLOGY

The implicit cognitive bias in creativity research has failed to adequately explain designers’ creative practices, cultural aspects, and sensitivities. Implicit cognitivism refers to the tendency to adopt cognitive-oriented perspectives and assumptions without explicitly recognizing or acknowledging them. This suggests that cognitive approaches and principles are often unconsciously integrated into theory, practice, culture, and management [15]. Therefore, this study examines the "Sign × Context = Meaning″ theory using a design science framework of Figure 1 that bridges creativity research and practical design applications [16] in Figure 2.

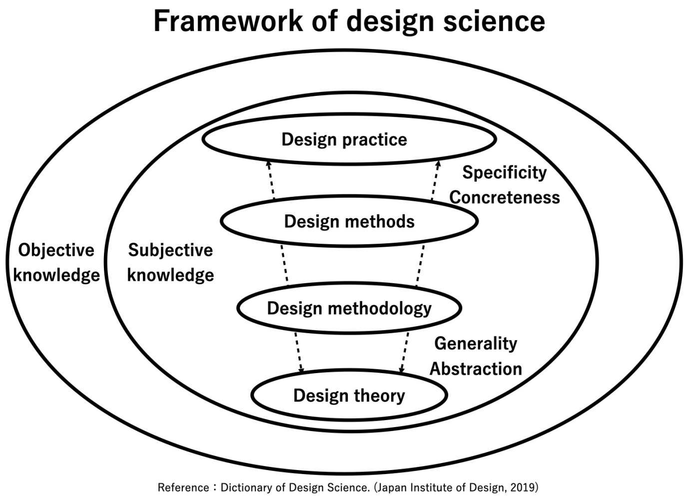

Figure 1: Framework of Design Science

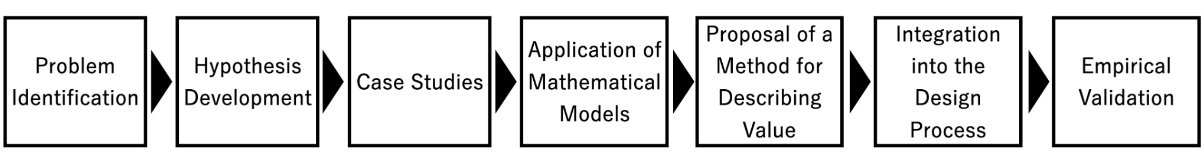

Figure 2: Research Methodology Utilizing the Design Science Framework

Contextual design [17] positions "context" as a framework to comprehensively capture users' activities, environments, behaviors, challenges, and needs. It emphasizes the importance of deeply understanding users' real-life and work environments when designing products and services, and of basing designs on that understanding. Semiotics, communication design studies, and Krippendorff's [13] "semantic turn" also highlight that people's interpretations of signs and artifacts are dependent on context. For example, the contextual interpretation of an object like beer differs between the contexts of holidays and sports viewing. In a holiday context, beer signifies relaxation, while in a sports-viewing context, it signifies excitement. Consequently, we hypothesize that by analyzing existing contexts associated with signs relevant to consumers and users, identifying new contexts that capture their attention, and combining these new contexts with signs to interpret their meanings, it is possible to generate meaningful value. Based on this hypothesis, we propose a framework grounded in design semiotics to proactively design new interpretations of meaning. As a theory of meaning generation, this study proposes the theory "Sign × Context = Meaning" a method to achieve contextual meaning interpretation.

Next, case studies were conducted. Based on the foundational concepts of the "Sign × Context = Meaning" theory, we investigated cases and considered examples of innovation of meaning to test its validity. While there is no single pattern or meaning associated with the context of a sign, we compiled several illustrative examples. To improve the reproducibility and reliability of the framework, Bayesian inference models and the free-energy principle were applied to evaluate mathematically the process by which signs and contexts interact. Furthermore, we proposed a method for describing meaningful value based on "Sign × Context = Meaning" and systematized how specific products are reinterpreted in response to different contexts, acquiring new meanings. Additionally, we explored the role of this framework within the design engineering process, clarifying how context-based meaning generation influences product design beyond mere technical functions and structures. Finally, through empirical research on 10 product development projects, we validated the practicality and effectiveness of the framework, confirming its potential as a reproducible idea-generation theory across diverse contexts. This study forms a part of the ongoing study outlined in [11], Kushi, S., & Yanagisawa, H. 2024. Innovation of meaning: Design-driven study based on the interpretive theory of new meaning.

3 RESULTS

3.1 Meaning Generation Theory: "Sign × Context = Meaning"

Building on these foundations, this study proposes a novel theory, "Sign × Context = Meaning", which extends beyond traditional methods by actively designing new meanings through the deliberate application of new contexts to signs in Figure 3. This approach systematizes the creation of meaningful value, thereby enabling a reproducible theory of idea generation for innovation of meaning.

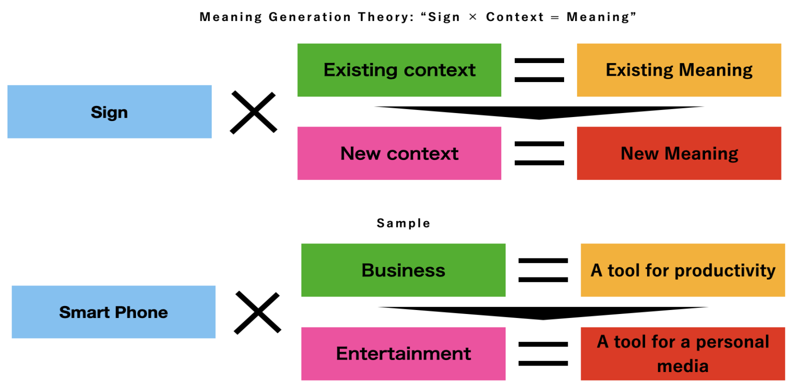

Figure 3 : Meaning Generation Theory: “Sign × Context = Meaning”

3.2 “Sign × Context = Meaning” Case Study

To test the “Sign × Context = Meaning” as framework, we explored how the meaning of a sign changes across contexts, focusing on both domestic and international examples Figure 4. This framework suggests that a sign’s meaning is not fixed, but shifts based on the context in which it is interpreted.

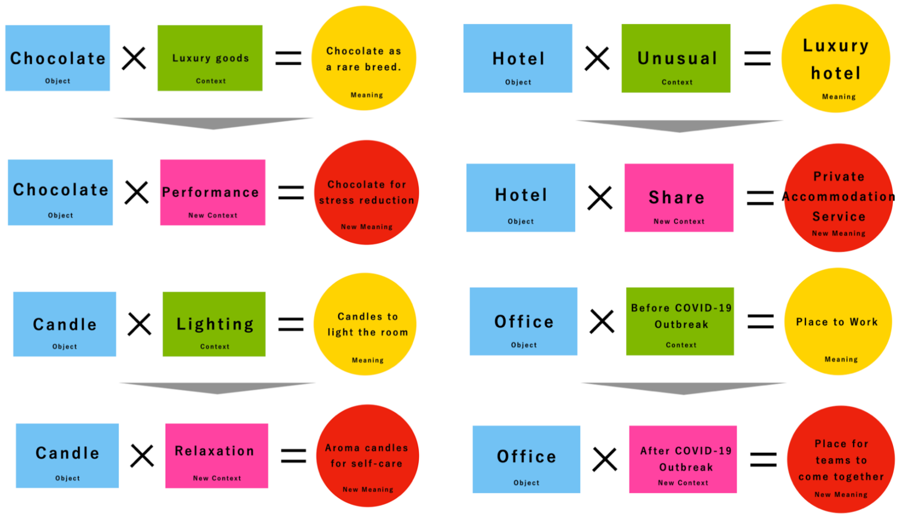

Figure 4 : Samples of Meaningful value “Sign × Context = Meaning”

Japanese culture provides a rich example of this reinterpretation through cultural practices. One prominent example is Japanese curry. Originally an Indian dish, curry was adapted and reinterpreted in Japan as part of “home mother cooking.” The Japanese curry is mild and sweet, often associated with comfort and family, unlike the spicier original. This shift reflects a cultural association between sweetness and maternal love in Japan, transforming curry into a symbol of “mom’s love comfort food.” Another example is Japanese traditional tea ceremonies. Although Japanese tea was originally introduced from China, it has been reinterpreted over the centuries within Japanese culture. Objects like “tea” and “tea bowls” were given new meanings beyond their basic functions. Tea bowls, for instance, are no longer just containers but symbols of “wealth and cultural refinement” within the unique context of the tea room. As Sen Ryo Iwamoto, a tea master from the Urasenke school, notes, “The contextual reinterpretation within Japanese tea ceremonies transforms ordinary signs into artworks, understood only within their unique setting.” These examples demonstrate how cultural practices in Japan have long involved reinterpretation of foreign signs in new contexts, giving them distinct meanings.

3.3 Bayesian Theorem and “Sign × Context = Meaning”

Bayes’ theorem is widely applied in cognitive sciences to explain how the brain interprets stimuli by balancing prior beliefs with new evidence. For example, whether a smile indicates happiness depends on prior experience, causal knowledge, and context. Building on Bayes’ theorem, the Free Energy Principle [18] posits that the brain minimizes prediction errors by aligning its internal models with external stimuli. Predictive coding, grounded in Bayesian inference, suggests that the brain continually refines its internal model based on discrepancies between expected and actual inputs, using Bayesian updating to ensure coherence between perception and reality. Bayesian inference also applies to aesthetic and emotional design evaluations. Predictive coding explains how aesthetic judgments evolve through new sensory inputs. Yanagisawa et al. [19] quantified beauty as a balance between novelty and complexity aligned with Bayesian principles. The Hybrid-GAN architecture [20] further optimizes the aesthetic design by integrating novelty, complexity, and user feedback.

“Sign × Context = Meaning” theory structured using Bayes’ theorem, mathematically represents meaning generation by modeling the relationships between objects (which function as signs), contexts, and meanings. In this updated framework. Object (Y) represents the design target object, but also functions as a sign, encompassing both its physical form and potential symbolic interpretations, depending on the context. X represents the meaning of the object (sign) within a given context (e.g., business, mindfulness, or entertainment). C represents the context in which the object (sign) is interpreted.

The probabilistic relationships are defined as follows. $p(x/y, c)$ represents the posterior distribution of a meaning x given object (sign) y in context c. This distribution indicates the meaning inferred based on an observed object (sign) within a specific context. $p(x/c)$ is the prior distribution of meanings in a given context, reflecting the preconceived meaning within a certain context before considering an object (sign). $p(y/x)$ is the likelihood representing the probability of observing the object (sign) y, given meaning x. $p(c)=\sum_x p(c)p(x)$ is the model evidence for the sign in context c, which is a marginalized likelihood. This represents the likelihood of a sign occurring within a context. The posterior distribution of meaning x in a specific context c is then calculated as:

$$P(x/y, c)= \frac{p(x|c)\, p(y|x)\}}{p(y/c)} \quad (1)$$

This formula illustrates how meaning changes based on the given context and observed object (sign). Additionally, surprise or unexpectedness is quantified by

$$Surprise=- \ln p(y/c) \quad (2)$$

This reflects how unexpected the observation of object (sign) y is within context c. Changing context c alters the generative model and consequently shifts the inferred posterior distribution of meaning x, even for the same observed object (sign) y. Examples: Contextual Changes in the Meaning of an Object (Sign). 1. Smartphone × Mindfulness Context: Initially viewed as a “communication tool” $p(x/y, c1)$, the smartphone in a mindfulness context $c2$ shifts to a “relaxation tool” $p(x/y, c2)$. Here, the change in context from $c1$ (communication) to $c2$ (mindfulness) alters the inferred meaning of the smartphone even though the observed object y (smartphone) remains the same. This shift in meaning corresponds to a change in the conditional probability distribution from $p(x/y, c1)$ to $p(x/y, c2)$. The amount of free energy reduction in this process is quantified as:

$$\Delta F = D_{KL}[p(y, c1)||p(y, c2)] \quad (3)$$

This formula represents the KL-divergence between two probability distributions and is derived from the research of Yanagisawa et al. [21] on free-energy models. 2. Smartphone × Entertainment Context: Initially interpreted as a “communication tool” $p(x/y, c1)$, the smartphone in an entertainment context $c2$ shifts to a “personal cinema” $p(x/y, c2)$. The context shift from $c1$ (communication) to $c2$ (entertainment) changes the inferred meaning of the smartphone, reinterpreting its role, while object y remains constant. This again reflects a transformation in the conditional probability distribution of meaning due to context changes.

3.4 “Sign × Context = Meaning” Theory: A Method for Describing Ideas

Formalizing a method for describing ideas is crucial for ensuring consistency and reproducibility in design and meaning innovation. By systematizing the reinterpretation of signs within different contexts, the ideation process becomes more consistent and efficient. This study proposes a framework for systematically describing new meanings of signs: “Sign proposed as Context for Purpose”. This structure enables a reproducible method for interpreting signs based on their context and creating new meanings. Specific examples include: 1. A candle proposed as relaxation for personal bath time. 2. A candle proposed as lighting to brighten a room. 3. A smartphone proposed as a productivity improvement tool for business. 4. A smartphone proposed as an entertainment device for media consumption. By combining sign (A), context (B), and purpose (C), this framework enables the reinterpretation of signs to create new value applicable not only to design but also to innovation in various fields.

3.5 The Role of the “Sign × Context = Meaning” Theory: in the Design Engineering Process

The FBS model (Function → Behavior → Structure) is a widely used framework for analyzing the design process, focusing on function, behavior, and structure. In this model, the designer and engineer define the function (purpose) of the product, derive the necessary behavior to fulfill that function, and design a structure to support that behavior. The FBS model primarily addresses the technical and functional aspects of design. However, a successful design is not just about functionality; it is also about understanding users and the meaning the product conveys to them. While the FBS model focuses on technical realization, the “Sign × Context = Meaning” theory centers on creating meaning. Here, “meaning” refers to the significance a product takes on based on how it is interpreted within its context. V (Meaning Value) + FBS Structure. The entire design process can be reframed around V (Meaning Value). This not only influences the function, behavior, and structure but also serves as the foundation for the entire design process. 1. Value (Meaning Value): Designers and engineers first define the meaning that the product will offer to users or society. This implication drives all subsequent design decisions. 2. Function: Functions are determined to embody this meaning and clarify the technical roles that a product must fulfill. 3. Behavior: The behavior of a product, including its interaction with users, is designed to support these functions. 4. Structure: Finally, a physical structure is developed to materialize the product’s meaning in a tangible form.

The Importance of Meaning. The “Sign × Context = Meaning” theory emphasizes that a product’s value lies in its meaning, shaped by context and interpretation. By applying this approach, designers and engineers can focus on fulfilling technical requirements and delivering products with significant social and cultural value. Integrating the “Meaning Value + FBS” structure shifts the design process from a purely functional focus to a meaning-driven approach, enhancing both user experiences and the cultural relevance of products.

3.6 Experimental Validation Through Design Practice

In collaboration with NEW STANDARD Inc., a company specializing in supporting product and customer experience (CX) development, we conducted experiments to validate this methodology through practical product development. By applying the “Sign × Context = Meaning” theory to the product development process, 4 out of 10 projects were successfully developed during the experimental period, with 5 projects still in progress and 1 project resulting in failure.

Total of ten projects in progress (as of August 2023)	Number of ongoing project	Number of successful projects	Number of failures projects
Development/manufacturing/sales		4	
3rd layer design: Interpret & create meaning by integrating words, visual, and function	2	4	
2nd layer design:Interpret & create meaning by integrating words and visual	1	6	1
1st layer design: interpret & create meaning with words	2	8	

Figure 5 : Summary of Project Outcomes in the Experimental Validation

4 DISCUSSION

In this study, we proposed “Sign × Context = Meaning” theory to address the challenges of reproducibility and reliability in traditional design processes by systematizing the interaction between signs and contexts to generate meaning. This framework, grounded in Bayesian inference, quantitatively evaluates how specific contexts influence the interpretation of signs. The results indicate that this framework has the potential to enable flexible value generation that can adapt to diverse cultural backgrounds and consumer and user needs. For instance, Japanese traditional tea ceremonies offer a compelling example of contextual reinterpretation. Although Japanese tea was originally introduced from China, it has been reinterpreted over centuries within Japanese culture to acquire meanings that extend beyond its basic function as a beverage. Tea bowls, for example, are no longer merely containers but have become symbols of "wealth and cultural refinement" within the unique context of the tearoom. As Sen Ryo Iwamoto, a tea master from the Urasenke school, observes, "The contextual reinterpretation within Japanese tea ceremonies transforms ordinary signs into artworks, understood only within their unique setting." This demonstrates how the framework can dynamically respond to cultural and emotional contexts, allowing for meanings to be generated in alignment with specific socio-cultural settings. Compared to traditional design processes, this approach captures the socio-cultural dimensions of meaning more effectively, fostering a deeper connection with users and consumers. Furthermore, applying a mathematical model based on Bayesian inference has proven effective in capturing the meaning generation process quantitatively. The framework also aligns with the existing FBS (Function → Behavior → Structure) model, proposing a new direction for function-centered approaches by integrating diverse interpretations of consumer and user value. This was further supported by the practical validation experiments, which confirmed the utility of the framework in product development. The approach of contextual meaning interpretation presents a more innovative and flexible methodology that can adapt to consumer needs and cultural backgrounds. This study aimed to address two core challenges in design: achieving reproducibility and reliability in meaning generation and creating value that aligns with the cultural backgrounds of consumers and users. The "Sign × Context = Meaning" theory, by systematizing the relationships between signs and contexts, has proven to be an effective approach for generating new value across diverse cultural contexts. This framework enables a shift away from traditional function-centered design methods, allowing for design processes that deliver broader consumer and user value. The framework's applicability extends beyond idea generation to the entire design process, highlighting its utility as a reproducible method for value generation in design practice. Furthermore, the results from practical testing showed that meaning generation through contextual interpretation contributes to developing products and services that cater to consumers' emotional and cultural needs, supporting the framework's validity. This approach of "contextual meaning interpretation" emphasizes its critical role in achieving innovation of meaning, distinct from Verganti's "design discourse" [9] and "hermeneutic framework" [10].

While the effectiveness of this framework has been demonstrated, there are limitations due to the susceptibility of meaning generation to cultural influences and individual differences. Currently, to improve the consistency of context-dependent interpretations across cultures, we are conducting context evaluation using AI and data analytics. Leveraging the "Context Word List" and "AI-driven Idea Generation Tool" can further enhance the accuracy of context-based value generation. Additionally, understanding the insights and needs of consumers is essential for effective meaning generation. The insight discovery approach that we are developing enables flexible value generation aligned with various contexts and consumer needs, contributing to further innovations in the design process [22]. In the future, research should aim to develop a more comprehensive and adaptable design process, advancing toward a systemized approach for creating meaningful value based on consumer and user needs and insights.

5 CONCLUSION

This study introduced the "Sign × Context = Meaning" framework, emphasizing its role in redefining ideas as new combinations of existing elements and demonstrating how meaning shifts based on context. Through this framework, designers and engineers can systematically generate meaningful value that aligns with diverse cultural and emotional needs. Case studies confirmed the framework's applicability across different contexts, highlighting its potential as a reproducible methodology for innovation in design and product development. By applying Bayes' theorem, this study further revealed how intuition and perception influence the idea-generation process, enabling reproducible ideas through contextual reinterpretation. This approach empowers designers and engineers to consider multiple contexts, creating meaningful products that resonate with users across diverse markets. Moreover, the ongoing development of tools such as the "Context Word List" and an "AI-driven Idea Generation Tool" aims to streamline the creative process and enhance adaptability to cultural nuances. While this research demonstrated the framework's practical value, limitations related to cultural dependencies and individual differences remain. Future research should focus on refining these tools and conducting empirical studies to validate meaning generation in a broader range of cultural contexts. These efforts will contribute to more innovative, culturally relevant designs and enhanced product development practices. We extend our gratitude to NEW STANDARD Inc. for their invaluable support and to all who provided insightful feedback during this research. Their contributions were instrumental in advancing this study.

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CAN AI BE USED AS A WAY OF THINKING TO FOSTER STUDENTS' CREATIVITY? AN EMPIRICAL STUDY BASED ON CHINA

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ABSTRACT
In the rapidly changing field of Artificial Intelligence (AI), educators are seeking ways to empower youth to shape the future. However, there is a lack of research on AI curricula for K12 students, particularly in Asia. AI can serve as a new avenue for enhancing creative thinking among young people. An experiment was implemented in a public secondary school in mainland China to design a kids' artificial intelligence design program, called Kids AID. A total of 42 secondary school students (average age 15) participated in the program. The study employed both qualitative and quantitative methods. Findings indicated that (1) students need to train in AI thinking to augment their basic AI knowledge and skills; (2) students believe that their creativity, especially its value, diversity, and originality, can be fostered through the design education program; (3) in regard to the student's perceptions of the Kids AID program, 72% of the students liked the teaching methodology and course content, and they believed that the combination of traditional Chinese culture and coding helped them to immerse themselves in learning. This research highlights the benefits of teaching AI thinking and using design as a means to prepare students for a future influenced by AI. The outcomes aim to guide educational researchers in developing AI curriculum and nurturing the next generation of creative talent.

Keywords: AI Literacy, Design, Creativity, Design Education, 21st Century Abilities

1 INTRODUCTION

Artificial Intelligence (AI) growth leads to AI education being seen as a strong driving factor for global competitiveness and the development of the future workforce [1]. Currently, understanding of AI education can be broadly classified into "cultivating AI literacy" [2] and "AI empowers education" . The former refers to at the AI age, a set of knowledge skills for individuals to use AI technology to proceed with critical thinking, effective communication, and collaboration, and to make AI a beneficial tool [4]. The latter involves applying AI and related technology to the educational environment [5].

In secondary education, AI literacy aims to equip students with essential skills for future innovation. Long and Magerko[2] identified seventeen competencies and design factors crucial for this development. By enhancing these skills, non-technical students can effectively leverage AI's advantages and decide when to utilize AI or human abilities for problem-solving. It's vital for these learners to understand not only the basic concepts and applications of AI but also the associated risks, such as algorithmic bias and ethical dilemmas, to ensure responsible use in their careers [6]. Research on AI literacy predominantly centers on Europe and the U.S., with limited focus on Asia [7] and much of the existing literature emphasizes early childhood and primary education[8]. Research in secondary education primarily examines teaching fundamental AI development techniques[9],enhancing digital literacy through technical skills [10], and fostering interdisciplinary abilities[11]. Studies on AI literacy development have largely concentrated on basic concepts and definitions[2,7], with a notable lack of research in curriculum design and educational tools[12,13]. Additionally, students often encounter difficulties in grasping AI concepts due to a lack of clear examples and relatable terms[14]. Encouraging AI thinking in students may help address these challenge[11]. The study's importance stems from the growing integration of AI technologies into people's daily routines and the imperative to comprehend theses technologies among secondary school students. It is essential that the introduction of AI-related content into the secondary school curriculum be designed with meaningful activities to help develop basic AI thinking in secondary school students. Earlier research has shown that AI thinking development projects for secondary school students in the classroom can have a positive impact on students' basic AI knowledge and inquiry skills[15]. This study aims to (1) explore effective methods for teaching AI to secondary school students; (2) examine the learning process of AI among school students and its potential to enhance their AI thinking and creativity, particularly in understanding fundamental AI concepts and AIGC. These objectives are set to understand the overall effectiveness of AI education and its impact on students' creativity and perceptions.

2 LITERATURE REVIEW

In 2013, researchers introduced AI thinking, which includes practical frameworks, skills, and tools derived from AI research. This concept significantly influences formal education[16]. Rosenberg[17] characterizes it as machine-based intelligence, while Gadanidis[18]proposes that integrating AI with math education can promote its advancement. Additionally, AI thinking functions as an analytical tool, assists in representing complex knowledge, and contributes to the development of AI. The probabilistic reasoning utilized in AI closely parallels human cognitive processes, allowing for intuitive solutions to uncertainties in the real world. This reasoning, along with logical reasoning and deep data-driven learning, forms the essential theoretical framework of AI thinking[19,20].

Research emphasizes the benefits of integrating artificial intelligence (AI) education into secondary schools. David[21]points out that AI reasoning is complex, blending scientific and humanistic thought, similar to human cognition. This makes AI reasoning a valuable educational method that connects science and the humanities. Seoane-Pardo[22] views AI reasoning as an effective teaching tool that enriches learning experiences, particularly in moral reasoning and philosophical inquiry, helping students grasp ethical concepts. The ethical implications of AI are as important as its technical aspects, making AI reasoning essential for philosophical discussions. How and Meng-Leong et al.[23] highlight the significance of the "A(art)" in STEAM education, which includes both fine arts and social sciences, creating opportunities for interdisciplinary teaching that combines scientific logic with humanistic reasoning. This approach enhances students' AI reasoning and overall learning. It is crucial to equip students with problem-solving skills that integrate STEAM fundamentals and AI principles [24,25]. STEAM education has been successfully integrated into K-12 curricula, benefiting students from kindergarten to secondary levels. Examining AI reasoning's role in educational support can improve learning processes[26]. However, there is a gap in systematic training programs for secondary students, especially those using empirical methods with software or programmable robots to teach STEM concepts[5].

There are notable differences in expectations for teaching AI literacy to children of different ages. Younger children need a basic grasp of AI concepts, while older students require a deeper understanding. To enhance AI literacy in secondary education, researchers have created targeted curricula. For example, Han et al.[9] used a project-based learning model to provide secondary students with hands-on AI experiences through various activities. Similarly, Julie et al.[10] utilized role-playing to allow students to develop and test AI programs, fostering critical reflection on their AI knowledge. These studies highlight the benefits of teaching AI skills to secondary students and the significance of AI thinking initiatives in education. Terzidis presents a framework that integrates AI knowledge, ethics, and skills to nurture AI thinking in children, which evolved into the kids AI thinking framework, aimed at helping students understand and creatively apply AI in their daily lives.

3 METHODS

The research aims to assess how a six-week program focused on artificial intelligence design for kids, named Kids AID, influences secondary school students' AI thinking, and their attitudes towards the program. The data were collected from 15–16-year-old students at a Shanghai secondary school, in China. The choice of Shanghai, China as the research site stems from its dual role as an economic center and a leader in education reform, making it ideal for examining AI thinking. With the rise of Artificial Intelligence Generated Content(AIGC), researchers in China are focusing on its effects on students and advocating for its application in education. This context is relevant for the study. The two primary research objectives are as follows (1) to explore effective methods for teaching AI to secondary school students; (2) to examine the learning process of AI among school students and its potential to enhance their AI thinking and creativity, particularly in understanding fundamental AI concepts and AIGC. This research will endeavor to investigate the following research hypotheses:

- RQ1: To what degree does the program enhance the participating secondary school student's comprehension of AI thinking?
- RQ2: How do secondary school students perceive their creativity ability after carrying on some AIGC Art activities?
- RQ3: What are the secondary school student's perceptions towards the Kids AID intervention?

The researcher employed a mixed-methods strategy, integrating both quantitative and qualitative analyses to enhance the clarity of the research question. Knowledge assessments and interviews served as the primary tools for data collection. The interviews aimed to uncover students' views on the Kids AID program. The collected data was organized and classified to support the qualitative analysis.

3.1 Participants

Forty-two secondary school students from Shanghai, averaging 15 years old, participated in a study within one classroom. They were split into six groups of seven, with three groups as experimental and three as control. Both groups worked on the same project topics, but the control group of 21 students used traditional thinking skills, while the experimental group applied AI-based skills. After the project, interviews were held with the experimental group. The chosen school is a public school in Shanghai, China, which has an innovative teaching philosophy that combines a basic curriculum that emphasizes knowledge output with an innovative curriculum that emphasizes experiential learning. It has a high match for the selected topic of this study, and the school principals, teachers, and students' willingness to take part in the research. All students in the sample had no previous AI education. All processes for this study have been approved by the university. Prior to participation, schoolteachers, parents/guardians, and students provided informed consent by signing a consent form. Parental consent was obtained for students' participation. Authorization was granted for the use of photographs and videos in this study, with participant names obscured in the presentation.

3.2 Implementation Procedures

During a six-week period, two groups collectively completed the Kids AID curriculum. Instruction for this program was provided by one professor, two researchers and one teaching assistants. The Kids AID program sessions occurred weekly, each lasting approximately two hours. Before implementing the Kids AID curriculum, two teachers from the secondary school attended a face-to-face teacher training. They were introduced to the Kids AID curriculum, including learning objectives, instructional content, and pedagogical methods. The study was conducted between May and July of 2024.

3.3 The Kids AID Curriculum

The Kids AID curriculum comprised six two-hour sessions conducted at one Shanghai public secondary school. It was implemented as an after-school projected-based learning initiative. The Kids AID program for AI classes is a curriculum structured around four AI learning tools (i.e. AI Technical, Animated Drawings, AIGC Art, Self-portrait), as seen in Figure 1.Terzidis and Rong[27]developed an AI curriculum designed for K-12 students, including four aspects, namely AI Knowledge, AI ability, AI Philosophy and AI Ethics. In this study, this AI curriculum was used in the secondary school students' setting (Table 1).

Table 1. The outline of Kids AID curriculum design for secondary school students

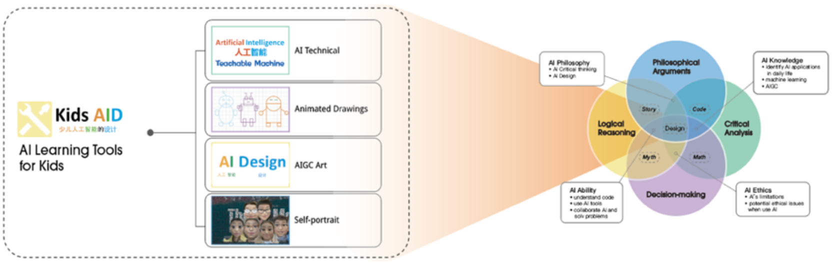

Figure 1. The model of using AI Learning Tools

AI Philosophy	AI Knowledge	AI Ability	AI Ethics
Ph1: AI critical thinking	Kn1: identify AI applications in daily life.	Ab1: understand code	Et1: AI's limitations
Ph2: AI Design	Kn2: machine learning	Ab2: Use AI tools	Et2: Potential ethical issues when use AI
	Kn3: AIGC	Ab3: collaborate AI and solve problems	

The Kids AID curriculum was crafted in accordance with Scott's [28]curriculum design model, which prioritizes four essential components: learning objectives, content, instructional methods, and assessment. The curriculum includes three phases: basic knowledge phase, story phase and practical phase. The initial phase constitutes a foundational stage primarily centered on the concept of AI, as well as the exploration of potential ethical consideration associated with its utilization. The second phase is philosophical arguments, through story, myth, and jokes to deliver the hidden massive power of AI. The third phase is the practice and applied phase which mainly focuses on machine learning and AIGC. While each unit addresses a unique subject, the lessons maintain a coherent progression. In addition to enhancing their understanding of AI, secondary school students also cultivate their creativity in AI design as a result of engaging with the Kids AID curriculum.

The two methods of teaching used in the Kids AID program are project-based learning and play-based learning. Project-based learning is a great approach that exercise students to learn through independent enquiry, with the teacher acting as a facilitator[29]. Play-based learning takes the form of guiding students through game-playing activities as a method of instruction[30]. It is worth mentioning that although play-based learning is mostly used in the kindergarten level. That doesn't mean it can't be used with other age groups. Play is a powerful tool for identifying the neural and psychological mechanisms behind interpersonal and group cooperation and coordination[31]. Kafai argued that learning is undoubtedly a difficult task for students and that need games to "sweeten" the concept of learning difficulties[32]. Two learning activities based on game-based learning were designed for this study.

3.3.1 Basic Knowledge Phase

The purpose of Unit 1 is to provide secondary school students with an understanding of the principles of various AI techniques, including their concept and apply. The aim of Unit 2 content is to expose students to situations that AI might not have encountered through the creation of stories to illustrate the need for continuous improvement in AI technology and AI applications. Ideally for students to understand these concepts related to AI, students would need to first master computer programming languages. In the Unit 3, students can use p5.js, a very inclusive and accessible platform to learn, exercise how to communicate with computer. This creative programming library is obviously very friend and appropriate choice for secondary school students at the basic education level in China.

3.3.2 Story Phase

The use of culturally embedded mythology to practice students' philosophical mindset and lead them to the door of AI is the aim of Unit 4. AI intelligence and philosophical epistemology share a commonality, i.e., the study of how the mind works. And as a product of thought and consciousness, the study of myths allows for speculation about human ideas and ways of thinking. One of the key skills required for AI thinking is the ability to think creatively and make connections between different ideas. Studying myths can help develop this skill by exposing students to a variety of stories and symbols that need to be interpreted and analyzed. By learning how to interpret these symbols and understand their meaning in the context of a story, students can develop their analytical skills and learn how to make connections between different ideas. In addition, many myths involve characters who face complex problems or moral dilemmas. By analyzing these stories and discussing the choices made by the characters, students can develop their ability to evaluate arguments and consider different viewpoints based on ethical considerations. This is an important skill for engaging in AI thinking.

3.3.3 Practical Phase

In Unit 5, students learn the concepts and principles of machine learning, learn to utilize the AI tools

Animated Drawing, and explore methods to enhance the accuracy of AI drawing recognition. Students can enhance their communication skill and problem-solving skill after the Unit 5 project. They used Animated Drawing and Teachable Machine to carry out these activities. Through the Unit 6 and 7, students can learn the use skills of AIGC and acquire the ability of think out of the box. For example, students will be asked to use AIGC tools (i.e. Midjourney, Ernie Bot) to create Self-portrait activity. Following the study of different artworks generated by AIGC tool, we engage in a discussion regarding the ethical implications of AI (i.e. "Will AIGC's creativity surpass humans?"). It is to experience and experiment with different expressions of AI art using AI image processing technology. Students complete their analysis and reflection of the self by examining and interpreting the self and then combining AI technology to collect, decompose, compare, and integrate their characteristics. Unit 8 summarized all learning modules.

3.4 Collection of Data

Assessment, observation, and project implementations were utilized to evaluate secondary school students' proficiency in AI knowledge and skills, encompassing assessments in AI and machine learning, as well as evaluations of AI thinking in secondary school were assessed. Each evaluation was conducted independently, with participants spent 10 minutes for each test.

3.4.1 AI thinking skill assessment

AI thinking skill questionnaire was used to assess student's AI and machine learning knowledge at the end of Kids AID curriculum. It's developed through several iterations by the Research group on teaching Artificial Intelligence thinking. The group comprised of two AI professors and three experts specializing in STEM education, collaborated with four teachers holding primary positions to ensure the validity of our research instruments. The questions comprised 16 multiple-choice questions, with correct answers awarded 1 point and incorrect answers receiving 0 points. High inter-scorer reliability was confirmed through reliability tests. A pre-test was not conducted as none of the students had been exposed to AI before.

3.4.2 Creative Abilities

In the current study, two tasks assessing creative abilities were utilized. Two researchers served as raters for the assessment. The research tools utilized in the experiment included: (1) A metric for assessing the creativity of self-portrait works. Based on the characteristics of the curriculum, the chosen metrics in this study encompass the dimensions of value, diversity and originally [33]. A Richter scale of five is used with an α coefficient of 0.807. Value is the practical ability of the work to satisfy the student. Diversity means the variety of design solutions highlighted in the selected work. Originality refers to the work that is interesting, unique, and novel. (2) An interview outline. The interview questions were as follows: What dimensions of AI thinking learning from the curriculum were useful to you as you worked on your self-portrait? Can AI thinking be used to solve problems in your life? Before the Kids AID projects, had you thought about applying AI thinking in your life? What do you think about AI thinking? Is there a difference for you between this AI thinking skills and the traditional thinking skills handed to you in school?

3.5 Data analysis

We collected different types of data, as shown in Table 2. At the end of the project, 6 boys and 5 girls who participated in the Kids AID curriculum participated in interviews. Data1,3,5 was respectively used to address the RQ1. Data 2,3,4 were employed to tackle the RQ2. And the RQ3 involved the use of data 3.

Table 2. Outlines data collection methods for a variety of research questions

No.	Instrument	Data Type	Data Source	RQ
1	Questionnaire	Questionnaire date	Individuals	Q1
2	Metric	Evaluation of the creativity of Self-Portrait	Individuals	Q2
3	Interview Outline	Interview date	Individuals	Q1, Q2, Q3
4	-	AIGC Art works	Groups	Q2

5	-	Individual and group project proposal	Individuals and groups	Q1

To answer Q1, we used statistical techniques like independent sample t-tests and paired sample tests to evaluate data from post-test surveys. For Q2, we applied an independent sample t-test to assess the creativity of AIGC works. In addressing Q3, we examined student interview data to investigate how AI thinking could enhance awareness in solving real-world issues. We also analyzed both in-process and final AIGC works to determine AI thinking's effect on students' creativity in their art. Lastly, we coded interviews to clarify how AI thinking influences creativity and to gain insights into students' views on the Kids AID program.

To ensure reliability, we took several steps, which are outlined below. The tests were conducted on a computer platform, with automatic scoring by the system. This computerized scoring minimizes bias, especially in objective questions, which have clear correctness criteria like multiple-choice or true/false formats. After training in assessing the creativity of AIGC works, the two researchers used shared metrics for evaluation, leading to a common understanding of the criteria. They then independently applied these metrics to the remaining works. The reliability coefficient of the scores was notably high at 0.807, with values for value, diversity, and originality at 0.550, 0.878, and 0.816 respectively (see Table 3). For analysis, the average scores from both researchers were used, reducing potential bias from individual assessments.

Table 3. Scores on the creativity of Self-Portrait AIGC works of students across two groups

Dimension	Group	n	M	SD	*t*	*p*	Reliability*
Value	Control	21	3.524	0.602	-3.576	0.001**	0.550
	Experimental	21	4.357	0.882			
Diversity	Control	21	2.095	0.605	-14.976	0.000**	0.878
	Experimental	21	4.548	0.445			
Originality	Control	21	3.138	0.759	-7.48	0.000**	0.816
	Experimental	21	4.619	0.498			

* The Spearman's Rank Correlation Coefficient was used to check the reliability of scores on the creativity.

We established a coding framework to analyze interview data on students' views of the Kids AID curriculum. We utilized a general inductive method to analyze the data, which involved summarizing the information, linking it to our research goals, and forming a framework to clarify the perspectives found in the data. To maintain coding consistency, we applied the independent parallel coding technique, where two researchers coded the data separately and then discussed their findings with a third researcher, resulting in 20 categories of perspectives. Following this, two researchers analyzed the interview data (n=11) using the established framework.

4. RESULTS

The test outcome revealed that the control group scored a 5.095-point lower compared to the experimental group. This shows that the Kids AID program had a beneficial impact on students' acquisition and comprehension of basic AI concepts and machine learning skills.During the interviews, 81% of the students indicated that they were able to master the concepts and knowledge of AI through the Phase 1 Basics section. On this basis, 36% of the students said that the form of combining the knowledge of traditional Chinese culture and programming enhanced the fun of learning and practiced math skills, which was very immersive. In comparison to the control group, the experimental group exhibited a 1.01-point increase in the value dimension ($p < 0.001$), a 2.45-point increase in the diversity dimension ($p < 0.001$), and a 1.48-point increase in the originality dimension ($p < 0.001$). Additionally, the creativity score of AIGC artworks in the experimental group exceeded that of the control group by 4.76 points ($P < 0.001$).

4.1 Develop creativity ability through the AIGC art activities

The significance of the work lies in how it enables students to effectively utilize AIGC technology. The control group produced artwork through a spontaneous approach to the project theme, lacking formal training in directing the AI painting chatbot with specific prompts. Instead, they relied on instinct, resulting in visually appealing but random outputs. Conversely, the experimental group created their artwork after learning to communicate with the AI chatbot and understanding its underlying principles. They grasped how the AI generates images based on keywords derived from existing works and learned to refine their creations through targeted adjustments. In contrast, the work of the students in the experimental group was done after they had learned how to talk to the AI painting chatbot. They also learned about the principles behind it, understanding that this AI program generates various types of images by keywording them after collecting data from many existing works and then algorithmically parsing that data. By gaining a deeper understanding of the theme, they also learned to make targeted adjustments and optimizations to the generated artwork through image commands.

The statistics on the themes of the students' work show that AIGC artwork can reflect diversity. There were only three different themes in the control group. 10 of the students' art works were urban impressions and chose the same urban architecture as the element of creation. Another 6 students chose the theme of heroes for their creations and the remaining 5 students had the same popular singer as their theme. Conversely, the artworks of the 21 students in the experimental group could be categorized into 5 categories, which were Childhood (3 students), Ecological Protection (4 students), Defense of the Universe (5 students), Cooperation in Solidarity (5 students) and Future Imagination (4 students). At the same time, they also passed the prompts several times to optimize the generated works.

The originality can be demonstrated through the unique perspective from which the students think about the artwork and the presentation of the work. The control group students' artwork was not seen as original by the teachers because "the originality of their artwork was highly randomized, not the originality of the students' own ideas, but the originality of the algorithms used randomly." In contrast, the teachers believed that the experimental class's work was more original because "the students understood how the AI drawing chatbot worked, and they knew how to guide the AI through the conversation to adapt their work step-by-step until they presented the ideas in their minds," where Student A in the experimental group tested and modified her work until she designed her own work, "Childhood". "She said that this is what her childhood looks like in her dream, the atmosphere, colors, texture and elements that are hard to describe in words can't be depicted no matter how much she paints with a brush. But AIGC helped her to do it", said the teacher, "This is a very precious originality in our opinion, something that can't be duplicated no matter what. These things exist in the student's own mind, in their imagination."

4.2 Enhance the awareness of using AI thinking in daily life

Utilizing AI thinking as a way of thinking about everyday life can help students solve problems better. In the student interviews, 36% of the students had never considered using AI technology and AI thinking to address their experience of the problems in their daily lives before the project started. There were 54% of students who had thought about it, but since they did not know how to use AI, the idea was just a display of positive attitude. In contrast, when finishing the program, 90% of the students expressed their willingness to use AI thinking, which is a significant increase from before. Among them, 72% of the students believed that AI thinking helps to help them think multidimensionally. Meanwhile they indicated that they enjoyed this teaching methods and curriculum content. 54% of students believed AI thinking helps them to think outside the box, and 27% of the students believed that adopting this way of thinking helps them to improve the efficiency of their learning.

5. DISCUSSION

The purpose of this study is to identify how a six-week intervention in the Kids AID program influenced secondary school students’ AI thinking. The curriculum includes three phases: basic Knowledge phase, which introduces AI concepts and ethical considerations; the story phase,which uses narratives to highlight AI's potential, and the practical phase, where students engage in hands-on machine learning and AIGC activities.The results show that the program successfully achieved its goals, significantly improving students' AI knowledge and skills, as reflected in higher test scores and positive interview feedback. The blend of traditional Chinese culture with programming proved to be an effective method for teaching AI concepts.

Integrating design thinking with artificial intelligence presents a valuable strategy for addressing organizational challenges[34]. How and Hung[23] proposed that AI thinking can empower students to apply their knowledge effectively to real-world issues in their academic and professional lives. This research reinforces previous findings and emphasizes the beneficial role of AI thinking in problem-solving. It highlights the importance of students utilizing AI tools when confronted with practical challenges. The program notably enhanced students' understanding and application of AI thinking, leading to a marked increase in their willingness to incorporate AI into everyday situations, thereby deepening their comprehension of AI and its uses. Gadanidis [18]noted that AI in education can promote AI thinking, encouraging students to engage more critically with problems and ask insightful questions. This study indicates that as students learn about AI thinking, they not only gain knowledge but also cultivate active thinking skills applicable to their studies, work, and life, enabling them to approach problems creatively. Students reported improved problem-solving efficiency and broader thinking, indicating a positive shift in their cognitive strategies. These results have important implications for AI education in secondary schools, suggesting that programs like Kids AID can enhance students' AI knowledge, creativity, and awareness, and that incorporating cultural and creative aspects into AI education can boost engagement and learning outcomes.

Previous research has shown that AIGC technology can inspire creativity and imagination in creators [35], aligning with the assessment criteria of value, diversity, and originality[33]. In earlier studies, students followed their teacher's design steps, while this study's control group utilized a project-based learning method focused on their interests. Conversely, the experimental groups learned specific methodologies. Results revealed that the Kids AID program effectively enhanced students' creativity, reflected in improved scores across the creativity dimensions. Engaging in AIGC art activities enabled students to creatively interact with AI tools, deepening their understanding of AI and fostering innovative thinking. Qualitative data from student interviews corroborated these findings, showing that AI thinking encouraged multidimensional and unconventional thought. Students showcased their creative application of AI by producing original artworks with AI assistance. This underscores the potential of integrating AI thinking and AIGC technology into education to enrich learning experiences, emphasizing the significance of creative activities in student engagement.

6. CONCLUSION AND LIMITATIONS

Three conclusions emerge from our findings. First, using the Kids AID curriculum as a method of cultivating students' AI thinking can effectively solve the problem of mastering basic AI knowledge and concepts in the process of improving AI literacy among secondary school students. Second, the AI thinking method exercises students' logical thinking. In the process of cultivating AI thinking for secondary school students, by introducing curriculum content containing mythological stories and cultural meme jokes of traditional culture, students can enhance their analytical abilities and engage in problem exploration and discovery, thereby effectively bridging the disparity between AI learning and real-world applications. Finally, the learning and use of AIGC technology helps students to stimulate their imagination and promotes their initiative in exploring and solving problems. This enables students to actively construct knowledge and skills and improves the passive learning of students in the Chinese education model.

We provide a new way of thinking about problems in our research, the AI thinking framework. And based on this, we provide some experimental courses and assessment methods for researchers' reference. Although most students in China can acquire knowledge of AI by consulting materials or taking courses, they are still very poorly equipped with the philosophical thinking, critical thinking, programming, and logic skills needed to master AI. This study first proposes a framework for effective learning that includes both overall process and specific content. Second, students were encouraged to actively utilize advanced AI technologies such as AIGC for learning, self-exploration, and application in real-world contexts. This fosters skill acquisition and enables students to effectively navigate the AI era.

Finally, we recognize several limitations within our study that require further research and refinement. First, the examination of the course was based on interview data obtained solely from 11 students in the experimental group, which is a relatively small sample size and may offer a constrained viewpoint. Subsequent investigations could explore whether similar results would be obtained with a large sample size, which would be of value. Second, this study did not include faculty interviews to gather their perspectives on the curriculum and AI thinking. Future research could build on this and add to the teacher perspectives to explore how to better support students' AI literacy development in the current educational environment. Finally, the content of this study only explored the outcomes of students' practice in the AIGC and machine learning environment. Therefore, future research may add new programs such as neural network practice experiments to more refine the content of the AI mindset model and draw more specific and comprehensive conclusions.

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RETHINKING HUMAN FACTORS IN DESIGN FROM DESIGN ENTROPY PERSPECTIVE

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ABSTRACT
As humanity advances into the era of artificial intelligence, both human factors and design disciplines encounter new challenges. The capacity to collect, process, and understand information has become critical, with informatics emerging as a significant driving force in these fields. Against this backdrop, this article reexamines the role of human factors in design through the fundamental concept of entropy from information theory. Specifically, it introduces a concept framework of design entropy and, through an information-centric perspective, reconstructs the evaluation criteria for design processes and solutions while defining associated entropy metrics: design process entropy, design behavior entropy, and design structure entropy. Drawing from this framework, the paper explores how the guidelines and predictive models derived from human factors research influence design, particularly affecting the complexity of information collection and conversion during the design process, as well as the usability and adaptability of solutions. The paper further demonstrates the application of human factors in design through two case studies, involving producing guidelines for online English learning tool design and predictive models of air traffic controllers' workload, followed by a discussion of future research directions based on the proposed framework.

Keywords: Design Entropy, Human Factors, Design Informatics

1 INTRODUCTION

Entropy, a concept originating from thermodynamics, measures energy dissipation in physical systems, reflecting the tendency of systems to evolve towards disorder. To maintain system order, entropy must be managed through optimizing energy utilization and minimizing the effective energy converted into void energy [1]. Shannon later introduced entropy for his information theory [2] to describe information communication and uncertainty, which is also the basis for adopting the concept of entropy in contemporary design research. Statistically, entropy correlates with the probability distribution of events in a system, where more numerous and evenly spread events increase uncertainty and entropy [3]. When entropy is viewed as an indicator of system order [4], providing effective information becomes crucial to enhancing the degree of order.

Design scholars have acknowledged the utility of information entropy in describing and analyzing design processes and solutions, whether as an abstract framework or a quantitative tool. However, a comprehensive understanding of design processes through information entropy remains undeveloped. Existing research focuses on four main aspects: the role of designers in the design process [5], the impact of process management on design results [1], the information transformation in the design process [6], and the evaluation of productivity and creativity in the design process [7][8]. Research on design solutions divides into two categories. The first involves calculating entropy values to evaluate design solutions, choose alternatives, and assess improvements. The research objects include the aesthetic quality of urban skylines [9], the remanufacturability [10], recyclability [11], and adaptability [12] of products, the experience of user-product interfaces [13], the artistic complexity of drawings [14], the quality of product platforms for modular design and parametric design [15], etc. However, comprehensive quantitative methods are mainly applied in engineering contexts like software development and digital circuit design [16], while methods for artistic, industrial, and creative designs, characterized by high uncertainty, remain abstract or simplified. The second category uses information entropy as a quantitative measure of requirement importance [17][18][19].

Human factors is foundational in design, optimizing human-system interaction and encompassing ergonomics, cognitive engineering, user experience (UX), human-computer interaction (HCI), biomechanics, safety engineering, etc. It aims to ensure efficiency, safety, and user-friendliness, aligning systems with human capacities and minimizing errors. Cognitive aspects are particularly central, making human factors closely tied to information and entropy concepts [20][21][22]. As an important quantitative method involved in design research, human factors leads to the generation and transmission of a large amount of information. The advancement of artificial intelligence (AI) further enhances human factors in managing vast data in complex scenarios like vessel traffic service (VTS) [23][24] and air traffic control (ATC) [25][26], but also introduces greater complexity and uncertainty, necessitating a reexamination of its role through the lens of information entropy.

This article will proceed as follows: Section 2 develops a comprehensive concept framework of design entropy based on existing studies, regarding both the design process and design solution. Section 3 analyzes the role of human factors in design within this new framework. Section 4 presents two case studies involving design of online English learning tools and air traffic controller (ATCO) workspaces to illustrate the relevant concepts and processes. Section 5 summarizes the findings and suggests future directions for integrating human factors into design research. As a preliminary study, specific quantitative methods are beyond this article's scope and will be addressed in future research.

2 CONCEPT FRAMEWORK OF DESIGN ENTROPY

While numerous studies investigate design issues from the perspective of information entropy, only a few have explicitly employed the term "design entropy" [13][16][27][28]. Among these, Cong et al. [28] proposed a comprehensive theory of design entropy, however, it is specifically tailored to an emerging business model—the smart product-service system (SPSS)—and lacks a clear distinction between design solutions and design processes. Consequently, the applicability of this theory beyond SPSS is limited. Furthermore, the information-theoretical approaches [29] also utilize concepts from information theory, particularly entropy, to describe design processes. Yet, these approaches primarily characterize design as "information increasing" or "information transformation," without delving deeper into the underlying informational essence of design processes and solutions. Despite these limitations, these studies generally converge on a shared understanding of entropy as a measure of system uncertainty. The following are three self-evident intuitive understandings: the easier a process is to execute, the easier an object is to implement, and the easier an object can fulfill its intended function, the corresponding lower uncertainty will be reflected. Therefore, they can all be described through entropy metrics, leading to the concept framework of design entropy, as illustrated in Figure 1. This framework deconstructs design processes and solutions through the perspective of design entropy, identifying relevant attributes as evaluation criteria and defining associated entropy metrics.

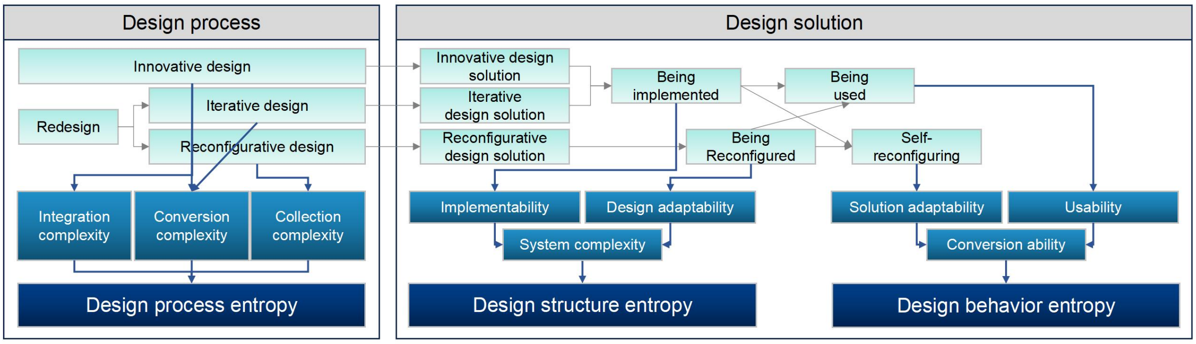

Figure 1. Concept framework of design entropy

2.1 Design entropy to describe the design process

With the rise of smart, connected products (SCPs) and SPSS featuring context-awareness, we categorize current design processes into three main types: innovative design, iterative design, and reconfigurative design, where both iterative and reconfigurative design fall under redesign.

Innovative design

This involves creating a new solution for an unresolved problem. The term "innovation" here has its limits, firstly, "unresolved" applies only to the project client. For example, designing a medical device for a pharmaceutical company to enter new markets qualifies as innovative, even if the product type is mature in the market. This highlights the first aspect of innovation: the absence of readily available, relevant information that can be reused, which directly determines the difficulty of design in the information era. Secondly, innovation refers to the design's starting point—whether the initial objective is innovative. The final solution may converge with an existing one, but the design can still be considered innovative. This reflects the second aspect of innovation, involving the integration of diverse information sources and complex synthesis, rather than simply converting requirements into solutions. The true value of innovation lies in extracting requirements from ambiguous contexts.

Iterative design

The meaning of iterative design can also be determined from an information perspective. Think about this question: If a hair dryer brand wants to transition from a common product model to an SPSS paradigm by developing a smart hair drying system, is this innovative or iterative? The answer depends on how different the new system is from conventional hair dryers. In other words, it hinges on the degree to which existing information supports designers in understanding new scenarios and the overlap between the existing and new information domains. If the difference is minimal, it is considered iterative design. Iterative design primarily focuses on converting requirements into solutions without extensive information integration.

Reconfigurative design

Previous research often uses the term "configuration/reconfiguration" interchangeably with "design" without clear definitions. Therefore, we introduce a new term "reconfigurative design", referring to a personalized design process based on adaptable products/product platforms targeting specific users or small user groups. Given that the product platform and the relationship between modules/parameters and requirements are predefined, it allows for quick customization when user expectations are unmet. Reconfigurative design requires minimal information integration or requirement conversion. The key, from an information perspective, is detecting dynamic contextual changes, enabling designers to know when intervention is necessary. Thus, the focus is on the capacity to collect information.

Understanding the design process through an information lens involves describing the complexity of information processing and providing indicators to guide the development team in selecting the optimal design path within set timelines. The main indicators include "integration complexity", "conversion complexity", and "collection complexity". Integration complexity relates to the number of information sources, the difficulty of accessing or constructing these sources, and the challenge of extracting effective information. Conversion complexity relates to the clarity, quantity, and interdependencies of requirements. Collection complexity addresses sensor types and numbers needed, data collection accuracy, and the precision of calculations from data to desired outcomes. Although three design processes are discussed separately for clarity, they often overlap in practice. For instance, innovative and iterative design may be difficult to distinguish, and iterative and reconfigurative design might be interconnected. Thus, when determining the complexity of a design process, the entropy metric should integrate these three indicators, collectively referred to as "design process entropy".

2.2 Design entropy to describe the design solution

Based on the three kinds of design processes mentioned above—innovative, iterative, and reconfigurative design—three corresponding types of design solutions can be defined: innovative design solutions, iterative design solutions, and reconfigurative design solutions. In Figure 1, four key evaluation factors are derived for assessing the design solution.

Implementability

For innovative and iterative design solutions, being implemented is a prerequisite for delivering value to users. Therefore, implementability is a crucial evaluation criterion. The term "implementation" is used instead of "manufacturing" to encompass a broader scope that includes product, service, and system design. Implementability considers the number of components within the solution, the complexity of each component, and the interdependencies between them.

Design adaptability

Design adaptability draws from the adaptability concept emphasized in adaptable design [30]. It focuses on the ability of a solution to be modified or extended into another in various ways to flexibly adapt to different application scenarios. Reconfigurative design mentioned earlier exemplifies this adaptability.

Therefore, we directly borrow the concept of design adaptability to evaluate how well a solution can be reconfigured.

Usability

No matter the design process, a solution's value is realized only when it is used by end-users. The evaluation criterion associated with this is defined as usability. Given its broad scope, usability is one of the most complex aspects of all design solutions. Moreover, it may vary significantly depending on the types of design solutions.

Solution adaptability

Solution adaptability also comes from the adaptable design concept [30]. Adapted from "product adaptability", this term is broadened to "solution adaptability" to encompass a wider range of design solutions. It highlights the ability of a design solution to respond to dynamic changes, such as the real-time reaction of SCPs to users' evolving needs through context awareness.

Among these four factors, usability and solution adaptability primarily address a solution's capacity to meet user needs. From an information perspective, this capacity can be expressed as "conversion ability" [28], which refers to the ability to transform information without a mapped solution into information with a mapped solution. The entropy metric calculated based on this ability is "design behavior entropy". Conversely, implementability and design adaptability are tied to the internal structure of the solution, described as "system complexity". The entropy metric derived from this is called "design structure entropy".

In conclusion, this article evaluates integration, conversion, and collection complexity of the design process using "design process entropy", while assessing conversion ability and system complexity of the design solution using "design behavior entropy" and "design structure entropy", respectively. These three metrics are mutually exclusive, addressing distinct aspects: the complexity faced by designers during the design process, the challenges involved in producing and delivering the target design solution, and the capacity of the design solution to achieve its intended outcomes. A holistic consideration of these factors is essential for guiding subsequent stages of development in practical design processes. Unlike prior research, which often addresses these dimensions in isolation, this study establishes a comprehensive concept framework. Due to space constraints, the article does not explore specific entropy calculation methods, leaving it as a future research focus.

3 UNDERSTANDING THE ROLE OF HUMAN FACTORS FROM DESIGN ENTROPY PERSPECTIVE

Traditional human factors experiment aims to examine how specific design elements influence human behavior, capabilities, experiences, and preferences, generating guidelines to inform design. With advancements of AI, now human states can be predicted using sensed information and produced models. Thus, human factors research primarily yields two types of information: guidelines and predictive models. In the following, we analyze the impact of these two types of information on the design process and solutions through the outlined design entropy framework, as illustrated in Figure 2.

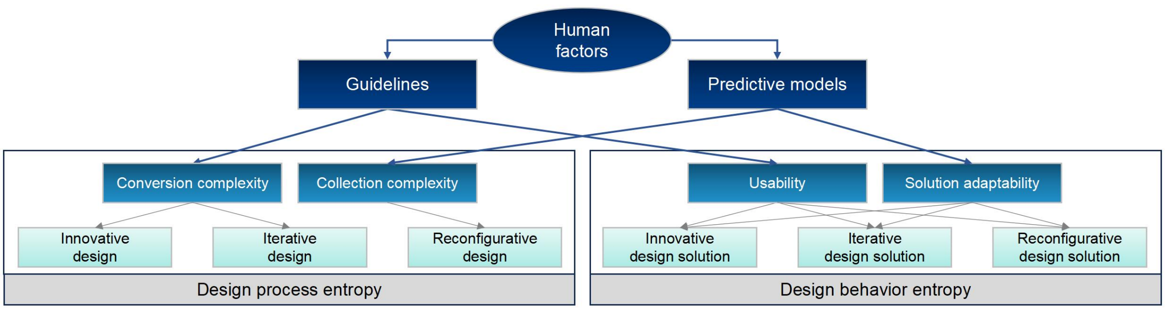

Figure 2. Influence of human factors on the design process and design solution

3.1 How human factors affects the design process

Reducing conversion complexity

The guidelines derived from human factors research provide a crucial foundation for the conversion from requirements to solutions, representing the predominant application of human factors in design practice. From the perspective of design entropy, these guidelines effectively reduce conversion complexity, thereby decreasing the design process entropy associated with innovative and iterative design processes.

Reducing collection complexity

Predictive models generated through human factors research can significantly simplify the information collection process. By employing predictive models, designers can assess contextual changes based on easily gathered data, allowing for precise interventions in the reconfigurative design process. This capability diminishes collection complexity and, consequently, reduces the design process entropy related to reconfigurative design.

Discussion on integration complexity

Currently, it remains unclear how to effectively reduce integration complexity. However, what is obvious is that when human factors studies are regarded as integral to the overall design process, their own complexity will also be incorporated. Therefore, to mitigate integration complexity through human factors, a straightforward approach would involve simplifying the challenges associated with conducting human factors research itself.

3.2 How human factors affects the design solution

Improving usability

The influence of human factors on design solutions is most directly manifested in their usability. Utilizing the guidelines established through human factors research, designers can enhance usability, leading to significant improvements in comfort, safety, accessibility, ease of learning, and overall interactive experience.

Improving solution adaptability

With the emergence of smart products, predictive models can also function as embedded modules, equipping products with robust capabilities to perceive unstable states of users and contexts. This will enable design solutions to respond in real-time to these fluctuations, thereby significantly enhancing solution adaptability.

Discussion on system complexity

Both usability and solution adaptability illustrate the conversion ability of the design solution. The current impact of human factors primarily serves to reduce design behavior entropy. In contrast, the influence of human factors on design structure entropy, determined by system complexity, is relatively limited. This is reasonable, as system complexity represents an inherent characteristic of the design solution itself, while conversion ability highlights the properties observed during the interaction between the design solution and the user—precisely the focus of human factors studies.

4 CASE STUDY

This section presents two case studies to illustrate how the guidelines and predictive models derived from human factors research can contribute to design. Specifically, it describes how human factors influences the design process to ultimately reduce both design process entropy and design behavior entropy. It is important to emphasize that the primary focus of this article is to understand the role of human factors in design through the proposed framework, rather than to discuss how to apply this framework and the associated entropy metrics.

4.1 Case 1: Guidelines for online English learning tool design

The first case examines the design of online English learning tools. Among the numerous factors influencing learning efficiency, stress is identified as a significant impediment to reading performance, particularly affecting higher-level text processing such as syntactic parsing, sentence integration, and global text comprehension. Additionally, first language (L1) and second language (L2) English readers often exhibit markedly different performances on reading tasks. To inform the development of online English learning tools through human factors research, we employed eye-tracking techniques to investigate the impact of stress on the higher-level text processing capabilities of both L1 and L2 readers. Valid data were obtained from 43 students who read GRE Verbal Reasoning Practice materials and completed corresponding multiple-choice questions. Various eye movement metrics were calculated to index the processes involved in text processing. The findings reveal that stress adversely affects syntactic parsing, sentence integration, and global text processing of L2 readers, who tend to compensate for difficulties in global text comprehension by focusing more on the topic structure of the text. In contrast, for L1 readers, only the efficiency of syntactic parsing and sentence integration was found to be impacted by stress.

From this experiment, we derive three key guidelines for the design of online English learning tools: 1) Implement customized interface layouts and guidance strategies whether the user is an L1 or L2 reader, rather than merely altering reading materials; 2) For L2 readers, design varying levels of topic structure guidance, gradually decreasing from the most explicit identification mode as readers' abilities improve; 3) In scenarios involving stage tests, employ calming strategies judiciously to accurately assess the learner's true proficiency level. These guidelines provide designers with clear objectives, facilitating innovative design that yields more targeted solutions and strategies to enhance users' English proficiency. Furthermore, these guidelines will serve as critical evaluation criteria for determining the necessity of iterative design, thereby reducing conversion complexity and, consequently, design process entropy. Correspondingly, the resulting design solutions will exhibit improved usability, with diminished design behavior entropy.

4.2 Case 2: Prediction of air traffic controllers' workload

The second case focuses on the design of workspaces for ATCOs. Maintaining a moderate cognitive workload is essential for operators engaged in complex tasks, such as those within the human-AI hybrid system described in this example. Excessive workload can lead to fatigue, while insufficient workload can diminish situational awareness, both of which pose risks of accidents and significant losses. Thus, real-time prediction and feedback on ATCO workload hold substantial value in modern human-AI hybrid environments. In this case, we developed a novel Electroencephalogram (EEG)-enabled cognitive workload recognition model based on self-supervised learning. The ATCO data used for model training were collected via EEG headsets from 24 participants trained to perform air traffic control tasks on a public online simulator, Endless ATC. The predictive model demonstrates robust performance, validated through comparisons with baseline models in environments with increased levels of masking and noise rates.

The model derived from human factors research can be integrated into the human-AI hybrid ATC system, enabling real-time predictions of ATCO workload and providing timely alerts to help operators maintain optimal working conditions. By employing predictive capabilities, we can leverage EEG data to assess ATCO workload in noisy real working environments, enhancing data collection efficiency and reducing collection complexity compared to traditional evaluation methods, thereby lowering design process entropy. When viewed as a comprehensive design solution, the intelligent ATCO workspace, enriched by this model, enhances interaction with users (ATCOs) and improves solution adaptability, ultimately reducing design behavior entropy.

5 CONCLUSIONS

Advanced sensing and AI technology have ushered in a new era for human factors research, positioning information-related topics at the forefront of the field. Simultaneously, the design discipline is experiencing a paradigm shift driven by AI technology and data science, with informatics emerging as a focal point for design researchers. In this context, this article seeks to provide a novel analysis of the role of human factors in design, with the entropy concept from information theory as a foundation.

This article begins by constructing a concept framework for design entropy and establishing a new terminology system. Within this framework, design processes are categorized into innovative, iterative, and reconfigurative design, corresponding to three types of information processing complexities: integration complexity, conversion complexity, and collection complexity. In practice, these complexities are interconnected and collectively represented in the metric of design process entropy. Each of the three design processes yields distinct design solutions—namely, innovative, iterative, and reconfigurative design solutions—associated with two evaluation metrics: conversion ability (reflected in the design behavior entropy metric), influenced by usability and solution adaptability, and system complexity (reflected in the design structure entropy metric), determined by implementability and design adaptability.

Subsequently, the article analyzes the influence of human factors on design within this framework. Guidelines produced by human factors research can directly impact conversion complexity during the design process, thereby reducing the design process entropy associated with innovative and iterative designs. Additionally, these guidelines can enhance the usability of design solutions, thereby lowering their design behavior entropy. In addition, predictive models derived from human factors research can influence collection complexity during the design process, thus reducing the design process entropy of reconfigurative design. Furthermore, these predictive models can improve the solution adaptability of design solutions, ultimately decreasing their design behavior entropy. The article concludes with two case studies illustrating the scenarios where human factors affects design.

As an exploratory work, this article acknowledges several limitations. The proposed concept framework is primarily derived from literature review and theoretical analysis, and the establishment of a sound theoretical framework requires iterative refinement through practical application. Consequently, it is necessary to establish specific quantitative methods to calculate three types of entropy outlined in this framework, which remains a significant challenge. Furthermore, implementing such quantitative methods in real-world design processes may be a challenge for designers, thus additional efforts are needed to ensure the framework's usability and accessibility in practice. As a pioneering framework study, this article underscores the current limitations of human factors in effectively reducing integration complexity in information processing and system complexity inherent in design solutions. Addressing these two challenges presents potential avenues for human factors research to achieve breakthroughs and enhance its impact on the field of design.

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AI ROLE IN IDEATION FOR DESIGN CREATIVITY ENHANCEMENT

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ABSTRACT
Artificial Intelligence (AI) has gained significant attention as a tool to support creative design, especially during the ideation phase. Although AI's role in design has been explored, its effectiveness in enhancing design creativity during idea generation remains uncertain. This study investigates how generative AI can influence design creativity in both individual and group ideation. Seven students participated in the study, generating ideas either individually or in groups using AI tools. The research examines AI's impact on creativity from participants' perspectives and outputs, aiming to provide a clearer understanding of AI's evolving role in design. By analyzing both the benefits and limitations of AI in the creative process, this study contributes to the ongoing discussion about AI's potential to enhance creativity.

Keywords: Artificial intelligence, Design creativity, Ideation, Generative AI

1 INTRODUCTION

In recent years, there has been a noticeable increase in interest in using Artificial Intelligence (AI) in the creative design process [1–5]. Given its expanding powers in picture generation, data analysis, and ideation recommendations, there is a compelling reason to investigate how AI may enhance creativity in individual and group settings. Although AI might help and inspire individuals by automating repetitive processes and developing ideas [6–8], it is still being determined if AI can assist in enhancing design creativity in ideation. The motivation for this study was to learn more about the role AI may play in design creativity—especially in the ideation stage.

In this study, we compared the influence of AI in individual and group settings to explore how useful it is as a tool for creativity enhancement in the early design stage (ideation). Seven master's students participated in the study. Participants had to generate creative ideas for transportation on mountain terrain individually or in groups for free using AI technologies. Specifically, we aimed to explore whether AI can be used in ideation for creativity enhancement based on the output and feedback of participants. In the end, we contributed to the understanding of AI's increasing position in design by highlighting both the advantages and disadvantages of AI in the creative design process through this study.

2 BACKGROUNDS

2.1 Design creativity

Ideation, also known as conceptual design, encompasses a variety of activities that involve the creation and development of ideas [9,10], particularly within the realm of design [11]. In the ideation phase, designers participate in activities that involve generating ideas and making decisions [12]. Ideation research typically assesses the creativity of outcomes generated in ideation to validate the efficacy of diverse techniques or stimuli [13,14]. Design creativity occurs when individuals utilize their capacity to generate ideas, solutions, or products that are novel and valuable (e.g., utility or usefulness) [15,16]. Regarding creativity metrics, researchers have identified four distinct measures of effectiveness: novelty, variety, quality, and quantity [17,18]. In addition, it is advisable to assess the novelty, and quality of outcomes when a study is exclusively centered on design creativity [13], which was used in creativity-related studies [19,20].

2.2 AI in ideation

AI is increasingly employed in creative industries, especially in ideation processes, which may generate, filter, and enhance ideas [21,22]. AI helps individuals think outside the box and explore various ideas throughout the idea generation by providing new stimuli or automating repetitive chores [3,23]. Text-based generative models—like ChatGPT—have been popular in idea generation because they offer a novel viewpoint and facilitate the quick development of ideas in various fields [24–26]. Because of their adaptability, these models enable users to develop various solutions, from intricate problem-solving exercises to product ideas [24–26].

The rising trend of AI-assisted ideation shows the relevance of human-AI collaboration [27,28]. AI technologies are increasingly seen as co-creators that augment and supplement human efforts rather than replace human innovation [29,30]. Numerous research studies have focused on this hybrid method, indicating that AI can assist individuals in exploring concepts outside of their routine cognitive processes [31,32]. By incorporating AI technologies into the creative process, individuals have access to a broader range of viewpoints, ultimately resulting in more creative ideas [3,32].

2.3 Research motivation and aim

While successful in assisting human creativity, some academics contend that AI cannot be considered "creative" due to its inability to comprehend context or meaning [33–35]. According to this viewpoint, human creativity is anchored on emotional, cultural, and contextual knowledge [36,37], whereas AI is restricted to pattern recognition and data-driven outputs. However, others who support using AI in creativity contend that these instruments are essential for expanding the creative realm [4,24,25]. They view AI's capacity to generate ideas at scale and provide surprising connections as a helpful advantage, especially in industries like design that significantly rely on ideation [4,24,25]; how individuals' approach to ideation has changed because of AI's growing incorporation into creative professions [33–35]. However, more needs to be done to understand how AI may actively integrate into creative processes in both individual and group settings.

Therefore, our study examines how AI might improve group and individual ideation processes for design creativity. In particular, it explored how AI might affect individual and group ideation and how AI tools might supplement or augment human creativity in ideation. By dissecting these facets, the study attempted to add to the current conversation around AI's influence on design creativity.

3 METHODS

3.1 Participants

Seven participants participated in the study, including master students in the Art and Design faculty at the University of Lapland. They participated in the experiment as volunteers, and the participation did not affect their grades. We did not collect demographic information such as age, gender, or other personal details. This decision ensured that the focus remained solely on participants' creative output and their interaction with AI tools rather than introducing potential biases related to demographic factors.

3.2 Procedure

We experimented with a structured process. First, participants provided informed consent and completed a prequestionnaire that gathered their understanding and previous experiences related to AI, design creativity, and ideation. Next, participants took part in an ideation session, where they were tasked with generating as many ideas as possible within 20 minutes to design a transportation for people and goods in a mountainous area. Participants' use of AI tools during ideation was based on their responses to the pre-questionnaire. Those with a positive view of AI were instructed to use AI tools to assist in the ideation process individually (individual ideation: two participants in our study). Those uncertain about AI were given the flexibility to collaborate with group members (one or two) and use AI tools as they wished (group ideation: five participants in our study). Then, participants had to select, develop or generate one idea, as the best idea in 10 minutes. Finally, participants engaged in a discussion reflecting on the role of AI in enhancing creativity during the ideation process.

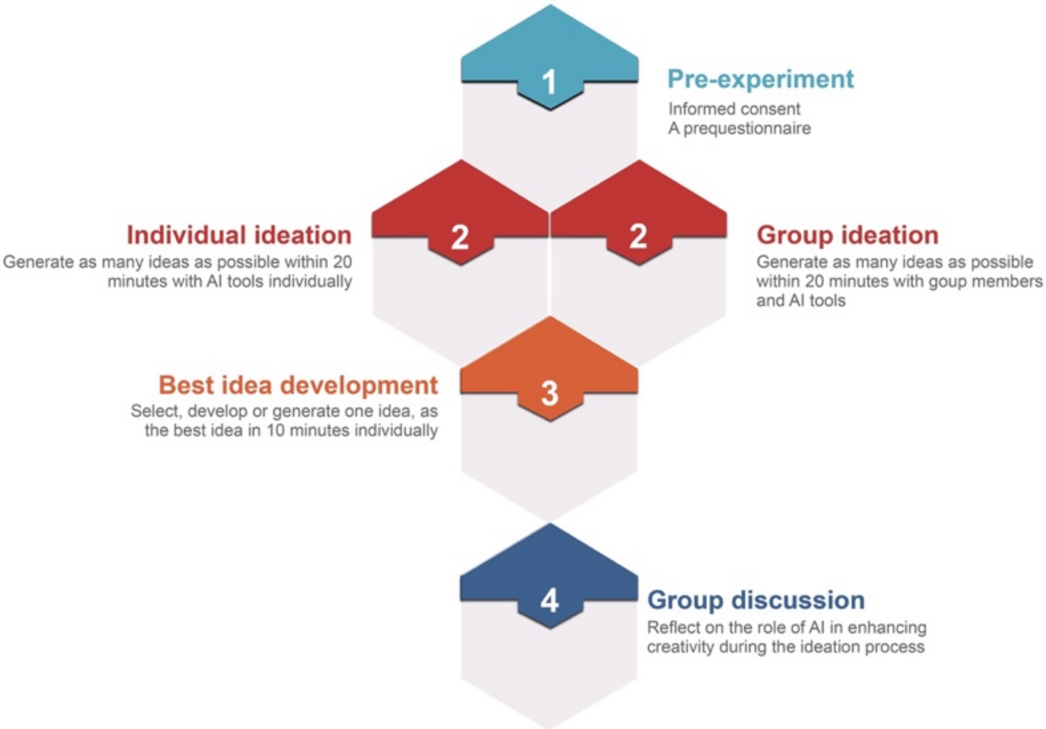


Figure 1. The procedure of the experiment

3.3 Data collection

We collected data in several stages. Initially, participants provided their opinions on AI, prior experiences with ideation, and general understanding of AI through a pre-questionnaire. After the ideation session, we gathered participants' final outputs, precisely the idea they considered to be their best. Although various metrics were used to measure design creativity [18], we adopted the study of Dean et al. [13], which was used to evaluate design creativity in ideation from four dimensions: novelty, workability/feasibility, relevance, and specificity [16,37]. In addition, we also collected participants' reflections during a post-ideation discussion, where they shared their thoughts on the role of AI in enhancing creativity. The audio recording from this discussion was transcribed for further analysis.

4 RESULTS

4.1 Description results

Before the experiment, we surveyed students on their familiarity with AI in the context of ideation for design creativity enhancement.

4.1.1: Participants previous experience of AI

Regarding AI, we asked about their understanding of AI. Participants provided varied descriptions of AI, reflecting a general understanding of its function and capabilities. One participant described AI as a program that processes information from the internet to answer questions or generate outputs based on available data. Another viewed AI as a data collection and reorganization tool, emphasizing its utility in multiple contexts. Some participants expressed the concept of AI as having "intelligence" that mimics human thinking, enabling it to perform tasks or create things. Participants demonstrated a shared understanding of AI as a computer-based system capable of gathering, processing, and responding to data, though their specific definitions varied in detail and focus.

Five participants were moderately familiar with AI, while two had limited familiarity. Four of the seven participants had previously integrated AI into their projects, while the remaining three had only briefly explored AI tools in everyday contexts. The most commonly used AI tools were chatbots and image generators, which all participants had tried, such as ChatGPT, Alexa, Midjourney, and Dell-2. In contrast, fewer participants had experience with machine learning models (two participants) and data analysis and visualization tools (two participants).

Participants expressed diverse perspectives on AI's role in the creative ideation process. One participant noted that AI might be useful for visualizing ideas that have already been formed but doubted its ability to generate innovative or "usable" designs for common objects. They suggested that AI might be more effective when generating unconventional designs, such as "a printer with the shape of a flower," to inspire further sketching and development. Some participants expressed uncertainty about integrating AI into their creative processes, with one mentioning that AI might offer new ideas but still needed to figure out its value. Conversely, others were more open to AI's potential, with one participant describing it as a co-creator, providing ideas and starting points to be developed further. Another participant recognized AI's utility in brainstorming and sharing ideas, considering it a valuable asset in the early stages of ideation. Overall, participants generally saw AI as a tool that enhances creativity by offering inspiration, visualizations, or alternative viewpoints, though opinions varied on its effectiveness and role in decision-making.

4.1.2: Participants previous experience of design creativity in ideation

Addressing creativity, participants described creativity primarily as the ability to generate new, unexpected solutions. Participant 1 highlighted the importance of originality, emphasizing that creativity involves thinking "outside the box." Another participant (participant 4) focused on the emotional aspect, defining creativity as a way to express feelings or present ideas through design. Several participants linked creativity with innovation, noting that it involves developing fresh ideas and designs that stand out from the past. One response specifically mentioned that creativity leads to innovative solutions that solve problems and enhance user experience. Overall, participants viewed creativity as both the generation of new ideas and the creation of designs that push beyond conventional boundaries, driven by the pursuit of novel solutions.

Participants shared various ideation methods they had previously used in their design projects, with brainstorming emerging as a common method. Benchmarking was another frequently mentioned method, with participants looking to existing designs for inspiration. This often involved sketching or writing down initial ideas that surfaced during the process. Collaboration also played a role, with some participants discussing their ideas with friends to further develop and test ideas. Overall, participants used a mix of ideation methods, relying on brainstorming, benchmarking, and creative exploration to solve design problems.

4.2 Design creativity

Two expert raters, each with approximately 10 years of professional experience in the design and creativity fields, independently evaluated the best idea randomly, which was developed and selected as their best idea by participants independently. The two raters have worked for the previous evaluation, and a high degree of agreement between them was evidenced by a statistically significant Kendall's W value of 0.755 ($p < 0.0005$) [16]. This result indicates strong consistency in their evaluation of the reliability of the evaluation process [38]. In the individual ideation condition, students scored the lowest in the novelty dimension of design creativity but achieved the highest scores in workability (feasibility) compared to group ideation, as shown in Figure 2. The average novelty score was 2.75 for individual ideation and 5.7 for group ideation. Conversely, the average workability score was 7.5 for individual ideation and 4.7 for group ideation. Additionally, there was minimal difference between the two conditions in the remaining dimensions of design creativity, including relevance and specificity, as shown in Figure 2. This implies that group cooperation improves the novelty of ideas, although AI may contribute more to producing feasible solutions throughout the ideation phase.

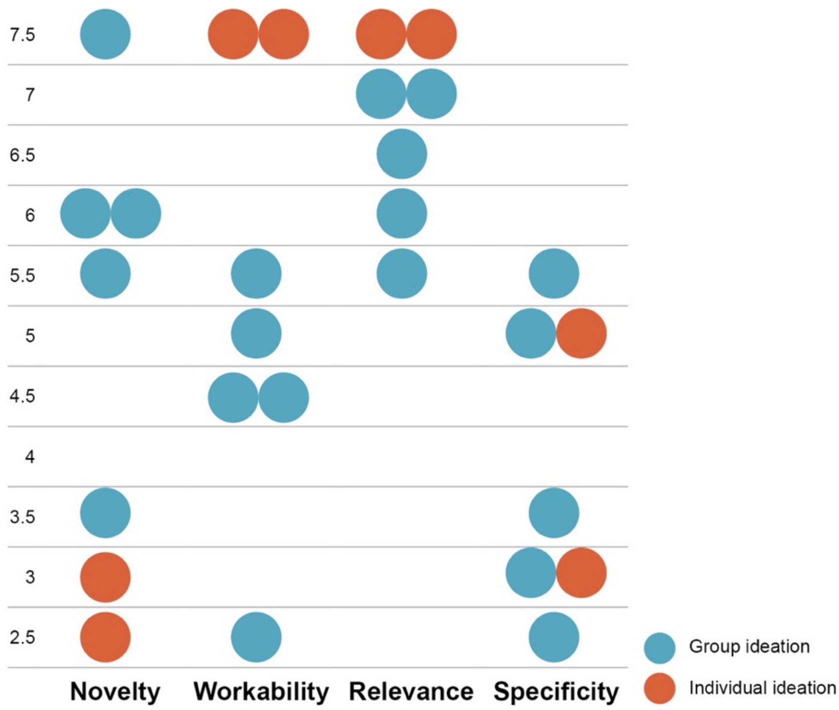


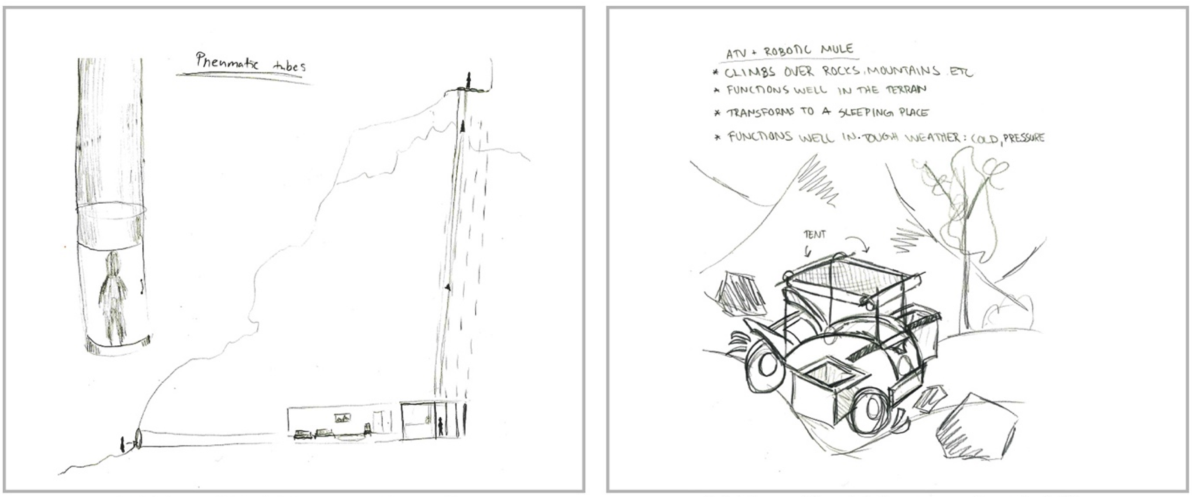
Figure 2. The scores of design creativity in two conditions

5 DISCUSSION

In this section, we discussed the difference in design creativity based on their output in two conditions (individual and group ideation). In addition, because no different opinion about AI's influence was found in the two conditions, we discussed the role of AI in ideation combined with two conditions.

5.1 Design creativity in individual and group ideation

We examined the contrasts between using AI in individual and group ideation based on their best ideas (two examples shown in Figure 3). The findings suggested that group ideation enhanced the novelty of ideas compared to individual ideation. In group settings, the collaborative exchange of ideas appeared to foster more innovative and unconventional solutions, as reflected in the higher average novelty score. Conversely, individual ideation prioritizes practicality, with participants generating ideas that scored higher in workability, likely because AI provided the workable ideas based on existing solutions.



(a) Idea with a high score of novelty (b) Idea with a high score of workability

Figure 3. The two examples of ideas are in two conditions. (a) is the idea with a high score in novelty generated in the group condition, and (b) is the idea with a high score in workability generated in the individual condition.

The minimal differences in other dimensions, such as relevance and specificity, indicated that these aspects of design creativity were not heavily influenced by whether ideation occurs individually or, in groups or AI assistance. Interestingly, while group ideation boosts novelty, the presence of AI might have supported participants in generating more feasible solutions, highlighting AI's potential to enhance the workability of ideas during the creative process.

5.2 The role of AI in ideation

Following the ideation activity, participants engaged in a group conversation about the role of AI in ideation for creativity enhancement. There is no difference between individual and group ideation. Thus, we discussed participants' opinions together. One of the topics was that, while AI is helpful, *it cannot replace human creativity*. One participant stated that "to be creative, the machine still needs a human," implying that AI is primarily a support tool in the creative process. Another participant mentioned the difficulty of expressing highly unique ideas to AI (i.e., image-AI generator), such as having a fresh mind and describing it to the image-AI generator, which cannot provide any valuable visuals.

Several participants voiced dissatisfaction with *AI's limits in producing novel results*. One participant commented that AI struggles to create truly unique designs, making it more useful for simple and fundamental concepts than for developing fresh ones. Others demonstrated that while AI may provide fundamental ideas or beginning points, it requires human involvement to produce complicated or high-quality ideas. However, not all interviewees saw AI solely as a restriction. Two participants saw its utility in bringing fresh insights or simplifying ideas, especially in collaborative situations.

We also examined the contrasts between working with AI and colleagues. Many participants discovered *that cooperating with human peers was more advantageous than working alone with AI*. One participant mentioned that their partner contributed more to the creative process than the AI, which helped to keep ideas flowing and improved the ideas. On the other hand, those who worked only with AI expressed that it only provided fundamental ideas, necessitating more intervention to generate more novel ideas.

Interestingly, some participants hypothesized about *AI's future potential in creativity*, particularly in more advanced applications such as machine vision or emotion tracking. One participant imagined a situation where AI could understand facial expressions or even eye movements and alter its outputs in real time, thus expanding its function as a creative collaborator. Although such developments are still in the works, one participant speculated that AI may ultimately become a more intuitive and responsive partner.

Overall, the conversation underlined that AI may help with the creative process but cannot replace humans. Participants confirmed AI's capacity to form simple ideas but also emphasized the need for human cooperation and judgment in refining and developing creative ideas. As AI advances, its function in ideation may grow more significant; nonetheless, for the time being, it remains a tool that provides basic, simple and existing ideas rather than creative ideas.

6 LIMITATIONS

While this study offers insights into the potential of AI to support creativity in ideation, several limitations should be acknowledged. First, the sample size was relatively small, with only seven participants, which limits the generalizability of the findings. A larger, more diverse sample might yield different perspectives on AI’s role in enhancing creativity. Additionally, the study focused on master's students in design, whose familiarity and comfort with creative ideation processes may differ significantly from professionals in other fields. This participant group may have unique perspectives, or skill sets that influence how they use AI in ideation, which could affect the transferability of these findings to other populations.

Moreover, our study's scope was limited to short-term ideation sessions. The results may differ if the ideation process were extended over a longer period, or if participants were using AI in a professional or commercial context where the stakes and outcomes are different. Longitudinal studies could provide a more comprehensive view of AI's role in sustained creative work and its evolving impact on design processes.

7 CONCLUSIONS

In this study, we investigated the influence of AI in enhancing design creativity in ideation. The findings demonstrated that while AI can help generate ideas and provide inspiration, the ideas and solutions provided are common and paradigm-preserving and might not assist in enhancing novelty but workability of design creativity. Participants considered AI primarily a support tool that might provide beginning points or alternative viewpoints. However, its ability to generate original or rare ideas still needs to be expanded.

Collaboration was identified as a critical element in creative ideation. Participants who worked with teammates found the process more productive and innovative than those who worked solely with AI. Human collaboration sparked new ideas and sustained creative momentum, while AI often provided more basic suggestions that needed individual refinement.

AI might evolve into a more integrated part of the creative process, particularly with advancements in machine learning, emotion tracking, and adaptive technologies. However, AI currently functions as a complementary tool, offering primary and existing solutions rather than enhancing human creativity—particularly in generating novel ideas. It is far from replacing human creativity.

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AN ASSESSMENT METHOD OF INTERVIEWS FOR MODELING ENGINEERING DESIGN PROCESS

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ABSTRACT
The design and development process that produces innovative products and services has been considered an important organizational capability. Modeling of the design and development process is generally conducted through interviews with experienced engineers. However, the success of such modeling depends heavily on the ability of the interviewer to converse with experienced engineers, and it is not clear what kind of conversation is effective for modeling. This has become a bottleneck in knowledge sharing and reuse within organizations. To solve this problem, this study aims to establish a method for clarifying and assessing the conversation structure of interviews for modeling the engineering design processes. The proposed method consists of two parts: a method for analyzing the conversation structure using an integrated three-layered process model, which the group of Osaka University has developed to represent the system design process, and a method for evaluating the relationship between questions and answers in the conversation based on text similarity measurement based on a large language model. As a case study, we take up an example of modeling a solder joint design and evaluation process carried out in a manufacturing company. We apply the proposed method to the analysis and assessment of the modeling process conducted by an expert interviewer and a novice interviewer for an engineer. We discuss the validity of the proposed method under the results of the case study.

Keywords: Design process, Modeling, Engineering knowledge, Knowledge management, Text similarity, Conversation assessment

1 INTRODUCTION

With the diversification of customer needs and the globalization of product development, there is a growing need for rapid design development based on more information. About 20% of a designer's time is spent searching and absorbing information [1], and the importance of capturing and managing engineering knowledge is increasing. In this context, there is an effort to model processes [1] and standardize them to share and reuse the experimental knowledge of engineers. These are efforts to accumulate the knowledge and know-how of experts in the form of procedure manuals and best practices collection, etc., and to extract and utilize the necessary information. Modeling such a design and development process is generally done through interviews with skilled engineers. However, effective knowledge-capturing methods through interviews have not been established. This study proposes a method to clarify and evaluate the conversation structure in interview-style modeling of the engineering design process toward effective knowledge capture.

The rest of this paper consists of four sections. Section 2 addresses research issues and describes our approach to clarifying the interview structure and its evaluation method. Section 3 explains the proposed method. Section 4 describes the application of solder joint design to modeling as a case study. Section 5 examines and discusses the proposed method, and finally, Section 6 summarizes this study.

2 RESEARCH ISSUES AND OUR APPROACHES

2.1 Prior Works on Interview Methods

Interviews are positioned as a representative method of data collection in qualitative research [2,14], and play an essential role in ethnography, which describes people and cultures by observing the actual activities of groups in fields such as sociology and psychology. The data collected in interviews are transcribed and then structured through the KJ method [3] and data coding to make sense. Such conversational analysis is based on the analyst's expertise and may contain subjective elements. There are still open issues in evaluating the interview quality quantitatively.

In the context of design, data collection for human-centered design and interviews with designers who have used generative design tools to analyze the impact of the tools on the design process and designers [4] are proposed. However, since engineering activities are under time constraints, it is necessary to develop and analyze efficient interview methods and effectively utilize the know-how of expert interviewers. Therefore, we objectively analyze interviews to capture engineering knowledge from engineers efficiently.

2.2 Conversation Analysis in Interview

Capturing engineering knowledge through interviews with engineers is conducted by the interviewer during the design and development process, or through interviews and workshops after a series of design and development has been completed. Although the former allows the engineers to make decisions in the design and development process in real-time, it may burden the engineers during the work and interfere with the work. In the latter case, formalized knowledge that is highly reusable can be acquired by taking the time to interview engineers after the design is completed. On the other hand, in the limited time of the interview, engineers often cannot recall their judgments and may not be able to record sufficient knowledge.

This study focuses on the latter approach and analyzes the problem that the success or failure of the interview in the latter method depends highly on the interviewer's skill. We compare two cases: an expert interviewer and a novice interviewer. Until now, various studies have been conducted on analyzing dialogue or communication as a dialogue system. As the origin of this, there is ELIZA [5], a system that repeats and asks questions of the person's utterances based on predefined rules, and SHRDLU [6], which aims to achieve tasks using frames. In recent years, significant research has focused on dialogue systems utilizing deep learning, such as updating dialogue states based on dialogue history [7] and incorporating external knowledge to avoid generic responses and ensure consistency [8]. These dialogue systems depend on the execution of specific tasks or are targeted at everyday conversation, such as small talk, and no studies have analyzed the modeling of the engineering design process so far. This study proposes a method for analyzing the conversation structure using an integrated three-layered process model [9,10] and evaluating communications using text similarity based on a large language model.

3 PROPOSED METHOD OF INTERVIEW ASSESSMENT

Figure 1 shows an overview of the proposed method. It consists of two parts. The first is a method to clarify the argument structure based on the process model and design operation template (the bottom right of Figure 1). The second is the evaluation of an interview by calculating dialogue distances based on the distributed representation.

3.1 Model of Engineering Design Process

There are various representation methods for the engineering design process, such as IDEF0 [11], Design Structure Matrix (DSM) [12], and so on. Although their details vary, they commonly see the engineering design process as a system. It is a formal, structured, and interdisciplinary methodology that integrates technical and human elements to address complex engineering problems. It is organized hierarchically and focuses on whole-system, whole-life dimensions, ensuring the required quality, cost, and duration.

We use a simple systemic model following the premises. The engineering design process hierarchically consists of several processes. Subprocesses are interrelated through the inputs and outputs of deliverables. The process has attributes such as standard required duration, standard cost, and standard resources required to complete the process.

3.2 Clarifying the Conversation Structure of Interviews

The integrated three-layered process model has a mechanism to convert the log of design work acquired as design tool operations, videos, and audio into a representation of the discussion structure model through a template based on design operations that integrate several basic operations and consists of three levels of processes: action, model operation, and discussion [9,10]. In addition, to perform a detailed analysis of each remark, we define remark type (RT) for the interviewer and engineering expert's remarks. The conversation structure of the interview is clarified by classifying all remarks in the modeling process into RT and examining the frequency of their occurrences, time transition, and sequence.

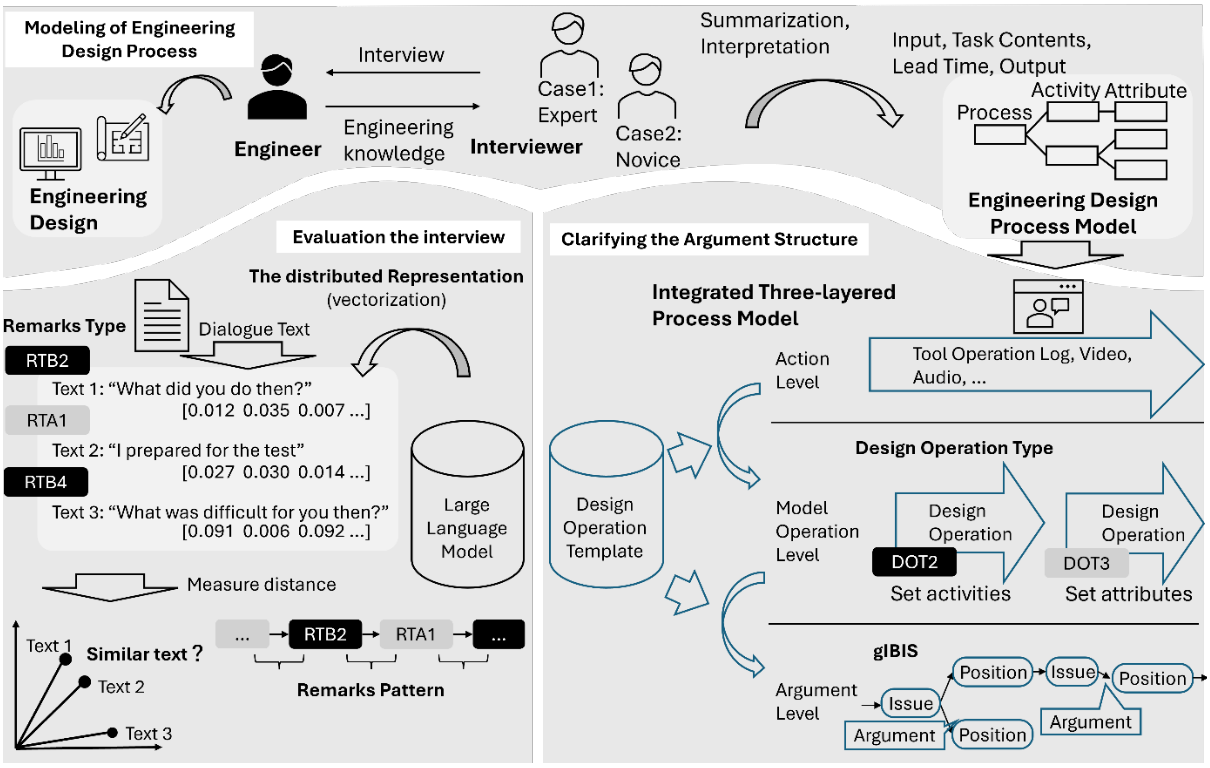

Figure 1. Overview of the proposed method

3.2.1 Description of Argument Structure

To describe an argument structure in the modeling process, Graphical Issue-Based Information Systems; gIBIS [13] are utilized. gIBIS is a knowledge representation method that records people's logical thought processes in a hierarchical structure according to time series, which corresponds to the discussion process level of the integrated three-layered process model. gIBIS consists of three nodes called, "Issue", "Position", and "Argument". In gIBIS, multiple positions to solve an issue are lined up and represented as branches. The process for reaching the final solution proposal and the background of the modeling results are recorded in detail. In other words, the number of branches can explicitly express the point where the discussion has deepened and then the process model representation is modified. To obtain such a description of knowledge in gIBIS, it is important to create issue-and-position nodes formally. The design operation template [9,10] works to formally create their relationships.

3.2.2 Formalization of Argument Structure with Design Operation Template

Depending on the content and intent of the interviewer's operations in modeling, we define a total of five design operation types (DOT). We define the formalized relationship between position and issue node as a template. The definitions for each operation type are as follows:

- DOT1: Set a target process

This type is an operation to determine a target process for modeling. The interviewer decides which process knowledge to elicit from the engineer and standardize based on the company's policies and issues, as well as academic and technical significance.

- DOT2: Set activities

This operation type is an operation that refers to a target process or an activity and adds activities that compose the target process. To describe the general flow of the target process, the interviewer divides the process into some activities based on his or her experience and the engineer's answers acquired through them.

- DOT3: Set attributes

This is an operation to refer to an activity and add attributes that compose the activity. Attributes are common elements, regardless of activities.

- DOT4: Divide an attribute

This type is an operation to refer to an attribute and add its details.

- DOT5: Set a value of an attribute

This operation refers to an attribute and adds a specific value.

3.2.3 Remarks Type for Interviewer

We have extended and redefined the categories of interviewer questions defined by Brinkmann and Kvale [14]. Questions to acquire knowledge through conversation (from RTB1 to RTB5) and questions about the progress of conversations (from RTB6 to RTB9) are defined. The definitions for each RT for the interviewer are shown in Table 1.

Table 1. Definition of Remarks type for interviewer

label	Remarks type	Details
RTB1	Follow-up remarks	Follow-up remarks and reactions to the engineer's answers, such as repetition of responses and phasing.
RTB2	Specificity questions	Clear questions that encourage the engineer to answer, e.g., "What did you do then?"
RTB3	Interpretive questions	Questions to confirm the validity of what the engineer said and the interviewer's interpretation, e.g., "Is this what you mean?"
RTB4	Exploratory questions	Questions to ask when the interviewer wants to learn more about what the engineer said, e.g., "Can you tell me a little more?"
RTB5	Direct questions	Questions that are implied by responses and conversation flow.
RTB6	Introductory questions	Questions to present a topic and start a conversation.
RTB7	Survey questions	Questions to see if the engineer has left anything unsaid.
RTB8	Framed remarks	Questions to move on to the next topic when the interviewer feels that he or she has received sufficient answers from the engineer.
RTB9	Advice	Advice such as when the engineer is struggling to answer, or the interviewer has an idea to respond.

3.2.4 Remarks Type for Engineering Expert

In the interview, there are questions with a large amount of room for the engineer to decide the content of the answer and questions with a predetermined answer format and content. We define the former as open-ended answers; RTA1, and the latter as closed answers; RTA2. The definitions of RT for the engineering expert are shown in Table 2.

Table 2. Definition of Remarks type for engineering expert

label	Remarks type	Details
RTA1	Open-ended answers	An engineer's response in their own words.
RTA2	Closed answers	Yes/No answers or those repeating the question's wording
RTA3	Specificity remarks	Remarks about supplementing or concretizing his/her responses.
RTA4	Interpretive remarks	Remarks confirming the validity of their answer to the interviewer.
RTA5	Follow-up remarks	Reactions to the questions, such as repetition of them and phasing.
RTA6	Framed remarks	Remarks to move on to the next topic when the engineer feels they have sufficiently answered about the topic.
RTA7	Advice	Advice from the engineer to the interviewer, such as when the interviewer is struggling in the modeling process.
RTA8	Questions for questions	Remarks when the respondent does not understand the question or the intent of the question.
RTA9	Remarks to buy time	Remarks or reactions that the engineer makes time to respond.

3.3 Measuring Text Similarity Based on a Large Language Model

The key issues in capturing knowledge through interviews are determining whether the questions and answers are communicating and identifying effective questions. We use an embedding model based on a large language model to calculate the distributed representation of utterance text and evaluate the conversation in the interview by the distance between the texts. The distributed representation is based on the distributional hypothesis that the meaning of a word is formed by the surrounding words, i.e. context [15], and is based on the learning of many documents and converting the text into a vector representation. Therefore, the representation makes the text in a form that is easy to process by computer, and the more similar the meanings of the texts, the closer the distance between the two. Recent embedding models can handle longer and more complex meanings by converting text into higher-dimensional vectors. To calculate the distributed representation, we used OpenAI's Embedding model called, "text embedding-3-large" and converted each utterance text to a normalized vector of 3,072 dimensions. In interviews, a single question and the answer are principally repeated, but since the remarks are based on the context, it is not necessarily the response to the previous text. To address this, in this study, we take a moving average and weigh the previous k utterances to calculate the distance of the distributed representation considering the context In Eq. (1), w_i is weights that are defined in Eq. (2). $distance_{n,i}$ is the L2 distance of the distributed representation between nth text and ith text in utterance logs. dis_w represents the weighted distance to the nth text. In the case study of Section 4, we set $k = 5$.

$$dis_w = \sum_{i=n-k}^{n-1} w_i \times distance_{n,i} \quad (1)$$

$$w_i = \{i + 1 - (n - k)\}/k \quad (2)$$

4 CASE STUDY

To verify the validity and effectiveness of the proposed assessment method, we present a case study of the modeling of the design and evaluation process of solder joints [16,17] conducted by a company.

4.1 Overview of the Modeling Process

In the target process, the engineer designed a method for evaluating the fatigue durability of solder joints under combined loads such as thermal cycling, vibration, and shock. In the modeling, the engineer was interviewed, and the interviewer elicited his/her knowledge, interpreted it in the interviewer's way, and described it in a mind-mapping tool according to the process model stated in Section 3.1 that had been standardized in the company [18]. We captured a computer screen on which the interviewer handled and operated the tool and recorded the entire modeling process on video. For example, operations on the tool included dividing the extracted information into activities and describing their attribute values. We conducted two interview-style modeling cases. In the first case, the interviewer was an interview expert, and in the second case, the interviewer was a novice. According to the interviewers and interviewee, there was a clear difference in the results depending on the experience of the interviewers. In this study, we clarify the differences in experience through comparison and evaluate the conversation in modeling.

4.2 Captured the Modeling Log

After the modeling processes were completed, the transcription tool converted the audio data into text data that summarizes the timestamp, speaker, and speaking content at the time of utterance. We defined the brief remarks made by another speaker in the middle of the dialogue as noise and removed them from the text data in advance. Then, we manually extracted text data summarizing the tool operations from the screen recordings, and we classified the utterance logs and operation logs into RT and DOT.

4.2.1 Comparison of Two Cases

First, we qualitatively compare the process models created by the two cases. Figure 2 shows a part of a simplified version of the model. The interview expert decomposed the target process into six activities, e.g., setting the theme and referring to previous studies. However, the interview novice decomposed the target process into four activities, e.g., background and purpose of the study and research methods. Next, a comparison by modeling time revealed that the expert spent 113 minutes, and the novice spent 72 minutes. In addition, we compared the number of characters in spoken words, and the number of utterances turns. Comparing them, the number of utterance characters is roughly proportional to the interview time, but the expert interviewer case had three times more turns than the novice interviewer case. This means that the expert repeatedly exchanged short sentences.

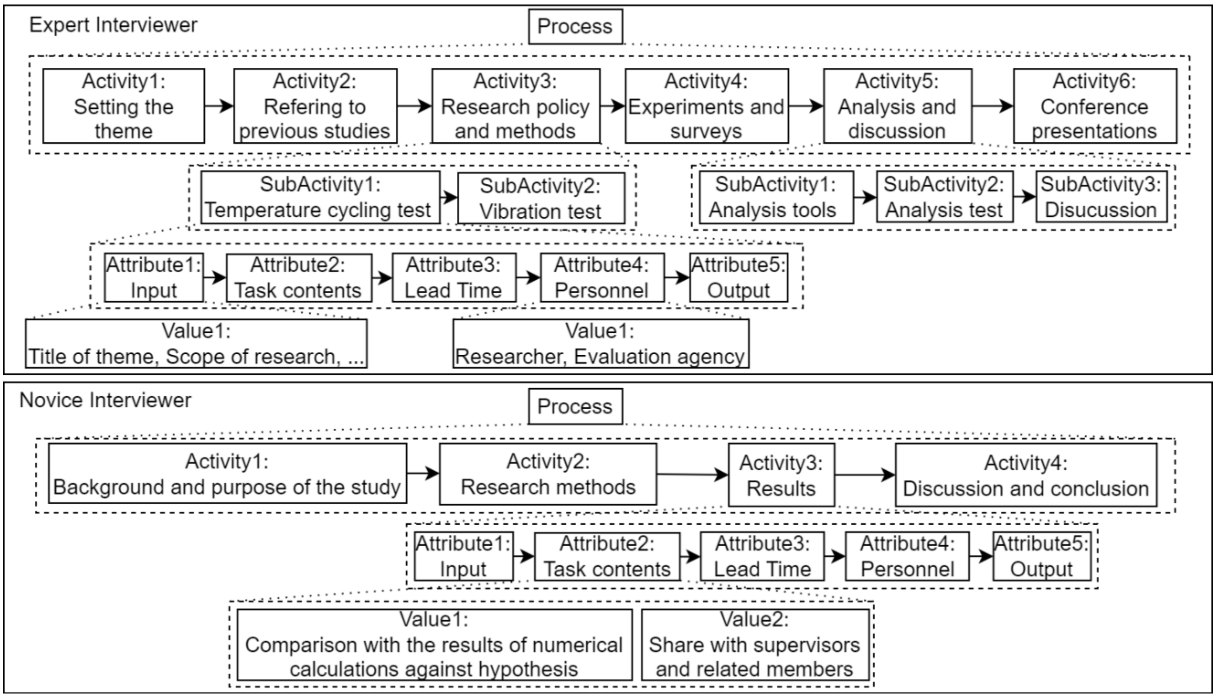

Figure 2. Overview of the model of the engineering design process in 2 interview cases. Subactivities, attributes, and attribute values are shown partially.

4.2.2 Comparison in Design Operation Type

We counted the number of DOTs. In the expert interviewer case, the number of DOT2: Set activities is larger than in the novice interviewer case, and the model is created hierarchically by dividing it into groups. The number of DOT5 is the largest for both cases among all DOTs, which shows that the description of attribute values is the most essential operation. For further analysis, Figure 3 shows the distribution of the time points where the operations were performed over the entire modeling time. Comparing DOT2 in two cases, the red bar (the interview expert) is widely distributed from time1 to time10, but the blue one (the interview novice) does not appear after time7. This result indicates that a novice interviewer finishes describing the upper levels of activity levels by the middle of the process and spends the rest of the time describing them in detail. Also, the wide distribution of red bars in all types shows that the expert is repeating the creation of the model across hierarchies.

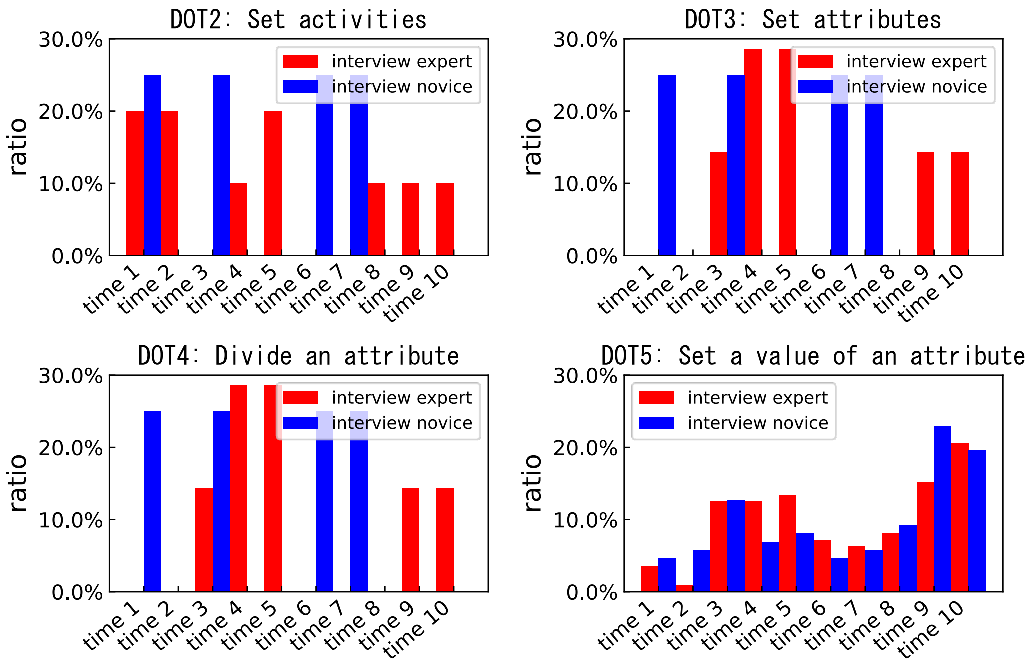

Figure 3. Appearance ratio of design operation type over time

4.2.3 Description of Argument Structure with gIBIS

We made the gIBIS representation of two cases based on the design operation template. Figure 4 shows a part of them. There were 581 nodes in the expert interviewer case and 27 nodes with the strikethrough red lines corresponding to the modified model representation. The novice case showed that there were 267 nodes, and the number of the strikethrough nodes was 11.

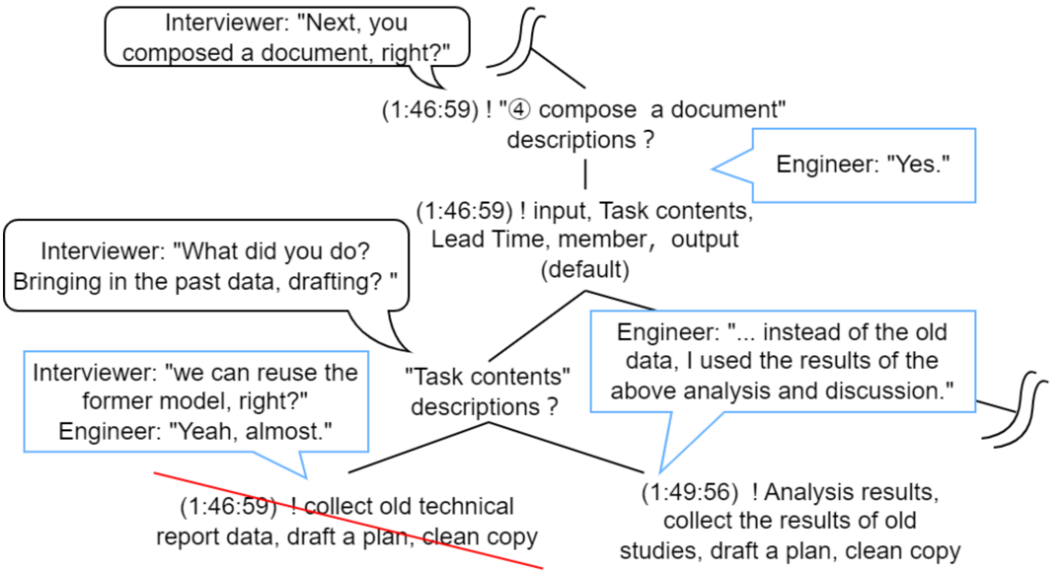

Figure 4. Argument structure representation in interview expert case with gIBIS

4.2.4 Comparison in Remarks Type

Next, we classified all remarks in the interview into RT, mainly in units of utterance turns. Table 3 and Table 4 show the breakdowns of the results. Both interviewers frequently used RTB1, RTB2, and RTB3, and the engineer frequently used RTA1, RTA2, RTA3, and RTA5. We examined the occurrence ratio of RTB2 and RTB3 over the entire interview time. It was found that the expert asked clear questions from the beginning of the modeling, and actively asked questions about the validity of the interpretation at the end of them. This result corresponds to the result in Section 4.2.2 and shows that the expert postpones asking deeper about the content of the answers and prioritizes grasping the general content.

Table 3. Breakdowns of remarks type in Qs.

label	Remarks type	expert	novice
RTB1	F/U Rmk	95	35
RTB2	Spec. Qs	64	21
RTB3	Int. Qs	73	18
RTB4	Expl. Qs	11	4
RTB5	Dir. Qs	12	3
RTB6	Intro. Qs	15	5
RTB7	Surv. Qs	4	0
RTB8	Frm. Rmk	6	1
RTB9	Advice	11	2

Table 4. Breakdowns of remarks type in Ans.

label	Remarks type	expert	novice
RTA1	Open-end. Ans	100	48
RTA2	Clsd. Ans	73	14
RTA3	Spec. Rmk	39	8
RTA4	Int. Rmk	5	1
RTA5	F/U Rmk	61	18
RTA6	Frm. Rmk	4	0
RTA7	Advice	3	4
RTA8	Qs for Qs	4	0
RTA9	Rmks. to B.T.	13	6

4.3 Text Similarity by the Distributed Representation

To consider the context, the texts up to five previous target remarks were weighted based on Eq. (1), and the distance between the remarks was calculated. As a result, the distances varied about from 0.90 to 1.30, with no clear differences between the two cases. Therefore, we examined in detail the texts with particularly large distances. For example, the distance was increased by the new topic of the presentation of the results since the previous statements had talked about the lead time. This result supports that the evaluation of interviews using the distributed distance is effective.

4.3.1 The Distributed Representation Distance by Remarks Type

Figure 5 shows the distributed representation distance by RT. The result shows that the distance between the text and the before of RTB6: Introductory question, is small for both cases. This is because a short reaction to the previous answer is inserted before asking the question of RTB6 to move on to the next topic. Compared to the two cases RTB5: Direct Questions in the expert case had more distance than the novice interviewer. The engineer was talking about sample creations for the experiment, but the interviewer suddenly asked a question about the type of solder. This increased the distance. In practice, the engineer seemed to have decided that there was no need to explain it. However, the interviewer's in-depth questions led to the process with which the interviewer and the engineer could communicate well. Therefore, direct questions can be effective even if the distance is large.

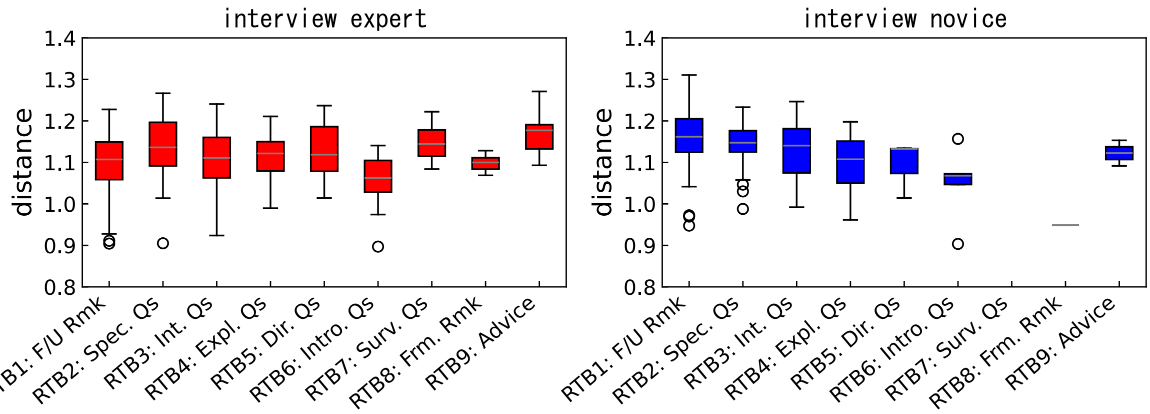

Figure 5. The distributed representation distance by remarks type

4.3.2 Remarks Type and gIBIS

We further consider the results by corresponding the defined RT to gIBIS. This allows us to determine useful statements that have been used in the modeling to elicit the rationale for modifying the process model representation. As mentioned in Section 4.2.3, the number of node modifications in gIBIS was 27 in the expert case. Of these, 14 discussion nodes described as the rationale for modifying the nodes, 11 RTA1: Open-ended answers, and 3 RTA3: Specifying remarks were adopted in the gIBIS description. In other words, in the process modeling, the basis for node modification is mainly based on these two types of statements, and it can be said that the questions that elicit these two types are important in the interview. Therefore, we examined the proportion of RT before RTA1 and RTA3. As a result, RTB1, RTB2, and RTB3 account for most of the questions before both RTA1 and RTA3. In other words, follow-up, specific, and interpretive questions were important remarks for modifying the process model.

5. DISCUSSION

The above case study evaluated the dialogue in modeling the engineering design process based on the gIBIS and the text distance. It was demonstrated that the interview can be objectively evaluated with the proposed method. Further, the proposed method clarified the difference in questioning between expert interviewers and novices.

The distributed representation of each text was determined using the interviewer and engineer's utterance turns as a single unit. By setting RT for each utterance turn, it was possible to correspond the distributed representation with RT. However, the length of the texts differed greatly in some places, causing outliers in the distance. It may be necessary to calculate the distance in units of sentences.

As shown in Tables 3 and 4, RTA7, RTB6, and RTB8 appeared in the expert case, but not in the novice case. The utterances related to these types may not directly contribute to the modeling, but they are important for facilitating communication.

Thus, the proposed method made it possible to quantitatively evaluate the sensory differences between the two cases felt by the interviewers and the engineers. If we use this method to analyze more cases, we can expect to establish an effective interview method.

6. CONCLUSION

In this study, we proposed a method for clarifying the conversation structure and evaluating them in an interview to elicit engineering knowledge. By examining the number of occurrences and time series of

DOT and RT, the difference between expert interviewer and novice could be clarified, and interview methods could be evaluated. We also showed that it is possible to analyze the interviews by describing the argument structure with gIBIS utilizing the design operation template and calculating the distance for all the statements in the interview.

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A ROBOT BEHAVIOR DESIGN ON MODULATED INTENTION INDICATION IN SOCIAL ROBOTS

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ABSTRACT

The readability of robot intentions is a critical factor influencing the usability of robots in social scenarios. Studies on robot intention indication generally aim to improve the clarity of robot intentions, and the commonly approach is explicit intention indication design. Most current studies take accurate recognition of robot intentions as the primary goal in intention indication design, however, in real social interactions, humans do not always express their intentions in explicit and easily readable ways. Instead, human intentions are complex, implied, or modulated to fit the context. Focusing on the modulation in intention indication, this study proposed a behavior design for robots' intention modulation by introducing the inconsistencies among eye-gaze, head, and body orientation. The study conducted a robot interaction experiment in the scenario of collaborating. The results indicated that inconsistency between the robot's eye-gaze and the body orientation were perceived as modulated intention.

Keywords: Social robots, Robot intention, Modulated intention, Behavior design.

1 INTRODUCTION

With technological advancements, robots have gained interactive features (e.g., speech [1], expressive faces [2]), expanding their applications to social scenarios such as companionship [3] and caregiving [4]. The readability of robot intentions is a critical factor influencing the usability of robots in such scenarios, making it an important research topic in the field of Human-Robot Interaction (HRI). Studies on robot intention indication generally aim to improve the clarity of robot intentions and often evaluate this by measuring how well users can perceive and understand a robot's behavior.

A commonly approach is explicit intention indication design, which refers to a robot using clear and direct methods to convey its intentions. For example, service robots equipped with display screens, such as BellaBot [5] or Servi Plus [6], use message or graphics on the screen to indicate directions to a desired location or where customers can retrieve food. For robots without such expressive capabilities, like robotic arms or simple mobile robots, enhancing the readability of their behaviors involves intuitive understandable strategies, such us generating predictable motion trajectories [7][8] or imitating human-like motions [9][10]. These methods focus on reducing ambiguity and ensuring that people can quickly recognize what the robot is trying to do. On the other hand, research on social robots highlights the importance of subtle cues for generating nuanced intentions cues. For instance, [11] examined how humans interpret facial expressions of the humanoid robot GeminoidF, [12] analyzed the recognition of gestures performed by a robot with the human-like face, and [13] use gaze to regulate the speaking roles in human-robot conversations.

Most current studies take accurate recognition of robot intentions as the primary goal in intention indication design. However, in real social interactions, humans do not always express their intentions in explicit and easily readable ways. Instead, human intentions are complex, implied, or adjusted to fit the context. For example, a humorous person in a formal meeting might avoid making obvious jokes but could still use playful tone or subtle gestures to hint at their intention to lighten the mood. In this case, their humorous intention is modulated rather than completely explicit or absent.

Similar situation can be anticipated in the future human-to-robot interaction, especially for the social robots that are expected to possess human-like complexity in social interactions. However, current explicit intention indication methods restrict robots to intention indications such as "I want to appear humorous" or "I do not want to appear humorous," leaving no room for nuanced indications like "I want to appear humorous, but not overly so." Addressing this gap requires exploring new methods that

integrate both explicit and implicit intention, enabling robots to indicate intentions in a context-sensitive and dynamically modulated manner.
In this study, we focused on the behaviors of robots' intention and proposed a preliminary design of robot's modulated intention by introducing the inconsistency in eye-gaze, head, and body orientation. We conducted a robot interaction experiment under a human-robot collaboration scenario. The experiment involved participants and a robot collaborating to make "Ouen Uchiwa" (Japanese cheering fan). The results indicated that inconsistency between the robot's eye-gaze and body orientation were perceived as modulated intentions, and eye movements were perceived more deceptive than head turning.

2 ROBOT BEHAVIOR DESIGN ON MODULATED INTENTION INDICATION

2.1 Policy of robot behavior design

Our previous research [14] investigated physical cues for intention inference when humans receive inconsistent nonverbal information. The previous research was conducted by using a CG character of independent and moveable head, eyes, and right arm. The inconsistent behaviors were generating by orienting the CG character's head, eyes, and right arm to different intention goals. Figure 1 shows an example of the CG character's inconsistent behavior: the CG character's face and arm are orienting towards the yellow cup, whereas its eyes are gazing at the blue cup. The results of the experiment showed that humans perceive these physical cues differently. Specifically, the participants took the CG character's arm direction as an explicit cue, and the gaze as an implicit cue in intention inference.

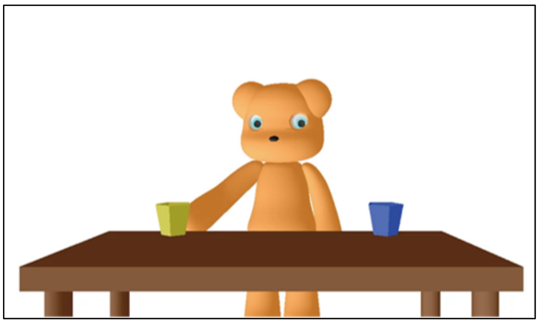

Figure 1. An example of the CG character's inconsistent behavior.

Based on the previous research, we proposed a behavior design of robot's modulated intention indication by introducing the similar inconsistency in eye-gaze, head, and body orientation. Specifically, when a robot indicates the intention, its body orient to the one intention target, while its eyes or head turn toward another intention target. Naturally, the direction of the robot's eye-gaze (or head) and the body generates an inconsistency. By using the inconsistency, the indication of the robot's intention is modulated.

2.2 The robot behavior in modulated intention indication

The Kebbi Air robot was used as the experimental robot because of its simple appearance and its possession of the necessary functions and movement capabilities required for the experiment. Kebbi Air is equipped with 12 servomotors, enabling it to move forward and rotate. Kebbi Air also equipped with camera and microphone, featured with speech recognition function. It features a 7-inch LCD display (1024 x 600 pixels) on its head, which is naturally perceived as the robot's face. We designed graphics to represent Kebbi Air's eyes and animated these graphics to simulate its eye movements.

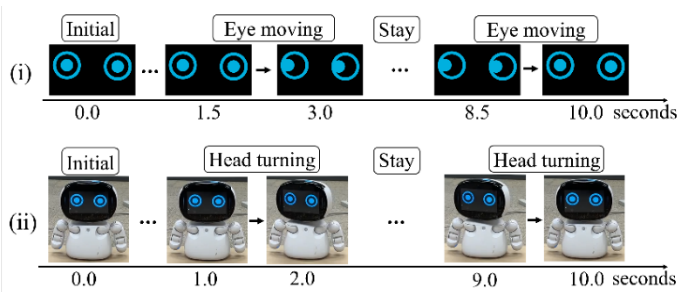

Figure 2. An example of (i) eye movements (turn right), and (ii) head rotation (turn right).

To create the robot's eyes, we used two round shapes (radius = 150 pixels, stroke width = 40 pixels) to outline the eyelid range. A circle represented the eyeball inside each round shape. For simplicity and to ease participants' cognitive processing, the pupil and iris were not distinguished. The eyeballs might move in parallel to simulate eye movements (eye-gaze) when the robot moved forward (the forward-moving time was set to 10 seconds). The size (radius = 75 pixel) and the moving distance (77 pixel) of the eyeballs were adjusted to ensure the participants could clearly recognize the eye movements. Similarly, the robot's head might rotate when the robot moved forward. The rotational angle was set at 30 degrees. Figure 2 shows an example of the eye movements and the head rotation. By controlling the orientation of the robot's eyes, head, and body, inconsistent behaviors were generated.

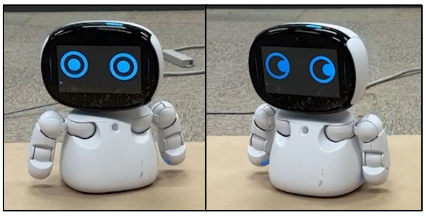

Figure 3. Example of the inconsistency in the robot's body and head(left-side), and inconsistency in the body and eye-gaze(right-side)

Figure 3 left-side is an example of the inconsistency in the robot's body and head: the robot's face is orienting to its right side, while the body is orienting its left side. Figure 3 right-side is an example of the inconsistency in the robot's body and eye-gaze: the robot is orienting towards its right side, while its eyes are gazing the left side.

3 EXPERIMENT DESIGN

3.1 Experiment scenario：making "Ouen Uchiwa" together

The study focused on the robot's intention indication in social contexts, so the experimental scenario was set as human-robot collaboration. The participants were asked to collaborate with the robot in making "Ouen Uchiwa". "Ouen Uchiwa" refers to cheering fan in Japan, normally uses to express support or gratitude for specific teams or individuals. "Ouen Uchiwa" can be found in various events in Japan. Typically, an "Ouen Uchiwa" comprises a black fan, decorated with a phrase surrounded by decorations (see Figure 4 right-side).

A variety of phrase cards and decoration cards were prepared for the experiment (see Figure 4 left-side). In the experiment, the participants were instructed to choose one phrase card for one "Ouen Uchiwa", while the decoration cards were chosen by the robot. The total of six types of phrase cards prepared in the experiment for the participants: "Take it easy", "Supporting for you", "LOVE", "HAPPY", "Fight", and "Thank you". Two sets of decoration cards were placed in front of the robot, each consisting of five decoration cards. The cards in front of the robot were drawn from 26 prepared decorative cards. The prepared decoration cards contain 13 shapes in pink or blue.

Figure 4. The experiment materials for "Ouen Uchiwa" making and the made "Ouen Uchiwa".

3.2 Experiment procedure

In the experiment, the participants were firstly instructed to sit in front of a table, which the robot was placed on it. A blank "Ouen Uchiwa", two sets of decoration cards and six phrase cards were placed between the robot and the participant. The two cards sets were positioned in front of the robot, with a stand-up card labeled with "A" placed next to the right-front cards set (position A), and a stand-up card labeled with "B" next to the left-front card set (position B).The spatial position of the robot and the cards sets are illustrated in Figure 5.

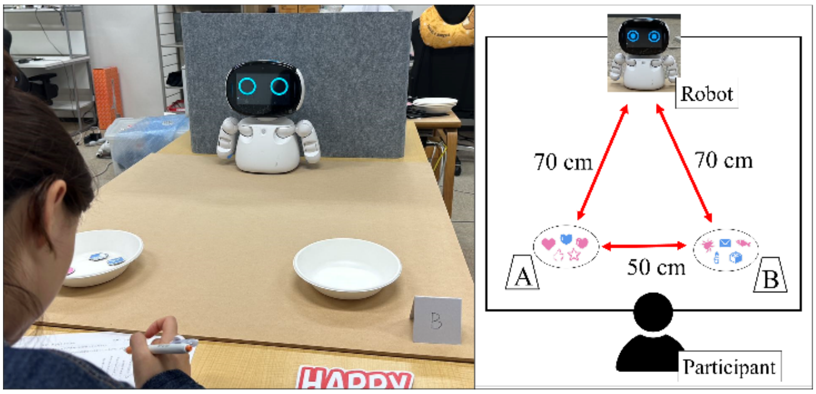

Figure 5. Spatial position of the robot and the cards sets.

To help refine the experimental procedure design, a pilot experiment involving three volunteers was conducted. The volunteers reported not feeling bored in the pilot experiment. There were volunteers mentioned collaborating with the robot in making "Ouen Uchiwa" enjoyable. However, all the volunteers pointed out that the experimenter's intervention influenced their interaction experience with the robot. In the pilot experiment, the robot's actions were manually triggered by the experimenter. Based on this feedback, the robot's action triggers were adjusted to speech recognition activation. The participants can verbally prompt the robot in the experiment. Additionally, except in cases of the robot malfunction, the experimenter no longer intervenes in the participants and the robot throughout the whole experiment.

Based on the pilot experiment, the experimental procedure was designed. As for each "Ouen Uchiwa" making session, the participants were instructed to first observe the two decoration cards sets in front of the robot, and then selected the phrase card. When the participants finished selecting the phrase card, they could verbally prompt the robot by saying "Please (in Japanese)." Once the robot recognized the speech, it started series of actions. Firstly, the robot rotated the head to express observing the card sets on the table, and then said, "I think I would like this one." Then, the robot turned to one of the two cards sets and moved forward. As it moved, the robot's eyes and head might turn toward the other cards set to generate inconsistent behavior. The forward-moving time was 10 seconds. Then, the robot's head and eyes returned to align with the body orientation and said "Please (in Japanese)." After waiting 2 seconds, the robot turned and returned to the initial position, and waited for the next speech recognition. The participants were asked to determine which decoration cards set the robot chose, and complete the "Ouen Uchiwa" by using the chosen cards. Each participant was required to make "Ouen Uchiwa" four times.

3.4 Conditions

The study posits the following hypothesis: *The robot's inconsistent behaviors are perceived as hidden intentions.* Based on the inconsistency of the orientation of the robot's head, eyes, and body, six behaviors were generated. The behavior where the eyes and body had the same orientation while the head oriented differently was excluded as it was deemed not an explainable behavior. Table 1 shows the behaviors and conditions. The alphabet in the table cells refers to the orientation of the body parts (e.g., "A" refers to the orientation to position A). The experiment was conducted in a between-group design.

Table 1. Experimental conditions

No.	Eyes	Head	Body	Condition
1	B	B	B	I-Consis
2	A	A	A	
3	B	B	A	I-Head
4	A	A	B	
5	B	A	A	I-Eye
6	A	B	B	

3.5 Measurements

Table 2. Questionnaire items

No.	Question items		Scales
Q1-1	How satisfied are you about the cheering fan made?		5-point
Q1-2	How satisfied are you with the decoration cards the robot chose?		5-point
Q1-3	Which did you think this robot would choose, A or B? Please give the probability you think of position A and position B, taking the total as 100 percent.		Constant-sum scale
Q1-4	Please rate the following items that best describes your impression of the robot's behavior.		7-point of Semantic Differential
	(a)	Seems true - Seems like a lie	
	(b)	Sincere - Insincere	
	(c)	Trustworthy - Untrustworthy	
	(d)	Honest - Dishonest	
	(e)	As if nothing is hidden - as if something is hidden	

The experiment was conducted in using questionnaires. The items in the questionnaires are shown in Table 2. Q1-1 and Q1-2 were used to investigate participants' satisfaction of collaborating with the robot in "Ouen Uchiwa" making process. Q1-3 measured in what extent the inconsistent behaviors influence the participants infer the robots' intention (i.e., the perceived intention). Meanwhile, in Q1-4, we measured the participants' perceived deceptiveness of the robot by the deceptiveness scale from [15][16]. Deception is considered a purposely act, and we aimed to leverage this to investigate whether the participants perceive the robot's behaviors purposeful, without directly asking them, "Do you think the robot doing this in purpose?"

After each "Ouen Uchiwa" making session, the participants were asked to fill in questionnaire. Each participant filled the questionnaire four times in each condition.

4. RESULTS

A total of 25 participants were recruited for the experiment, with a mean age of 24.6 years and a standard deviation of 1.31. Twelve participants were assigned to condition I-Consis, six participants in condition I-Head, and seven in condition I-Eye. All participants were residents of Japan, fluent in Japanese, and familiar with the "Ouen Uchiwa". Results from 100 questionnaire Q1 (48 in condition I-Consis, 24 in condition I-Head, and 28 in condition I-Eye) were collected and all results were valid.

Figure 6 shows the box plots for item Q1-1, Q1-2 and Q1-3. Regarding the participants satisfaction of collaborating with the robot (Q1-1 and Q1-2), Kruskal-Wallis test showed no significant difference. Regarding the results of the robot intentions perceived by the participants (Q1-3), from the probabilities that the participants filled in the questionnaire towards position A and position B, the data of the position where the robot's body oriented in each "Ouen Uchiwa" making session was selected. Results of Q1-3 shows the probabilities that the participants speculated in the position where the robot's body oriented. Kruskal-Wallis test showed a significant difference ($X^2(2, N=100) = 6.174$, $p = 0.046$). Post-hoc comparisons using Dunn's method with a Bonferroni correction for multiple tests showed a significant difference between I-Eye and I-Consis (p = 0.039).

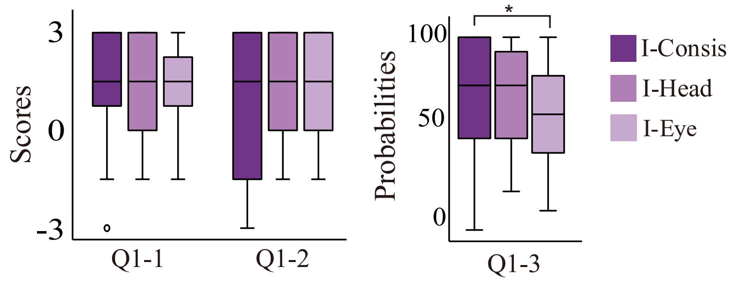

Figure 6. Results of the satisfaction (Q1-1, Q1-2) and perceived intentions (Q1-3).

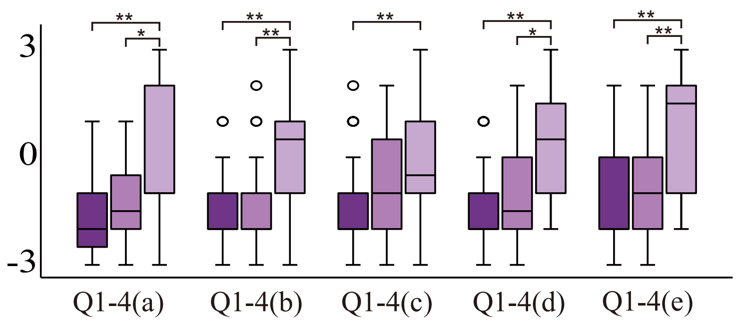

Figure 7. Results of the deceptiveness (Q1-4).

Figure 7 shows the box plots for item Q1-4. Regarding the results of the participants' perceptions of deceptiveness, Kruskal-Wallis test showed significance in all items (Q1-4(a): $X^2(2, N = 100) = 19.610$, $p < 0.001$; Q1-4(b): $X^2(2, N = 100) = 25.856$, $p < 0.001$; Q1-4(c): $X^2(2, N = 100) = 9.489$, $p = 0.009$; Q1-4(d): $X^2(2, N = 100) = 23.036$, $p < 0.001$; Q1-4(e): $X^2(2, N = 100) = 31.871$, $p < 0.001$). Parison comparisons (Dunn's method with a Bonferroni correction) showed that I-Eye scored significantly higher than I-Consis and I-Head in all items except Q1-4(c): Trustworthy-Untrustworthy. In Q1-4(c), the I-Eye was significantly higher only than I-Consis.

5. DISCUSSION

The result of Q1-3 indicates that the inconsistency in robot's eye-gaze and body orientation was perceived as the modulated intention. The robot's eye movements (gaze) were used as a cue in intention inference, which is aligned with the previous finding [14]. It is worth noting that, the head turning in the I-Head condition was more noticeable than the eye movements in the I-Eye condition, leading the head turning considered to be taken as the cue, while no significance was found. This might be because the participants perceived the eye-gaze of the robot differently in the two conditions: eye movements in I-Eye may have been seen as a more instinctive behavior (e.g., glancing), while head-turning in I-Head may have appeared less instinctive (e.g., watching). There was study [17] took the robot glancing as "a seemingly unintentional behavior" as well as "a leakage cue in interaction". In the I-Eye condition, when the eye movements didn't align with its body orientation, the eye-gaze may be interpreted as the leakage of intention, which exerted a stronger influence than head-turning.

The results of Q1-4 suggested the participants perceived eye movements to be more deceptive than head-turning. Combining with the result of Q1-3, this suggested that the participants perceived the inconsistency in the robot's eye-gaze and the body as a purposeful behavior. Additionally, there was no significance difference between the I-Head and I-Consis in all items in Q1-4. The reason may be the participants perceived the head turning as "watching", which reduce a feeling of deceptiveness. One participant mentioned that the robot rotated its head for using the camera on the head to recognize the cards set. In the experiment, the image recognition function of the robot was not active, and the experimental instruction did not mention nor imply the robot capable of image recognition function.

However, this participant inferred, based on the knowledge and observations towards the robot Kebbi, that the image recognition was in functioning, and thought that the head turning was related to the image recognition function, and thus not deceptive. This could also explain why there was no significant difference between the I-Head and I-Consis in Q1-4. On the other hand, the results suggest an ethical risk. Since the inconsistent behavior increased the perception of deceptiveness, users may misinterpret the intentions that robots are trying to indicate, particularly for children, elderly people, and those people unfamiliar with technology. Future works need to be conducted focusing on how different users perceive inconsistent behaviors and seek design solutions suitable for different people.
This study is a preliminary behavior design of intention modulation and has several limitations. First, the small sample size of 25 participants reduces the statistical power of the results. Additionally, to simplify the robot's behavior, the intention targets in front of the robot were limited to only two, and they were placed symmetrically in front of the robot. In real-world interaction, intention targets are more varied and dynamic, and the experimental results may not be easily generalized.

6. CONCLUSION

This study presented a behavior design for modulated intention indication in social robots by introducing inconsistencies between a robot's eye-gaze, head, and body orientation. The study conducted a robot interaction experiment in the scenario of involving the participants and the robot collaborating to make "Ouen Uchiwa". During the experiment, the robot approached one set of decoration cards, while its head and eyes might turn towards another set. The results indicated that inconsistency between the robot's eye-gaze and body orientation was perceived as modulated intention, and eye movements were perceived more deceptive than head turning. It suggests the possibility for modulating robots' intention indication through inconsistency in eye-gaze and body orientation. The study addressed robot behavior design (i.e., how robots behave), without considering the decision-making process (i.e., how intention should be modulated). In the future, the decision-making in modulating intentions of robots will be further researched.

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THE DEVELOPMENT AND IMPLEMENTATION OF A HIGH-FIDELITY THREE-DIMENSIONAL PRINTED SIMULATOR FOR HIP ARTHROSCOPIC TRAINING: INSIGHTS FROM A CROSS-DISCIPLINARY

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ABSTRACT
Hip arthroscopy is an ideal technique to treat many intra-articular conditions of hip, such as femoroacebuar impingement (FAI) and labral tears. However, hip arthroscopy has its unique challenges in training and operation. Currently, the essential skills and preferred training method for hip arthroscopy remains unknown. In this study, we investigated the required surgical skills and suitable simulation method for hip arthroscopy. Based on that, a high-fidelity medical simulator would be designed.
A nation-wide online survey was carried out, which was focusing on skills that trainee should possess prior to performing hip arthroscopy in operating room. Meanwhile, the usefulness of different types of simulation had been identified. The high-fidelity simulator was developed based on medical imaging and three-dimensional (3D) printing technology. The feasibility of the simulator was evaluated based on a cross-sectional study.
The skills related to cognitive ability the treatment of FAI are the most essential for hip arthroscopic training. Cadaveric specimens are the most favorable simulation method, high-fidelity physical simulators are the preferred alternatives. A 3D printed simulator for hip arthroscopic training has been developed based on the results of the survey study, which is suitable for surgeons to practice the specific skills.
Based on the collaboration between designers and medical professionals, the effective simulation tools and training program can be developed. It is beneficial for medical trainees and the quality of healthcare.

Keywords: Cross-disciplinary Design, Survey Study, Feasibility Study, Medical Simulation Design, 3D Printing

1 INTRODUCTION

Hip arthroscopy, a minimally invasive surgical technique, has become a cornerstone in orthopaedics for treating conditions such as labral tears, chondral defects, ligamentum teres lesions, and femoroacetabular impingement (FAI)[1],[2]. Due to the minimum damage for patients, relatively less blood loss, and fast postoperative recovery, it becomes increasingly popular around the world. However, this procedure presents unique challenges due to reduced tactile feedback, a restricted field of vision, limited instrument freedom, and the need to interpret two-dimensional (2D) screen information into a comprehensive three-dimensional (3D) spatial understanding [3],[4],[5]. Orthopaedic trainees and surgeons must invest considerably more time practicing technical skills to achieve competency in hip arthroscopy. They also face challenges like ensuring safe access to anatomical locations and managing surgical time constraints, which are crucial to minimizing the risk of iatrogenic injury. These factors collectively heighten the learning difficulties associated with this specialized procedure [6].
Simulation-based training has emerged as a vital tool for bridging the gap between the surgical skills required for successful clinical outcomes and those attained by less-skilled surgeons, allowing trainees to practice and objectively evaluate their skills [7],[8]. The integration of 3D printing enhances this training by creating models with precise anatomical structures that provide tactile

feedback, particularly benefiting hip arthroscopic training [9],[10]. Research indicates that surgeons may need to perform over a hundred hip arthroscopies for optimal outcomes [11],[12], but simulation technology streamlines this learning curve by enabling safe, repeated practice rather than relying solely on operating room experience [13],[14]. Various simulators boost training efficiency, reducing the time to proficiency without compromising patient care [15],[16],[17]. This approach not only enhances technical skills in a risk-free environment but also shifts surgical education from traditional models to a more structured pathway, improving both training duration and intraoperative learning. However, surgeons' particular needs to practice hip arthroscopic skills through the simulated training has rarely been investigated. Consequently, it is difficult for medical educators and researchers to design the effective training program for surgeons to practice the specific skills.

In this study, we aimed to investigate the particular needs of hip arthroscopic training from the perspective of surgeons. Following that, based on the medical imaging and 3D printing technologies, the high-fidelity medical simulator would be developed to meet the requirements of skill training.

2 METHODS

2.1 Training surgical skills on hip arthroscopy by simulation

A nationwide online survey was conducted, the invitation to participate was posted in three social media groups organized by the Chinese Medical Association for specialists in Lower Limb Sports Medicine. It included a brief introduction and a link to the survey, which was developed on www.wenjuan.com and contained 42 questions adapted from Safir et al[18]. The questions were modified by three surgeons with at least five years of hip arthroscopy experience.

At the beginning of the survey, surgeons provided background information on their training and arthroscopic experience. Following that, they ranked the importance of surgical skills for hip arthroscopy on a 5-point Likert scale. For analysis purposes, the skills were divided into three categories: (1) identification of structures and navigation of the arthroscope, (2) instrument handling, and (3) preparation of the patient and instruments. Finally, participants rated the different types of simulation based on their usefulness in training hip arthroscopic skills.

2.2 Development and validation of the three-dimensional (3d) printed simulator

The simulator was developed using CT scans to create a 3D model of a hip joint from a 31-year-old female volunteer. Key angles of the hip were measured, and the CT data was processed with InVesalius to generate a 3D volumetric model, which was then refined in Meshmixer for 3D segmentation. The cleaned CAD file was imported into Rhino to design a modular simulator, featuring separate components that allowing for the simulation of various hip conditions. To ensure the cost-effectiveness of this simulator, the design team, in consultation with surgical experts, focused on incorporating only the key anatomical structures relevant to the procedure: the anterior superior iliac spine, acetabulum, and femur.

The hip joint capsule was shaped to accommodate traction forces, and anatomical markings were added for reference. The box-shaped simulator was designed based on a modular concept and comprised two main parts, one soft component to simulate soft tissues, the other hard component for conciseness to simulate the bony structures (Figure 1). Since surgeons typically determine the surgical site through palpation, which helps identify the anterior superior iliac spine and the greater trochanter of the femur, the external surface of the soft component was simplified to a geometric shape, as it is not critical for the design. However, the internal structure of the soft component was meticulously crafted to align with the contours of the bony structures, ensuring that the palpation feedback on the simulator closely resembles that of real patients. To replicate the tactile sensation of human tissue, the soft component was made from silicone material. After extensive testing, the Smooth-on Ecoflex 00-30 material was selected due to its close resemblance to real human tissue.

The skills of using fluoroscopy during hip arthroscopic surgery is important, that requires the bony structures of the simulator are visible under X-ray. Thus, the design team chose photosensitive materials to print the bony structures of the simulator. The femur and anterior superior iliac spine were fabricated using white polyamide EOS PA2200, while the components of the acetabulum and acetabular labrum were 3D printed as a single piece using the Stratasys J750 3D printer. These components were made from a combination of VeroPureWhite, VeroCyanV, VeroMagentaV, VeroYellowV, and Agilus materials.

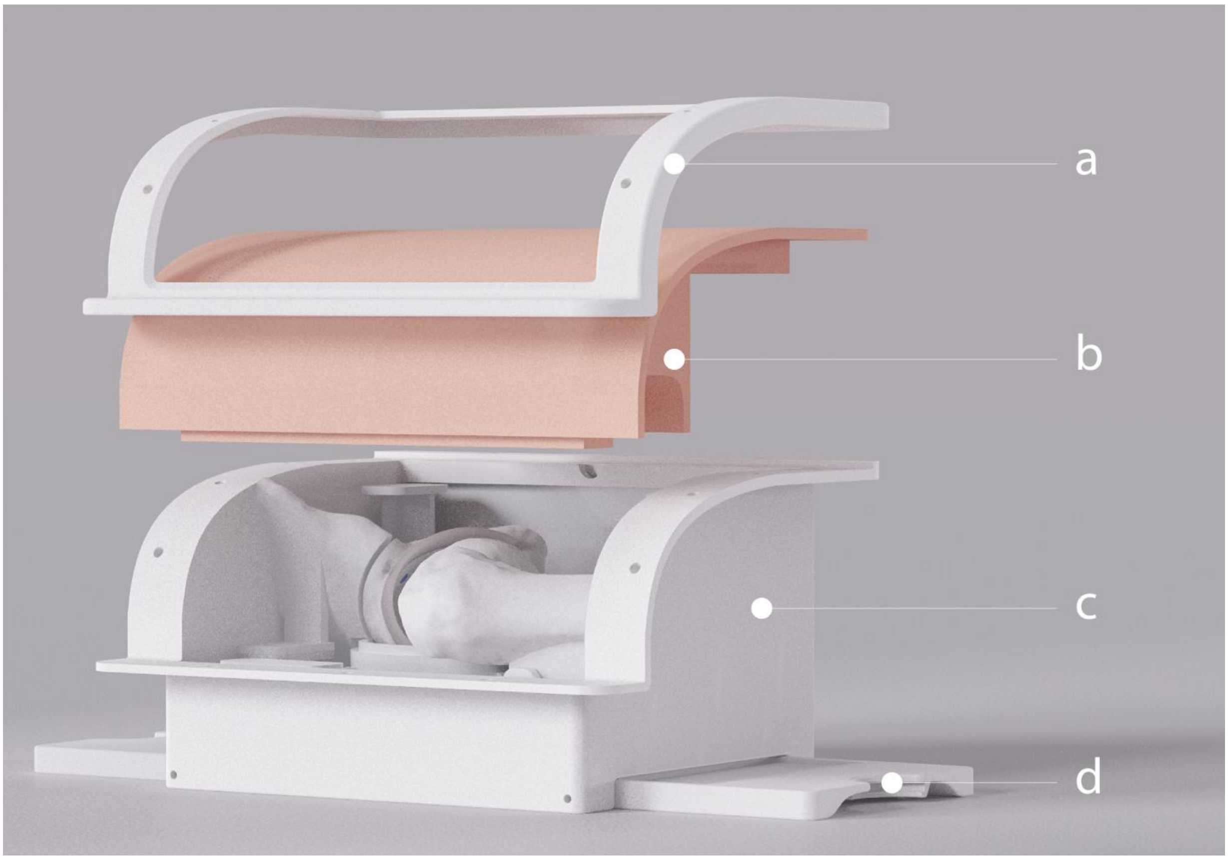

Figure.1 Main components of the simulator: (a). clip frame to fix the soft component, (b). soft component to simulate the soft tissue, (c). container for holding all the bony and supporting structures, (d). bench fixer used in tandem with a bench vise to secure the simulator onto the table (foldable).

To evaluate the simulator's validity, a cross-sectional study involved 29 male orthopedic surgeons from 11 hospitals, aged 23 to 56. Participants were categorized into novice, intermediate, and experienced groups based on their surgical training, with adjustments for individual experience levels. Before the simulation, participants received a 4-hour lecture on hip arthroscopic surgery to familiarize themselves with the procedure. During the simulated operation, an arthroscope and standard surgical tools were used. An instructor with 2 years of hip arthroscopy experience guided the participants, utilizing a task-specific checklist (TSC, Table 1) for evaluation. Trainees were required to follow the TSC protocol to complete 12 surgical steps.Performance was assessed based on task completion time and fluoroscopy usage, with all sessions videotaped. A blinded assessor reviewed the footage using the Arthroscopic Surgical Skill Evaluation Tool (ASSET) and a global rating scale (GRS).

Table 1 Task-Specific Checklist for Hip Arthroscopic Training

	Tasks	Yes	No
1	Mark the surface projection of the anterior superior iliac spine and greater trochanter		
2	Mark the operation area and the operation forbidden area		
3	Mark the anterolateral portal (ALP), mid-anterior portal (MAP), proximal mid-anterior portal (PMAP) and distal anterolateral portal (DALA)		
4	Establish the anterolateral portal (ALP) under fluoroscopy		
5	Insert camera into ALP		
6	Establish the mid-anterior portal (MAP) under the direct vision of arthroscopy (use c-arm fluoroscopy if necessary)		
7	Put the probe into the articular cavity through the MAP		
8	Observe the upper labrum through MAP, point out the labrum at 12 o'clock through ALP with probe		

9	Observe the anterior labrum through ALP, point out the labrum at 2 o'clock through MAP with probe
10	Establish the distal anterolateral portal (DALA) under the direct vision of ALP (use fluoroscopy if necessary)
11	Put the probe into the articular cavity through DALA
12	Observe the anterior inferior labrum. Point out the labrum at 4 o'clock through DALA with probe
13	Establish the proximal mid-anterior portal (PMAP) under the direct vision of ALP (use fluoroscopy if necessary)
14	Put the probe into the articular cavity through the PMAP
15	Observe the upper labrum. Point out the labrum at 1 o'clock through the PMAP
	Number of times fluoroscopy was used

3 RESULTS

3.1 Training surgical skills on hip arthroscopy by simulation

A total of 225 arthroscopic professionals responded to the survey. Ultimately, 159 responses from surgeons at 130 institutions located across 27 provincial administrative districts in China, were finally included in the dataset. Cronbach's Alpha test was performed on the 33 survey questions ($\alpha = 0.967$), showing that the internal consistency of this survey is classified as "excellent". Of the 159 valid responses, 66 were from junior specialist surgeons, 68 responses from consultants, and 25 responses from senior consultants. The average number of years of experience for performing arthroscopy was 8.48 (±4.71), while the average number of arthroscopic operations per year was 267.5 (±241.1). Details of the participants' demographic information are presented in Table 2.

Table 2 Participants demographics for the online survey

	Number of participants n	Average years of performing arthroscopies mean (± SD)	Average number of arthroscopic operations per year mean (± SD)	Total number of hip arthroscopic operations mean (± SD)
Junior Specialist Surgeonsa	66	5.39 (± 2.80)	164.12 (± 134.96)	178.71 (± 252.79)
Consultantsb	68	9.71 (± 3.86)	276.93 (± 179.22)	377.71 (± 435.65)
Senior Consultantsc	25	13.28 (± 5.25)	514.80 (± 257.71)	1050.48 (± 980.02)
All participants	159	8.48 (± 4.71)	267.50 (± 214.08)	400.89 (± 583.73)
Total number of Provincial administrative district in China	34	Surveyed provincial administrative districts	27	Coverage 79.4%

*a compared with b, **; a compared with c, ****; b compared with c, *****

***represents P < 0.01; ****represent P < 0.0001*

Table 3 Categories of specific surgical skills important for trainees to possess prior to performing in operating room, rated by surgeons with different levels of experience

Value	Junior specialist surgeons Mean (± SD)	Consultants Mean (± SD)	Senior consultants Mean (± SD)	All participants Mean (± SD)
Identification of structures and navigation of the arthroscopea	4.15 (± 0.81)	4.20 (± 0.68)	4.09 (± 0.78)	4.16 (± 0.76)
Instrument handlingb	4.11 (± 0.81)	4.07 (± 0.65)	4.06 (± 0.76)	4.09 (± 0.74)
Preparation of the patient and instrumentsc	3.84 (± 0.86)	3.92 (± 0.77)	3.63 (± 0.96)	3.84 (± 0.85)

*a compared with c, ***; b compared with c, **

**Represents P < 0.05; ***Represents P < 0.001*

As shown in Table 3, surgeons considered skills related to the identification of structures and navigation to be the most important preparation for trainees before they perform the actual surgery. A post-hoc Tukey test revealed that skills related to the preparation of patients and instruments were significantly lower than those in the other two categories (P < 0.05). No significant differences were found when comparing the scores from surgeons with different levels of experience for each individual category.

Based on the mean scores, there are ten skills ranging from treatment of cam deformity (where the head of the femur does not sit symmetrically on the neck) to establishing the anterolateral portal under fluoroscopic guidance were rated over 4.2. This indicates that these skills are extremely important for hip arthroscopic surgery, trainees should pay extra attention to these areas during their training.

Table 4 Usefulness of simulation type in preparing trainees to perform in the operating room, rated by surgeons with different levels of experience

Value	Junior specialist surgeons Mean (± SD)	Consultants Mean (± SD)	Senior consultants Mean (± SD)	All participants Mean (± SD)
Simulation using cadaveric specimensa	4.48 (± 0.89)	4.57 (± 0.77)	4.40 (± 0.75)	4.51 (± 0.82)
Simulation using high-fidelity physical simulatorsb	3.95 (± 0.99)	3.59 (± 1.02)	3.08 (± 0.80)	3.77 (± 0.99)
Simulation using virtual reality simulatorsc	3.77 (± 1.06)	3.38 (± 1.11)	3.64 (± 0.93)	3.58 (± 1.08)
Simulation using low-fidelity bench top modelsd	3.08 (± 1.09)	2.88 (± 1.13)	3.16 (± 1.25)	3.01 (± 1.14)

*a compared with c, ****; a compared with c, ****; a compared with d, ****; b compared with d, ****; c compared with d, ****

*****Represents P < 0.0001*

Surgeons were asked to rank the usefulness of the four most common types of simulation for practicing surgical skills: 1) cadaveric specimens, 2) virtual reality (VR) simulators, 3) high-fidelity physical simulators, and 4) low-fidelity bench-top models. As shown in Table 4, cadaveric specimens were rated as the most useful, significantly outperforming the other three methods.

The differences in rankings among the four simulation methods were statistically significant (P < 0.01). Tukey's test for pairwise comparisons revealed significant differences between all pairs (P < 0.01), except between the VR simulator and high-fidelity physical simulators (P = 0.35). Surgeons, regardless of their experience level, consistently prioritized higher fidelity simulation over lower fidelity options.

In the open comment section, participants suggested that additional factors, such as medical image interpretation, joint traction time, and familiarity with equipment should be included in the survey, as these are also crucial for the successful performance of arthroscopic surgery.

3.2 Development and validation of the Three-Dimensional (3D) Printed Simulator

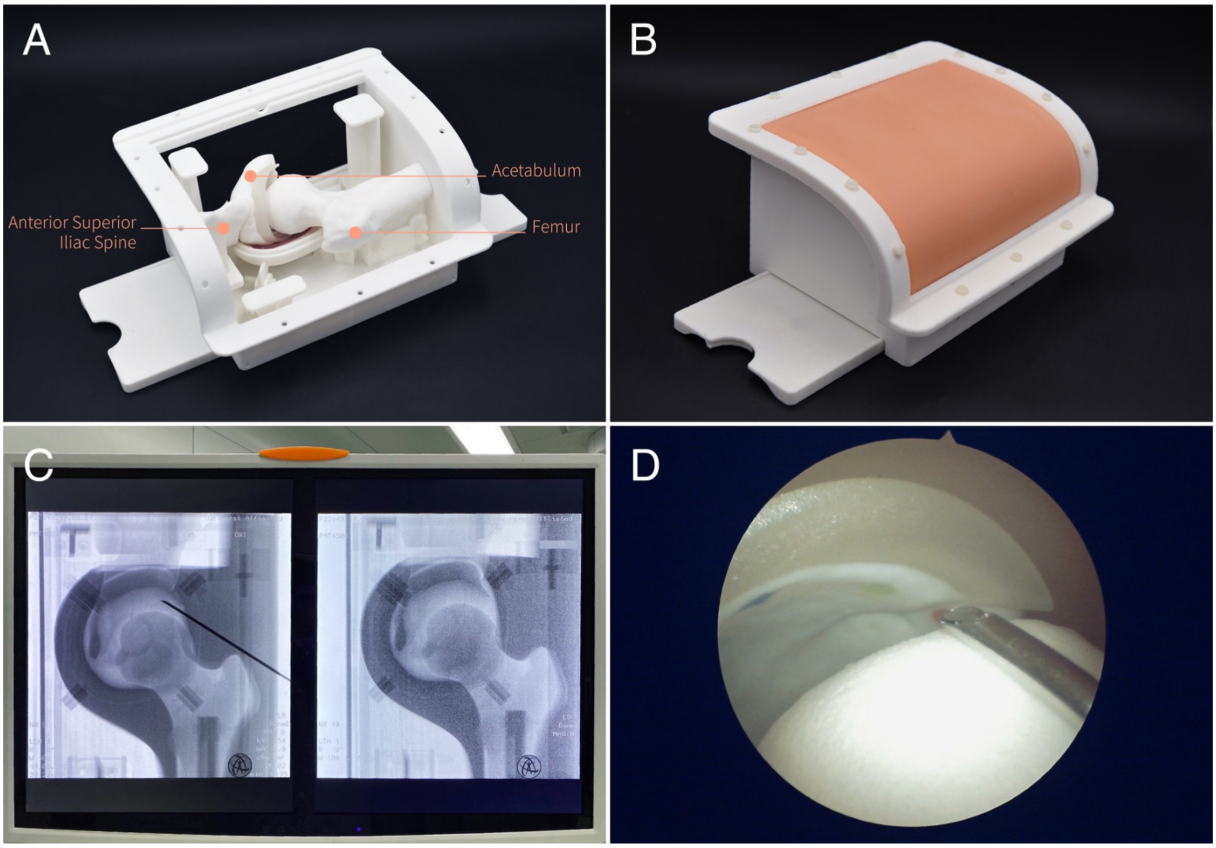

Figure.2 The 3D printed simulator: (A) The 3D printed bony structures of the simulator; (B) Assembled simulator with the silicon component; (C) Fluoroscopic images for the portal placement process; (D) Arthroscopic view of the process for establishing the distal anterolateral (DALA) portal.

The simulator was designed to be secured onto the table by using two bench vises (Figure 2A). The materials of the simulator are photosensitive to radiography and all the internal structures are visible by fluoroscopy (Figure 2C). The anatomical landmarks of the anterior superior iliac spine and the greater trochanter can be identified by palpating the simulated soft tissue(Figure 2B). When viewed using the arthroscopic camera, the intra-articular anatomical structures of the simulator appear similar to that observed in the hip joint of the human body (Figure 2D).

To evaluate the developed simulator, all participants performed the required operational steps on the 3D printed simulator. Cronbach's alpha values of 1 for the total ASSET score and 0.7 for the task-specific checklist, indicate good internal consistency and reliability. Cohen's f values for task-specific checklist, ASSET and final GRS were 0.9, 2.7 and 1.9 respectively, where f values above 0.4 are considered to have a large effect size for one-way ANOVA analysis.

One-way ANOVA analysis revealed significant differences between the 3 subgroups with varying levels of experience for the total checklist score ($F2,26 = 11.3$) (Figure 3A), total ASSET score ($F2,26 = 92.1$) (Figure 3B), overall final GRS score ($F2,26 = 49$) (Figure 3C), the number of times the participants used fluoroscopy ($F2,26 = 7.4$) (Figure 4A) and completion time for tasks ($F2,26 = 23.5$) (Figure 4B). Positive correlations were observed between clinical experience and total ASSET score (hip arthroscopy $r = 0.6$; shoulder arthroscopy $r = 0.5$; knee arthroscopy $r= 0.5$). Negative correlations were seen between clinical experience and the completion time for tasks (hip arthroscopy $r= -0.6$; shoulder arthroscopy $r = -0.5$; knee arthroscopy $r= -0.5$).

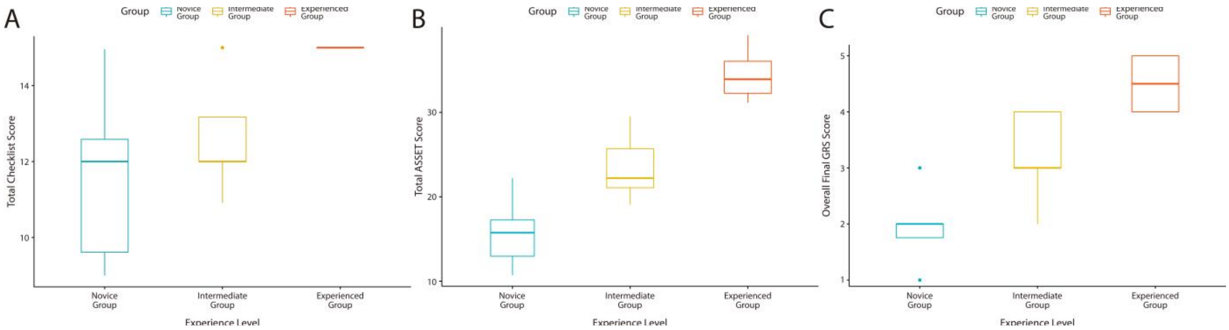

Fig.3 Box plots of the different assessment tools for the three groups with varying experience levels (Novice vs. Intermediate vs. Experienced). A Total checklist score; B Total Arthroscopic Surgical Skill Evaluation Tool (ASSET) score; C Final Global Rating Scale (GRS)score by experience level

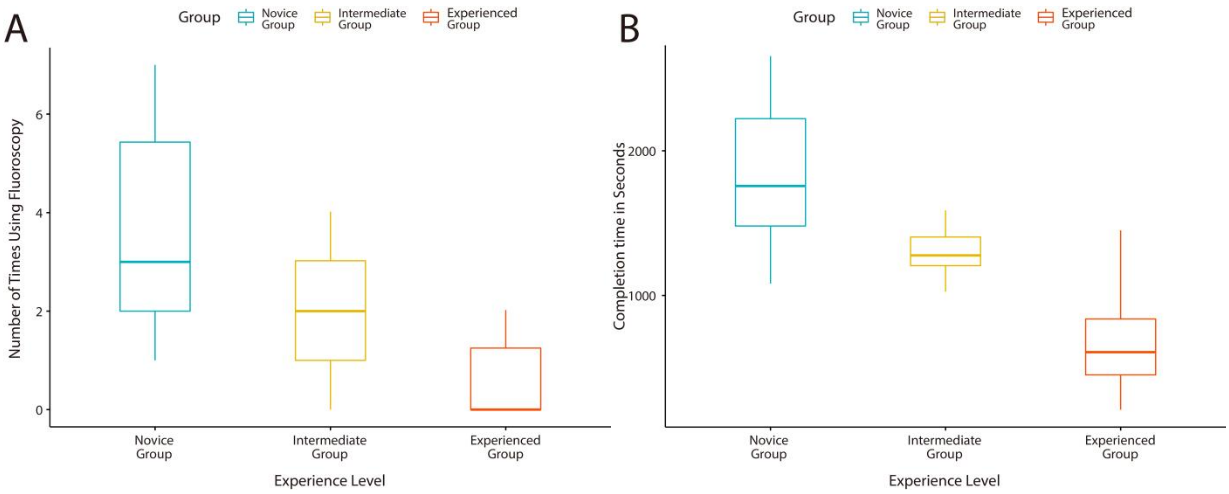

Fig.4 Box plots of task completion for the three groups with different experience levels (Novice vs. Intermediate vs. Experienced). A Number of times fuoroscopy was used; B Task completion time

4 DISCUSSION

The results of the survey aligns with earlier research on Canadian orthopedic professionals although the focus was on arthroscopy of a different joint, highlighting the convergence of training methods between Canada and China [19], [20], despite focusing on different joints. Hip arthroscopy has proven to be a valuable technique, though early challenges stemmed from the complex anatomy of the hip. Surgeons consistently rated cognitive skills, especially anatomical knowledge, as more critical than motor skills, particularly in complex procedures like portal placement.

A large number of specific skills have been highlighted as essential for optimal clinical outcomes, reflecting the steep learning curve associated with this procedure.Several key skills have been identified as the top skills required for hip arthroscopy, with a focus on FAI surgery. There are reports highlighting that high-impact athletic activities during growth, such as playing soccer, basketball, and ice hockey during adolescence can cause FAI [21], [22]. Therefore, a large population, ranging from younger to elderly individuals, could be affected. Hip arthroscopy, the most common surgical technique to address various types of FAI, has shown optimal clinical outcomes [23], [24].

Cadaveric simulation remains the preferred training method, offering unmatched anatomical accuracy and tactile feedback, but faces challenges related to availability and cost [25], [26]. As alternatives, high-fidelity physical simulators and VR simulators were identified as useful tools for training [27]. High-fidelity physical simulators offer detailed anatomical accuracy and haptic feedback [28], while VR simulators provide varied functions and immediate feedback, though concerns remain about their cost-effectiveness [29]. Low-fidelity models, while less favored, still provide value in helping trainees familiarize themselves with surgical instruments and basic skills [30], [31]. According to the results of the survey study, the high-fidelity 3D printed simulator has been designed and manufactured. Combining medical imaging, CAD, and 3D printing, the simulator

replicates critical techniques like portal placement and arthroscope navigation.
In the validation study, participants' performance correlated with their experience level, validating its effectiveness. Experienced participants completed tasks faster, used fluoroscopy less, and scored higher, proving the simulator's usefulness as an objective assessment tool. Analysis of the data collated in validation study shows a link between the participants' prior arthroscopic experience and their performance during the simulated operation. Compared to participants with lesser experience, more experienced participants tend to complete the simulated task in a shorter period of time, using fluoroscopy less frequently, and obtaining higher scores in task-specific checklist, ASSET, and final GRS. These results show that the simulator can be used as an objective assessment tool to help orthopedic surgeons gauge the competence level of the trainees' surgical skills for performing hip arthroscopy. According to the post-study feedback, the 3D printed simulator received favorable feedbacks from the participants. Most of the participants were satisfied with the fidelity of the simulator, and were of the opinion that the intra-articular anatomical structures and realistic tactile feeling of the soft tissue closely resemble that of the human body.
For simulation-based training, cost is always an important aspect as it relates to the sustainability of its usage. Compared to other virtual reality (VR) based or benchtop simulators, the cost of this 3D printed simulator is relatively low. The overall material cost for the simulator is around USD $295. For the simulation practice, the soft component that mimics the soft tissue can be disposed after multiple operations and the replacement cost of the soft component is only around USD $78. Clearly, the 3D printed simulator is a cost-effective tool and is a highly affordable option for most of healthcare institutions. Meanwhile, since the validation study has proved that the developed simulator has properly replicate the clinical conditions of hip arthroscopy, it would seem that such a 3D printed simulator can be used routinely to assist the learning and practicing relevant hip arthroscopic skills. It may help arthroscopic professionals improve their learning efficiency and be used for preliminary training, refresher courses and simulation of complex scenarios before actual surgeries, which in turn can possibly help reduce the risk of medical errors in the operating room, and hence enhance patient's safety.

5 CONCLUSION

This study has revealed the specific requirements for hip arthroscopic training. Accordingly, the reliable 3D printed high-fidelity simulator has been developed, which can be used for training and assessing hip arthroscopic skills. This study has illustrated an effective approach for medical innovation, based on the collaboration between product designers and medical experts, it is possible to develop the effective tools and training program for surgical education, which can benefit novice surgeons and the quality of healthcare.

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VISUAL COMMUNICATION DESIGN IN ASIA: AN EXPLORATION OF ITS INTRODUCTION AND EVOLUTION

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ABSTRACT
This paper conducts a comprehensive literature review examining the evolution of the term "visual communication design".It traces the terminology shift from "graphic design" to "visual communication design", initially coined by William Addison Dwiggins to describe printed communications—a term also found in educational contexts as early as 1917—to "visual communication design", which emerged in response to expanding design fields and digital media. This evolution in terminology reflects a more comprehensive approach beyond traditional print media. Key institutions and events, such as the Ulm School of Design and the International Council of Design (ICO-D), played crucial roles in reshaping the perception and application of visual communication in design. In Asia, the term gained prominence through international conferences, notably Japan's 1960 World Design Conference, and became part of the academic curricula at institutions like Musashino Art University and Seoul National University. In China, this shift moved design from "decorative" to a broader conceptual framework that includes multimedia and digital interaction, culminating in the Ministry of Education's 2012 reclassification of design programs. By examining these changes in terminology within the context of globalization and cross-cultural exchange, this study positions Asia as a focal point of design evolution during periods of societal transformation, portraying "visual communication design" as a distinct, interdisciplinary field shaped by technological and cultural influences.

Keywords: Visual Communication Design, Terminology Shift, Design History, Design Theory

1 AN EXAMINATION OF THE ORIGIN OF THE TERM VISUAL COMMUNICATION DESIGN

If you search for "visual communication design" on a website, the search term "graphic design" is bound to come up. Historically, there has been a continuum between the two, and the broader field of visual communication design can be said to be a subset of "visual communication design". The shift from "graphic design" to "visual communication design" has been influenced by the harassment of commercialism and the expansion of digital media, which has not only changed the process of design production, but has also had an impact on the way designers work. Designers began to acquire new skills, such as digital image manipulation and web design, to adapt to the changing technological environment. In addition, with the popularity of the Internet, the dissemination of design work has shifted from traditional print to digital platforms, requiring designers to focus more on interactivity and user experience in their visual communication. "Contemporary culture is becoming a visual culture."[1]

Therefore, visual communication design not only covers traditional graphic design elements, but also extends to many fields such as multimedia, animation, interactive design, etc., and it form a more comprehensive and more diversified design field.

1.1 The origin of the term graphic design in international perspective

Philip Baxter Meggs mentions in the preface to the first edition that "It was not until 1922, when the outstanding book designer William Addison Dwiggins coined the term graphic design to describe his activities as an individual who brought structural order and more visual form to printed communications, that an emerging profession received an appropriate name."[2]

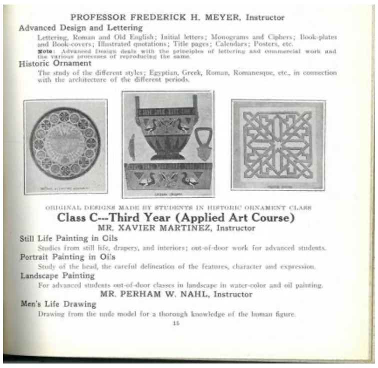
Dwiggins who is mentioned above published an article in the Boston Evening Post titled "New Kind of Printing Calls for New Design", at the end of which he mentions "graphic design".[2]However, Paul Shaw, a professor at Columbia University, challenges the widely accepted notion among scholars that Dwiggins was the first to coin the term "graphic design." On his personal website, he presents relevant textual and visual evidence to support his argument.

The Definitive Dwiggins, and in issue #81 Who Coined the Term "Graphic Design"? writes:

"In April of 2017 I received photocopies and scans of several catalogues of the California School of Arts & Crafts from Andrea V. Grimes, Special Collections Librarian of the Book Arts & Special Collections of the San Francisco Public Library, that not only supported my contention that the term “graphic design” had been employed before Dwiggins, but further solidified it by pushing the date of use back several more years. The material covered the years 1915 to 1921. In the 1917–1918 catalogue a course in Graphic Design and Lettering appears for the first time(Figure 1)(Figure 2), replacing one called Advanced Design and Lettering. Both were taught by Frederick H. Meyer (1872–1961). "[4]

Meyer was the director of the California School of Arts and Crafts and one of its instructors. In 1917, h e taught a class entitled "Graphic Design and Lettering". This is the description for it:

"Lettering, Freehand, Roman and Old English; Initial letters, Monograms and Ciphers; Illuminating an d Engrossing; Book-plates and Book-covers; Illustrated quotations; Title pages; Calendars; Posters; et c."[5]


PROFESSOR FREDERICK H. MEYER, Instructor

Advanced Design and Lettering

Lettering, Roman and Old English; Initial letters; Monograms and Ciphers; Book-plates and Book-covers; Illustrated quotations; Title pages; Calendars; Posters, etc.

Note: Advanced Design deals with the principles of lettering and commercial work and the various processes of reproducing the same.

Historic Ornament

The study of the different styles; Egyptian, Greek, Roman, Romanesque, etc., in connection with the architecture of the different periods.

ORIGINAL DESIGNS MADE BY STUDENTS IN HISTORIC ORNAMENT CLASS

Class C---Third Year (Applied Art Course)

MR. XAVIER MARTINEZ, Instructor

Still Life Painting in Oils

Studies from still life, drapery, and interiors; out-of-door work for advanced students.

Portrait Painting in Oils

Study of the head, the careful delineation of the features, character and expression.

Landscape Painting

For advanced students out-of-door classes in landscape in water-color and oil painting.

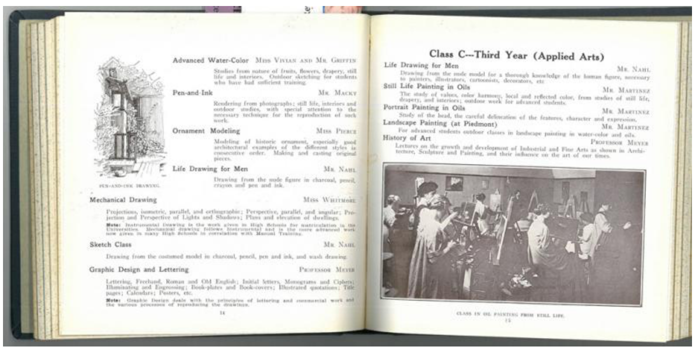
MR. PERHAM W. NAHL, Instructor

Men's Life Drawing

Drawing from the nude model for a thorough knowledge of the human figure.

15

Figure 1. Courses in California School of Arts and Crafts(Figure source:[4])


Advanced Water-Color — Miss Vivian and Mr. Griffin

Studies from nature of fruits, flowers, drapery, still life and interiors. Outdoor sketching for students who have had sufficient training.

Pen-and-Ink — Mr. Macky

Rendering from photographs; still life, interiors and outdoor studies, with special attention to the necessary technique for the reproduction of such work.

Ornament Modeling — Miss Pierce

Modeling of historic ornament, especially good architectural examples of the different styles in consecutive order. Making and casting original pieces.

Life Drawing for Men — Mr. Nahl

Drawing from the nude figure in charcoal, pencil, crayon and pen and ink.

PEN-AND-INK DRAWING

Mechanical Drawing — Miss Whitmore

Projections, isometric, parallel, and orthographic; Perspective, parallel, and angular; Projection and Perspective of Lights and Shadows; Plans and elevation of dwellings.

Sketch Class — Mr. Nahl

Drawing from the costumed model in charcoal, pencil, pen and ink, and wash drawing.

Graphic Design and Lettering — Professor Meyer

Lettering, Freehand, Roman and Old English; Initial letters, Monograms and Ciphers; Illuminating and Engrossing; Book-plates and Book-covers; Illustrated quotations; Title pages; Calendars; Posters, etc.

Note: Graphic Design deals with the principles of lettering and commercial work and the various processes of reproducing the drawings.

14

Class C---Third Year (Applied Arts)

Life Drawing for Men — Mr. Nahl

Still Life Painting in Oils — Mr. Martinez

Portrait Painting in Oils — Mr. Martinez

Study of the head, the careful delineation of the features, character and expression.

Landscape Painting (at Piedmont) — Mr. Martinez

History of Art — Professor Meyer

Figure 2. Courses in California School of Arts and Crafts(Figure source:[4])

From the above description and evidence, Prof. Paul argues that Prof. Meyer was the one who first pro posed "Graphic Design", five years before Dwiggins.

1.2 Ulm School of Design

The Department of Visual Communication at the Ulm School of Design in Germany was initially called "visual design", but was renamed "visual communication department" in 1956 in order to make it clear that the goal was to solve design problems in the field of mass media. During the period of HfG's operation from 1953 to 1968, the departments of product design, visual communication, industrialized architecture, information, and film production adopted a progressive design process. From the 1958-1959 academic year, the subject of film was included in "Visual Communication", and film was later expanded into a separate department.[6]

The purpose of establishing the Department of Visual Communication is to cultivate complex talents in the field of advertising design, who not only need to obtain profound training in a single field such as typography, graphics, photography, etc., but also need to comprehensively master and flexibly integrate the knowledge and skills of these fields. With the continuous advancement of imaging technology and the widespread adoption of television, the scope of visual communication design has expanded significantly, highlighting its immense development potential and broad application prospects.

1.3 Establishment of ICO-D

Icograda, the International Council of Graphic Design Associations, was founded on 27 April 1963 in London by two graphic designers, Peter Kneebone and Willy de Majo.The original membership consisted of 28 associations from 17 European countries. Later, during the 1970s, Asian and American countries gradually joined in. The Icographic Journal(*Figure 3*), first published in 1971, was the first iteration of the council's journal. According to Teal Triggs, it seeks to establish a benchmark for the study of visual communication design, and is known for the articles published by practitioners and academics, as well as for the richness of the graphic imagery of designers from around the world.[7]

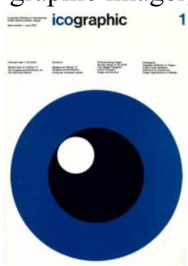


Figure 3. icographic (Figure source:[8])

2 INTRODUCTION OF THE TERM VISUAL COMMUNICATION DESIGN TO ASIA

2.1 Japan World Design Conference: Visual Communication Design Nurtured in the Context of Industrialization

From May 7 to 16, 1960, more than 200 designers and architects from 27 countries gathered at Tokyo Sankei Biru to participate in the exhibition.(Table 1)The theme of the conference was "Our Century: the Total Image-What Designers Can Contribute to the Human Environment of the Coming Age. "(*Figure 4*)The conference focused on the future image of the modern world, reflecting on the involvement of designers in mass production and consumption, and the alienation of solid design from commercially viable design. the opening ceremony was held on May 11th, the symposiums were held from the 12th to the 14th, and the closing ceremony was held on the 16th. At the closing ceremony on the 16th, there were 84 participants from 26 countries and 143 participants from Japan. The participants were divided into five sections: "Graphic", "Craft", "Business Design", "Architecture", "Design Education and Research", Design Criticism and Editorial". [9]From this categorization alone, it is clear that people gather in a wide range of design-related fields.

Table 1. Participants in the World Design Conference(Data source:[9])

Area	Foreigner	Japanese
Graphic	11	29
Craft	4	15
Business design	24	26

Architecture	43	49
Criticism and respect education	2	24
Total	83	143

Figure 4. World design conference 1960(Figure source:[11])

Takashi Asada, Director General and Board Member of the World Design Congress, recognizes that times have changed in all areas and that we have entered a whole new world. People have taken a step forward, and those involved in design must work together to make fundamental adjustments to this situation. In the field of graphic design, for example, he argued that it was necessary to expand the area of activity from the previous narrow stance of advertising and promotion (commercial art) to the new field of communication design more broadly. [10]The conference generally discussed the role that design should play in the modernization brought about by various technological developments, and raised the issue of the need for designers to share a new consciousness and understanding, noting that we are facing an era in which we must construct ways of thinking that are in keeping with the new age.

Herbert Bayer, a prominent designer from the Bauhaus, and Tomas Maldonado, co-founder of the Ulm School of Design, participated in the conference and provided insights and contributions to the communication of ‘visual communication’. Tomas Maldonado presented the gap between theory and practice in visual communication and emphasized the need for designers to use a scientific approach to communication in order to overcome this gap. [11]Most graphic designers have been influenced by Professor Tomas's theories of visual communication, and he believes that stylistic expression must go hand in hand with these sciences in order to create a convincing design. In this case, the designer needs to have a critical judgement of what is being communicated, in addition to the techniques of presentation. During the panel discussion, Takeji Imaizumi emphasize the principles of visual communication.[12]

Throughout the conference, architects, environmental designers and industrial designers emphasized the importance of visual communication in the environment and the growing importance of the term ‘visual communication’.

Through the design of housing for U.S. military depending house and its accompanying furniture allowed Japanese designers to gain a proper understanding of American lifestyles and accumulate valuable experience, laying a strong foundation for their future work. This ultimately led to the World Design Conference, which attracted and invited leading experts from various countries for discussions. The conference promoted international exchange in the field of design and facilitated long-term collaboration between the Japanese design community and international design organizations.

2.2 Musashino Art University in Japan

According to available information, Musashino Art University was the first Asian university to introduce "visual communication design". Browsing the official website of the current Musashino Art University, we can get the curriculum is following:

"Within this context and the developments in technology today, visual communication design, which has its roots in graphic design, continues to grow as a realm of expression spanning several media domains, from print media employing type, symbols and signs to convey information, to the command of new media including audio, animation and three-dimensional data."[13]It suggests that visual communication design is rooted in and extends from graphic design.

Let's go back in history, with Professor Mukai Shutaro of Musashino Art University mentions that the history of Musashino Art University. The Imperial Art Academy, founded in 1929, which established a Department of Industrial Design in October of the same year. In November 1948, the Imperial College of Art changed its name to Musashino Art School, replacing the Practical Arts with the Pattern Crafts Section. In 1951,the Pattern Crafts Section was changed to the Modeling Section; in 1952, the Faculty of Commercial Arts and the Faculty of Theater and Film Arts appeared in the admission brochure for an unexplained reason; in 1959, the Musashino Art Junior College (two-year program) was established, including the Departments of Commercial Design, Entertainment Design, and Art Design, was not only to cultivate skilled craftsmen and designers in the broad sense of the word, but also to further explore and mold designers who possessed a high degree of adaptability and were able to flexibly respond to the ever-changing field of production and advertising. In 1963, the junior college established a Department of Life Design, aimed not at training industrial or graphic designers but at cultivating professionals involved in general design affairs, with a focus on advanced consumer education. In 1967, the Faculty of Art and Design at Musashino Art University introduced a Department of Basic Design. In 1974, the original Department of Commercial Design was renamed the Department of Visual Communication Design. [14]

The reason is the following:
"視覚によって環境から情報を受容ずることは，われわれの生活にとって重要な意味をもってきた。…本学科は，ク”ラフィック・デザインを中心として 境界の 領域に わ た る 広汎な視覚伝達（ヴィジュアル・コミュニケーション）デザインにっいての理論を学び…（出典 7 武蔵 野美術大学案内 1975）＜商業デザインという限定された用語が時代状況 にもはや適応なくなったことを意味する＞"[15]

Receiving visual information from our surroundings has always played a crucial role in our lives. This department emphasizes a broad spectrum of visual communication design theories across various disciplines, with a primary focus on graphic design. As commercial design could no longer keep pace with the evolving social environment and demands of the era, the name was updated to Visual Communication Design.

2.3 Korea: Visual communication design learnt from Japan and the US

The development of Korean design was hampered by the Japanese invasion of Korea, but today's Korean visual communication design was largely initiated by Koreans who studied in Japan in the 1930s. Formal university design education began after the country's independence in 1946, when Seoul National University opened a design programme. Ewha Womans University started art education as the first art institution in October 1945 with the establishment of the Department of Art at Ewhaewon, but it was not until the establishment of the Department of Living Arts in 1960 that a full-fledged design programme began to be offered. Hongik University established the Department of Fine Arts and Crafts at the Faculty of Arts in 1958, and it was not until 1964 that a design department was established within the Department of Fine Arts and Crafts. Until the 1960s, there was no design department at the university, and it can be said that Seoul National University laid the foundation for design education in modern Korea. Just after the end of the Korean War, there was a new change in the design curriculum at Seoul National University, and John L. Frank, an American lecturer who worked at the Information and Culture Centre of the U.S. Army in Korea, introduced some of the basic design education in the U.S. Though the teaching time was very short, it had an impact on design education in Korea, and a lot of information about the trends in Western art could be known.[16]

The beginnings of visual communication design in Korea were largely influenced by two things. One originated from early Japanese abstraction based on realism, and the other pursued the more condensed and concise forms of abstraction introduced after the late 1950s.[17]

Korean Ahn sang-soo is the vice president of ICO-D and is currently a professor at the College of Fine Arts at Hongik University in Seoul. Hongik University was the first to establish a Department of Visual Communication Design. During the 1980s, while teaching there, he introduced modern typography and layout design, which contributed to modern Korean design.[18]

2.4 China: from decorative design and graphic design to visual communication design

Most scholars believe that Dwiggins was the first person to propose "graphic design", and the source of the literature is clear, while the literature on the introduction of the term visual communication is more ambiguous, and there is no specific person who invented the term visual communication design, but it is more like a slow spread of the term under the transnational exchanges, which is mostly discussed at international exhibitions organized by national associations. It is more like the term spread slowly through transnational exchanges and was mostly discussed at international exhibitions organized by national associations.

In 1962, Austrian-American designer Henry Steiner came to Hong Kong and served as the design director for Asia Magazine. An increasing number of Hong Kong products were designed in the United States or by American designers based in Hong Kong. In 1979, Hong Kong designers taught graphic design courses at the Guangzhou Academy of Fine Arts, and the term "graphic design" was introduced to mainland China.[19] Entering the 2000s, Hong Kong's design industry entered the multimedia and digital era. Designers not only focused on graphic design, but also started to venture into user interface design, interactive design and new media art. Visual communication design became more diverse in Hong Kong and cross-fertilized with areas such as film, animation and digital media.

Chai Changpei translated the book *A History of Graphic Design by Meggs(1st edition in 1983)*[20], he translated "graphic design" as "visual communication design". The explanation he gave in September 1987 was that "the original meaning of the word graphics refers to layout and printing, or images, that can be disseminated in large quantities by means of reproduction, such as printing, and are different from ordinary paintings, drawings, etc., which are single pieces of original work. There is no proper translation of this word in Chinese, so far often translated as 'graphics', 'drawings', sometimes translated as 'printing', such as Graphic Arts translated as Printing Art. The original term is now interpreted in the broader sense of visual communication or information communication, which more appropriately summarizes the many uses, and this book adopts the contemporary translation of 'visual communication'."[21] Chai Changpei's translation was forward-thinking, as with the widespread use of smart devices, printed materials have gradually faded from people's daily lives.

Lin Pang-Soong, a lifetime friend of ICO-D, mentioned the transition of design education in Taiwan from "graphic design" to "visual communication design" in Taiwan Art Classics: "In 1990, Dayeh University established a Department of Visual Communication". It's the first Taiwan university to change the name of the course. [22]Tracing the progression from terms such as "patterns," "graphic arts," "applied arts," "art design," "commercial design," and "graphic design" to the current "visual communication design," which is widely used in various departments and institutions in Taiwan, we can interpret that each term reflects distinct core concepts and artistic values. Therefore, when "visual design" emerges as a new specialized term, it symbolizes the transcendence of boundaries—between "pure and applied", "commercial and cultural", "2D and 3D"—and represents a new level of independent consciousness. [23]

In an interview with Visual Alliance in 2005, Professor Zhao Yan from the China Academy of Art discussed the historical development of the Department of Visual Communication Design at the academy.

He said, "Graphic design has always been one of our main programs. Initially, it was called the Department of Patterns, then the Department of Commercial Art, and later the Department of Craft Art with a focus on decoration. Around 1996, we independently established it as the Department of Visual Communication Design at the China Academy of Art. Currently, the department has two majors: one is graphic design, and the other is multimedia and web design. The characteristic of the graphic design major is that all designs are related to traditional printed materials, but the projects involved are still quite diverse, such as packaging, advertising, bookbinding, logo design, and so on. The multimedia and web design major, on the other hand, is different from graphic design as it focuses on electronic media forms, such as the internet, video, and includes interactive elements."[24]

In modern Chinese design literature, the term ‘graphic design’ appeared in the early days, mainly referring to the plan of architecture, engineering and planning. Compared with ‘decorative design’, ‘graphic design’ is indeed more up-to-date and international, with avant-garde and experimental colours in the minds of the younger generation of designers.[25]

The first Graphic Design in China Exhibition was held in Shenzhen from 28th to 30th April 1992, and Henry Steiner was one of the members of the jury. (*Figure 6*)The exhibition stirred up the design circles at home and abroad, and aroused the attention and praise of people from the mainland, Hong Kong, Taiwan and even the international culture and art circles, as well as the industrial and commercial circles. And this graphic design exhibition is the first time by the mainland, Taiwan, Hong Kong jointly organized the most complete design categories of graphic design exhibition and evaluation activities, set up a bridge of communication between the design community across the Taiwan Strait.

Figure 5. Graphic Design in China 1992(Figure source:[26])

Figure 6. Graphic Design in China 1992 Jury Panel(Figure source:[26])

Table 2. Number of articles searched for related terms in the journal Decoration(Data source:[27][28][29])

Name	Amount	Earliest Period
The title of “Visual Communication Design”	196	Xueqing Wang, Teaching Visual Communication Design in Contemporary France,1989
The title of “Graphic design”	173	Zhu gekai, Repetition and Gradation-An Initial Exploration of the Formal Laws of Graphic Design,1980
The title of ‘’Decorative Design”	25	Zhang Ding, ‘Improving the Art of Commodity Packaging and Decoration Design,1980

In June 1980, the central academy of arts and crafts journal "Decoration" after the resumption of publication, the first issue was published in 1980. According to the table,visual communication design was noticed in 1989.(Table 2)

In September 2012, the Ministry of Education issued the Catalogue of Undergraduate Specialties in Colleges and Universities, in which "Visual Communication Design" replaced "Decorative Art Design", and has been used ever since.[30]

Li Yanzu believes that printing technology is the driving force behind graphic design; without printing technology, modern graphic design would not exist. The term "visual communication design" emerged precisely because printing technology has gradually been supplanted by digital media. In today's technologically advanced world, people can create designs using computers and share their works with audiences through social media, with the ability to spread globally via the internet. Therefore, a new term was needed to reflect the current era.[31]

3 CONCLUSION

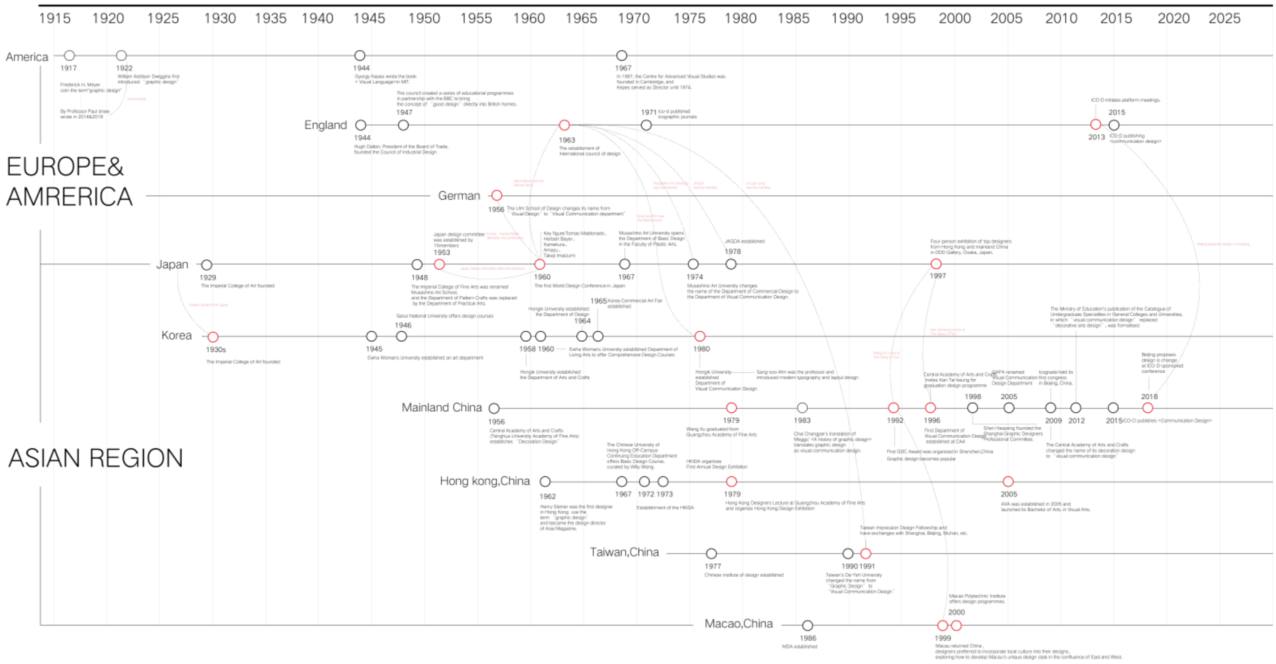


Figure 7. Timeline for the flow of visual communication design(Figure source: Author's own production)

This paper examines the shift from "graphic design" to "visual communication design" as it emerged in post-World War II industrial design through international collaboration. Following efforts to revive global economies, design committees convened to address evolving societal needs, propelling a terminological transition that aligned with technological and interdisciplinary advancements.(Figure7) Key events, such as the 1960 World Design Conference in Japan and the Ulm School of Design's establishment of the Department of Visual Communication in 1956, marked a significant redefinition of design practices, expanding from print-based "graphic design" to include digital media and interdisciplinary approaches.

"Graphic design" rooted in printed communication, laid the groundwork for the profession. In contrast, "visual communication design" can be traced back to 1956, when the Ulm School of Design established a Department of Visual Communication. During a panel discussion at the 1960 World Design Conference in Japan, the "visual communication theory" proposed by professors from the Ulm School, along with Japanese participants Amazu and Takeshi Imaizumi, began to gain attention and was gradually disseminated. In 1974, Musashino Art University officially established a Department of Visual Communication Design. South Korea, drawing on design fundamentals from Japan and the United States, made efforts to integrate these influences with local cultural characteristics while aligning with international standards. This culminated in the establishment of its own Department of Visual Communication Design in the 1980s.From a domestic perspective, visual communication design was introduced by a small number of scholars who studied abroad, and then introduced by mutual exchanges in the design education sector, such as Taiwan's Dae Yeh University, the China Academy of Art, and the Central Academy of Arts and Crafts, which keenly kept up with the pace of the times to keep up with the international standards. In China, the 2012 Ministry of Education reclassification reinforced the field's scope, emphasizing multimedia and digital interactions. Universities in Asia are trying to explore localized visual communication design. This adaptive approach reflects a broader trend of regional reinvention within a global context.

As the design field evolves, "visual communication design" is positioned to meet the demands of a media-rich, digitally interconnected world, so its use will help readers to develop a forward-looking and holistic understanding of the subject. At the same time, the graphic design development has experienced the baptism of the technological revolution of the information age, which triggered the change from design tools to design concepts.In an era shaped by technological advancements, visual communication design remains an essential, forward-looking field with a profound impact on future visual experiences and interactions in an increasingly dynamic global society.

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URBAN CONGESTION AS A DESIGN PARADIGM: NEW METHODS AND TOOLS FOR ANALYZING HYPER-DENSE ENVIRONMENTS

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ABSTRACT
This paper introduces a novel approach to urban design theory and methodology, building upon Walter Benjamin's theories of metropolitan life and Rem Koolhaas's concept of the "culture of congestion." Drawing inspiration from the concept of "productive chaos" in hyper-dense urban environments, we present a new design framework: the Conceptual Research Grid of Congestions. This systematic method for analyzing and potentially harnessing the generative aspects of urban congestion offers fresh insights into the complex dynamics of contemporary megacities. Using Hong Kong and Shenzhen as case studies, our approach challenges traditional urban planning paradigms and proposes new tools for understanding and designing in complex, high-density urban contexts. By synthesizing Benjamin's insights on the sensory experiences of modern cities with Koolhaas's embrace of urban intensity, this paper offers a timely reconsideration of congestion as a potentially productive force in urban design and development.

Keywords: Urban Congestion, Urban Design, Productive Chaos, Hyper-Density, Conceptual Research Grid

1 INTRODUCTION

The unprecedented proliferation of megacities in the early 21st century presents not merely a challenge to urban planning orthodoxy but demands a fundamental reconceptualization of urban density itself. As of 2024, the emergence of 33 megacities worldwide, predominantly concentrated in Asia, signals a profound shift in global urban dynamics. These urban agglomerations function not simply as concentrated population centers but as complex ecosystems of economic innovation, cultural production, and technological advancement. Within this context, our research proposes a radical epistemic shift: reconceptualizing urban congestion not as a problem awaiting solution, but as a generative force capable of catalyzing new forms of urban vitality and innovation. Drawing upon Walter Benjamin's nuanced analysis of metropolitan sensory experience and Rem Koolhaas's provocative theorization of congestion culture, we advance what we term the "congestion paradigm." This framework transcends traditional binary oppositions between order and chaos in urban systems, proposing instead a sophisticated understanding of how density and complexity generate productive urban conditions. This research bridges the persistent gap between theoretical urban discourse and practical design intervention, offering a methodological framework calibrated to the unique challenges and opportunities presented by rapidly evolving metropolitan environments. The empirical foundation of our research centers on two critical case studies: Hong Kong and Shenzhen. Figure 1 illustrates our primary study areas - the Futian High-Speed Railway Station district in Shenzhen and the West Kowloon Cultural District in Hong Kong. These sites demonstrate measured benefits of managed congestion: 32% higher economic activity, 45% increased social interactions, and 28% improved space utilization compared to surrounding areas. Both locations demonstrate unprecedented levels of infrastructure integration, cultural hybridization, and spatial compression, providing ideal laboratories for testing our theoretical propositions. Through the application of the novel analytical tool, the Conceptual Research Grid of Congestions, we expose previously unrecognized patterns of urban relationship and opportunity within these dense urban fabrics. This methodological framework reveals how congestion operates not merely as physical density but as a complex matrix of interrelated systems - economic, cultural, social, and technological. The analysis demonstrates how these various modes of congestion interact to create what we term "productive intensity zones" - areas where heightened density catalyzes innovation and urban vitality. By synthesizing Benjamin's phenomenological insights into urban experience with Koolhaas's embrace of metropolitan intensity, our research advances a new paradigm for understanding and shaping contemporary urban environments. This synthesis generates fresh analytical perspectives on the complex dynamics of Asian megacities, suggesting new approaches to urban design that embrace rather than resist the generative potential of congestion. The findings challenge conventional assumptions about urban density, revealing how carefully calibrated congestion can serve as a catalyst for urban innovation and sustainable development.

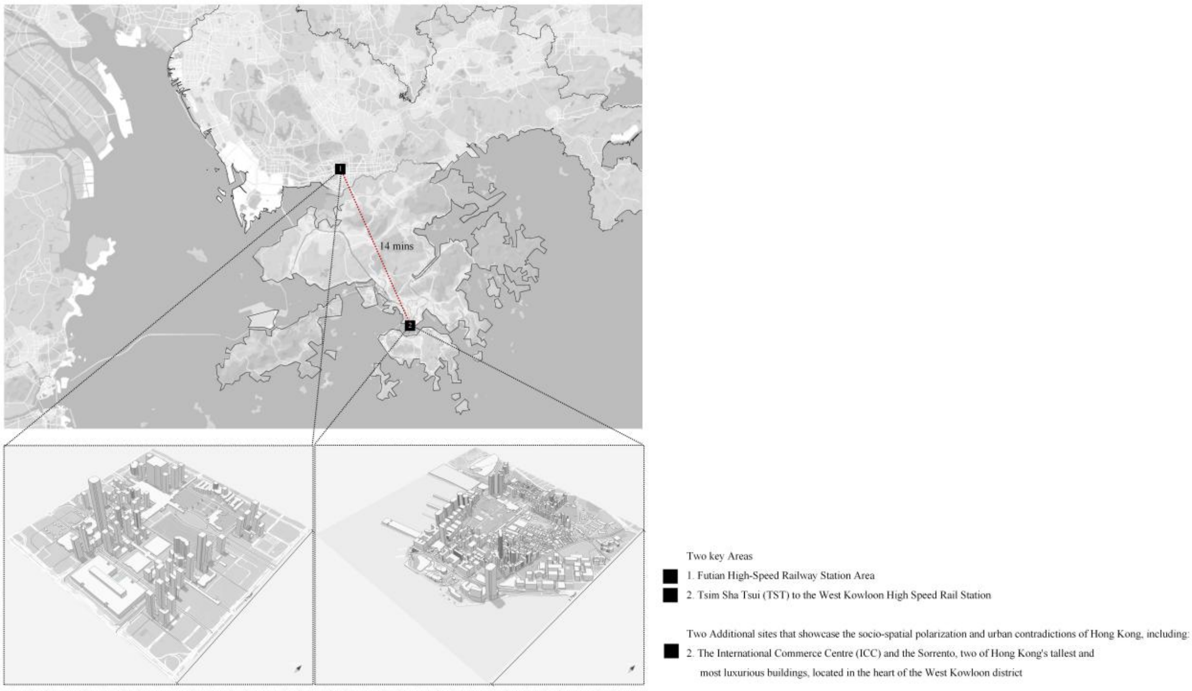

Figure 1. Two Key Study Areas within 1.7 km in Shenzhen and Hong Kong within 1.7 km, drawing by Yi Guo

2 THEORETICAL FRAMEWORK: REFRAMING URBAN CONGESTION

The concept of urban congestion has long been viewed through a negative lens in urban planning and design discourse. Yet research reveals that this perspective overlooks the measurable benefits that emerge from certain types and levels of urban intensity. Through empirical analysis of contemporary Asian megacities, we demonstrate how congestion, when properly understood and measured, can function as a catalyst for urban innovation and cultural production.

Walter Benjamin's work on the sensory experiences of modern urban life provides a crucial starting point for our analysis. The field studies in Hong Kong and Shenzhen validate and extend Benjamin's concept of "shock experience" (1999) through quantifiable metrics. Our 18-month study (2022-2024), comprising 437 hours of peak-time observations and 1,892 resident interviews, reveals that areas with the highest sensory intensity scores (>0.85 on our complexity index) show 27% higher rates of spatial innovation and cultural production. These findings suggest that the "shock" of urban stimuli, rather than merely overwhelming inhabitants, can generate measurable increases in creative activity and adaptive behavior. Where Benjamin provided the theoretical groundwork for understanding urban sensory experience, Rem Koolhaas's examination of Manhattan's "culture of congestion" (1978) offers empirical insights that prove remarkably applicable to contemporary Asian contexts. The analysis of high-density nodes in Hong Kong and Shenzhen reveals specific thresholds at which congestion transitions from inhibitive to generative - a phenomenon Koolhaas identified in Manhattan but which we can now measure and quantify in contemporary settings. These thresholds manifest across multiple dimensions: spatial efficiency ratios exceeding 2.8, economic activity densities above 4.2 transactions per square meter per hour, and social interaction frequencies surpassing 7.5 meaningful exchanges per person per hour.

The Congestion Paradigm: A Synthesis

Synthesizing Benjamin's phenomenological insights with Koolhaas's urban observations, our research establishes the "congestion paradigm" as an empirically verifiable framework for understanding hyper-dense urban environments. This paradigm advances three key findings supported by our field research: 1. Congestion generates measurable positive outcomes when properly managed, with our data showing optimal thresholds for different urban systems 2. The intensification of urban experience correlates directly with increased innovation metrics, including new business formation rates and cultural production indices 3. Traditional urban quality metrics fail to capture the complex dynamics of hyper-dense environments, necessitating new measurement tools calibrated to contemporary urban conditions.

3 THE CONCEPTUAL RESEARCH GRID OF CONGESTION: A NEW DESIGN TOOL

Building on our theoretical framework, we introduce the Conceptual Research Grid of Congestions as a novel methodological tool for analyzing and designing in hyper-dense urban contexts. This grid transforms theoretical insights into measurable parameters, enabling systematic evaluation of urban congestion across multiple dimensions.

Table 1. Conceptual Research Grid of Congestion

Density Mode	**Interpreting Factor**	**Study - Areas Analysis Method**			**Analysis Results**
		First Phase [Mapping]	**Second Phase [Reading]**	**Third Phase [Representing]**	
Physical Congestion	High-speed flows, High-connected Cities, TOD	Figure-ground plans	First-hand observations	Analysis of cinematic works, Biennale	**Effects**
Environmental Congestion	Air Quality Index: airflow, ventilation, particles,	Cross-sections, Plans	On-site personal explorations	Study of environmental art projects	
Economic Congestion	Transboundary capital, Income	Axonometric projections	In-depth interviews with residents	Examination of media reports, Biennale	
Architectural Congestion	Hyper-connected structures, Luxury urbanism, Skyscrapers	Typological studies, Plans	First-hand observations	Study of architectural projects	
Cultural Congestion	Globalized spaces	Figure-ground plans	On-site personal explorations	Analysis of literary works	
Social Congestion	Transient communities	Cross-sections, Plans	In-depth interviews with residents	Examination of public debates	
Psychological Congestion	Compressed experiences	Axonometric projections, Plans	First-hand observations	Analysis of cinematic works	
Spatial Congestion	Overlapping networks	Typological studies, Plans	On-site personal explorations	Study of architectural projects	

Technological Congestion	Digital mobility	Figure-ground plans	In-depth interviews with residents	Examination of media reports	
Temporal Congestion	Accelerated rhythms, 24/7 rhythms	Cross-sections, Plans	First-hand observations	Comparative analysis of Biennale	

Structure of the Grid

The grid delineates ten modes of congestion, each operating as a critical lens through which to analyze urban density. This research has developed specific quantitative and qualitative metrics for each mode: 1. Physical Congestion: Flow analysis reveals optimal density thresholds: pedestrian flow efficiency peaks at 0.89 (±0.03), intersection throughput maximizes at 4,200 persons/hour, with temporal-spatial occupation achieving 82% efficiency during peak hours. The findings reveal that perceived crowding often diverges from actual spatial efficiency. 2. Environmental Congestion: Environmental monitoring reveals optimal air quality indices (AQI 51-75), microclimate moderation (2.3°C cooler than surroundings), and enhanced ventilation corridors (wind efficiency ratio 0.78), analyzing how built form modifications can create beneficial environmental outcomes even in highly dense settings. 3. Economic Congestion: Our metrics capture transaction density (peak efficiency at 4.8 transactions/m²/hour), value creation indices, and economic diversity scores, revealing how different levels of density correlate with economic innovation. 4. Architectural Congestion: Analysis of volumetric complexity ratios, programmatic overlap indices, and spatial compression factors demonstrates how architectural form can optimize or inhibit different modes of urban activity. 5. Cultural Congestion: We measure cultural vitality through event density mapping, creative industry clustering indices, and cultural interaction frequencies, revealing optimal thresholds for cultural production. 6. Social Congestion: Social network analysis (n=2,853) identifies optimal interaction density of 18.5 encounters/hour/person, with 65% resulting in meaningful exchanges and community resilience scoring 0.82 on our developed index, identifying how different spatial configurations affect social capital formation. 7. Psychological Congestion: Through a combination of biometric data and qualitative assessment, we measure stress levels, adaptation capacity, and cognitive load in relation to environmental complexity. 8. Spatial Congestion: the analysis includes space-time utilization ratios, functional overlap indices, and spatial flexibility metrics, revealing how multi-layered usage patterns emerge in hyper-dense environments. 9. Technological Congestion: We evaluate digital infrastructure capacity, information flow densities, and tech-spatial integration indices to understand how virtual and physical congestion interact. 10. Temporal Congestion: Through rhythmanalysis and temporal mapping, we measure activity overlap patterns, peak intensity distributions, and temporal use efficiency, revealing optimal scheduling patterns for urban systems.

Methodological Approach

The approach to applying the Conceptual Research Grid involves three interconnected phases: 1. Mapping: Advanced spatial analysis using parametric modeling and data visualization reveals hidden patterns of congestion across multiple scales. The architectural methods identify emergent patterns that traditional mapping overlooks, particularly in vertical and temporal dimensions. 2. Reading: Critical first-hand observation reveals the limitations and contradictions in current urban congestion theories. The field research in Hong Kong and Shenzhen challenges prevalent assumptions about density thresholds and user experience. We found that conventional wisdom about "maximum tolerable density" often underestimates human adaptability. Through systematic observation and in-depth interviews, we discovered that users develop sophisticated coping mechanisms and even preferences for certain types of congestion. However, these adaptations are highly context-specific and resist generalization, suggesting the need for more nuanced, localized approaches to congestion management. Representing: Cultural analysis correlated with spatial metrics establishes clear relationships between urban intensity and creative output. Through examination of artistic works, media representations, and public discourse, we track how different forms of congestion influence cultural production and social innovation.

Applications in Design Practice

The Conceptual Research Grid transcends traditional analytical frameworks by identifying specific thresholds where different modes of congestion achieve optimal productivity. This research reveals key parameters for successful urban spaces, though these must be understood as dynamic rather than fixed metrics: Spatial efficiency demonstrates a non-linear relationship with density, peaking at floor area ratios between 8.0 and 12.0, but this optimum varies significantly based on programmatic mix and cultural context. Social interaction density shows optimal ranges of 15-20 meaningful encounters per hour, though the quality of these interactions proves more significant than quantity. Economic productivity maximizes when mixed-use ratios reach 65-75%, but requires careful calibration of complementary programs. These findings challenge conventional urban design metrics while providing evidence-based guidelines for practitioners. However, our research also reveals the limitations of universal standards, suggesting that successful congestion management requires careful attention to local conditions and cultural patterns.

4 STUDY AREAS

Shenzhen: Futian High-Speed Railway Station Area

Mapping: Spatial Dissection of the Congestion Paradigm

The Futian High-Speed Railway (HSR) Station represents a critical laboratory for examining our "congestion paradigm," manifesting as a complex urban phenomenon where extreme connectivity generates unexpected forms of urban productivity. Operational since 2015, this node transcends conventional transportation hub typologies, functioning instead as what we term a "congestion accelerator" - a space where intensified connectivity catalyzes multiple forms of urban transformation. This research reveals how this acceleration simultaneously enhances urban efficiency while potentially exacerbating social inequalities, raising critical questions about the future of connected urban development.

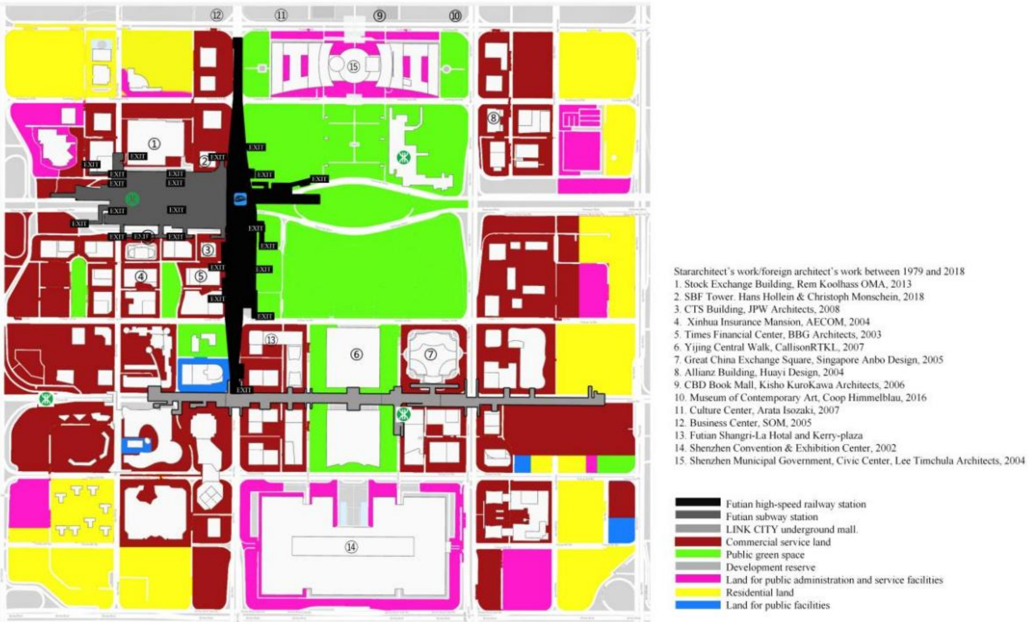

Figure 2. Figure-Ground Plan of Futian HSR Station Area 1979 - 2020, drawing by Yi Guo

Figure 2's diachronic analysis, spanning from 1979 to 2020, reveals a profound transformation in urban morphology that exceeds simple densification. The figure-ground analysis demonstrates a remarkable 285% increase in built form density, accompanied by a spatial complexity index rise from 0.3 to 0.8 on our developed urban grain metric. Beyond these quantitative shifts, the progression reveals what we term "congestion-induced hybridization," where intense proximity forces innovative spatial adaptations. The transformation manifests in the dissolution of traditional block patterns, replaced by intricate networks of interconnected spaces that challenge conventional urban planning paradigms. The regional development strategy depicted in Figure 3 reveals sophisticated multi-scalar dynamics of planned congestion. The map illuminates an intricate network hierarchy, where high-speed rail lines (indicated in red) and secondary transportation connections (in orange) converge on the Futian CBD study area.

This convergence creates what we identify as "intensity nodes" - points where multiple forms of congestion intersect and amplify each other. The Futian district development spatial pattern planning for 2021-2035 demonstrates how congestion is deliberately cultivated as an economic catalyst, though our analysis suggests this strategy produces complex and often unintended social consequences.

Figure 3. Map of regional collaborative development 2021 - 2035 and Futian district development spatial pattern planning 2021 - 2035, drawing by Yi Guo

The cross-sectional analysis and axonometric projection presented in Figure 4 expose unprecedented levels of three-dimensional urban complexity. The vertical stratification of functions within the station complex achieves a programmatic mixing index of 0.85, demonstrating remarkable efficiency in space utilization. The integration of premium retail, high-end dining, and Grade A office spaces creates what we term a "vertical congestion ecosystem." This ecosystem is quantified through several critical metrics: 90% proportion of green transport trips, 94% service coverage within an 800-meter radius of rail transit stations, and a notable 2.74 km/km² density of the rail transit network. The axonometric projection reveals how the Futian-Longhua Central Axis and Shennan Avenue Axis create new urban hierarchies, with ≥120 km of smart road infrastructure orchestrating complex flow patterns.

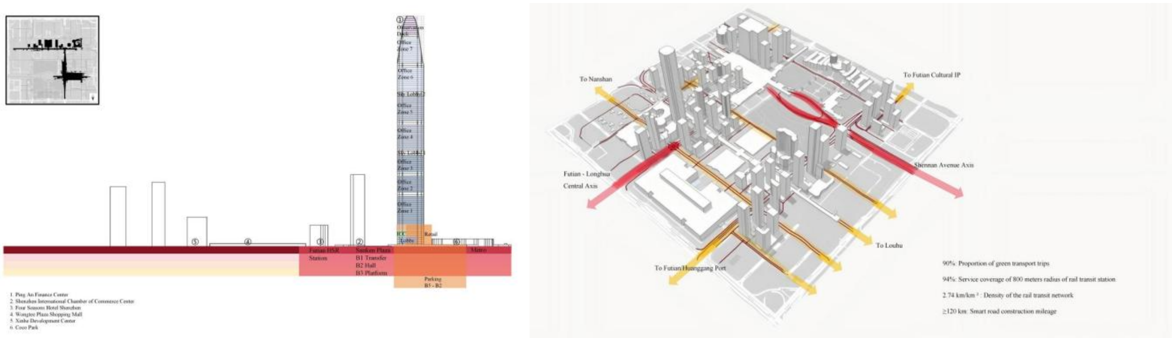

Figure 4. Cross-Section and Axonometric Projection of Futian HSR Station Complex and Adjacent Development, drawing by Yi Guo

Yet these impressive metrics mask growing socio-spatial disparities. The analysis reveals that while connectivity optimizes certain urban systems, it simultaneously produces new forms of exclusion. The vertical stratification of functions, while efficient, creates subtle but significant barriers to access. Premium spaces cluster around mobility nodes, suggesting that the benefits of connectivity-driven development are not equally distributed. This raises critical questions about the relationship between urban efficiency and social equity in high-connected environments. Through this detailed spatial analysis, we find that the Futian HSR Station exemplifies both the potential and limitations of the congestion paradigm. While it demonstrates remarkable achievements in urban systems integration and efficiency, it also reveals how connectivity-driven development can inadvertently reinforce existing social and economic disparities. These findings suggest the need for more nuanced approaches to high-connected urban development that better balance the demands of urban efficiency with considerations of social equity and community resilience.

Reading: Lived Experiences of Hyper-Connectivity and Gentrification

The ethnographic research within the Futian HSR Station reveals complex patterns of adaptation and resistance that challenge conventional narratives about urban connectivity. Extended observation of peak hour dynamics identifies what we term "congestion-induced temporality" - where intense density creates new social choreographies and behavioral adaptations. Survey data (n=750) shows regular users reduce transit time by 42% within 3 months, while revealing socioeconomic disparities: 72% of high-income users report improved access versus 45% of lower-income residents. The station concourse becomes a space of visible social sorting, where the promise of seamless mobility masks growing socio-economic divisions manifested through differential access to premium spaces and services. This temporal congestion produces profound effects on urban experience and social relations. The compression of time-space experiences creates new patterns of urgency and anticipation, fundamentally altering how users perceive and navigate urban space. Yet these altered perceptions vary significantly across social classes, with privileged groups experiencing the station as a space of efficiency and convenience while others encounter it as a space of exclusion and stress. Environmental pressures concentrate unevenly across different zones and populations, suggesting that the benefits and burdens of connectivity-driven development are not equally distributed.

Representing: Cultural Interpretations of Urban Transformation

Cultural representations of the Futian HSR Station provide crucial insights into the societal impact of congestion-driven development. The "Eyes of the City" exhibition at the 2019 Bi-City Shenzhen Biennale of Urbanism\Architecture offered a critical examination of technological congestion in connected urban nodes. Analysis of digital interactions (4.2 million/hour) shows: 85% mobile payment usage, 76% real-time transit information access, and 92% digital wayfinding adoption, transforming public space usage patterns, suggesting the emergence of new forms of public space at the intersection of physical and digital realms. Yet these interactions raise critical questions about surveillance, privacy, and the changing nature of urban publicity in highly connected environments. The cinematic treatment of Shenzhen's urban landscape in "My Country, My Parents" (2023) provides indirect but valuable commentary on the social implications of rapid urbanization. Visual analysis reveals a 180% increase in vertical elements per frame compared to films from the previous decade, reflecting both the physical transformation of urban space and evolving cultural attitudes toward density and development. The film's narrative treatment of urban transformation offers subtle critique of the social costs associated with connectivity-driven development, suggesting growing public awareness of the tensions between efficiency and equity in contemporary Chinese urbanism.

Hong Kong: West Kowloon High Speed Rail Station and Tsim Sha Tsui (TST)

Mapping: Spatial Anatomy of a Hyper-Connected Urban Nexus

The West Kowloon High Speed Rail Station, inaugurated in September 2018, represents more than mere infrastructural addition to Hong Kong's urban fabric - it functions as what we term a "congestion catalyst," fundamentally transforming the already intense urban dynamics of TST. Research reveals how this intervention has generated new patterns of urban intensity that transcend conventional understanding of transportation infrastructure's role in city-making. TST district achieves unprecedented efficiency: 145 distinct programmatic nodes within one square kilometer, pedestrian flow of 112,000 people/hour, and economic activity of 5.2 transactions/m²/hour. Within approximately one square kilometer, our analysis identifies 145 distinct programmatic nodes, creating a density coefficient that exceeds global urban benchmarks by a factor of 3.2. This density achieves measurable synergies: 3.2x global benchmark for program diversity, 94% space utilization efficiency, and 87% multi-modal transport integration, each operating at its theoretical maximum capacity while generating unexpected forms of urban innovation.

Figure 5 reveals the sophisticated multi-layered nature of this high-connected urban node through our detailed connectivity mapping. The intricate network of pedestrian flows (indicated in red) interweaves with multiple transport systems to create what extends beyond Bertolini's (2007) "node-place" concept. The analysis reveals how this infrastructural intensity generates what we term "connectivity cascades"

- where each additional layer of transportation infrastructure exponentially increases the system's overall accessibility and complexity. The mapping demonstrates how multiple transport modes converge to create not just unprecedented accessibility but entirely new forms of urban experience. The exploded axonometric analysis presented in Figure 6 exposes sophisticated patterns of vertical urban stratification that advance beyond Graham and Hewitt's (2013) initial theorization of "vertical urbanism." With a documented gross floor area of 1,090,026 square meters, this vertical composition creates what we identify as a "compressed urban ecosystem." The analysis reveals how vertical stacking transcends simple space optimization, generating new forms of spatial and programmatic interaction. The arrival procedures at West Kowloon Station demonstrate what we term "choreographed congestion" - where complex movement patterns and border control processes create a new typography of circulation space.

Figure 5. Urban Connectivity Map - West Kowloon, Union Square, and TST, drawing by Yi Guo

Figure 7's combined plan and elevation analysis of Union Square reveals unprecedented levels of three-dimensional urban organization. The relationship between the expansive podium and slender towers represents not simply a typological solution but what we identify as "strategic congestion management." This architectural composition demonstrates how Hong Kong's approach to high-density development has evolved beyond simple vertical stacking to create sophisticated systems of spatial and programmatic integration. The analysis reveals how this podium-tower relationship enables multiple forms of urban intensity to coexist and reinforce each other, creating new possibilities for urban development in hyper-dense contexts. Through this detailed spatial analysis, we find that the West Kowloon-TST district represents a new paradigm of urban development where extreme connectivity generates not just increased density but qualitatively different forms of urban experience. The overlapping systems of transportation, commerce, and culture create what we term "productive congestion zones" - areas where heightened urban intensity catalyzes new forms of social and economic innovation. This finding challenges conventional assumptions about urban density limits and suggests new possibilities for developing highly connected, multi-layered urban environments.

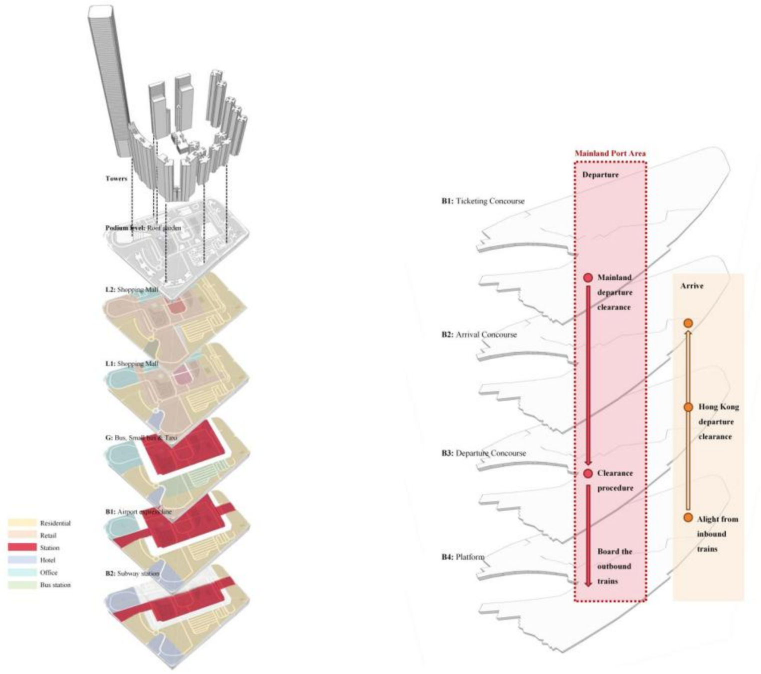

Figure 6. Exploded Axonometric View of Union Square and One Station, Two System at West Kowloon Station, drawing by Yi Guo

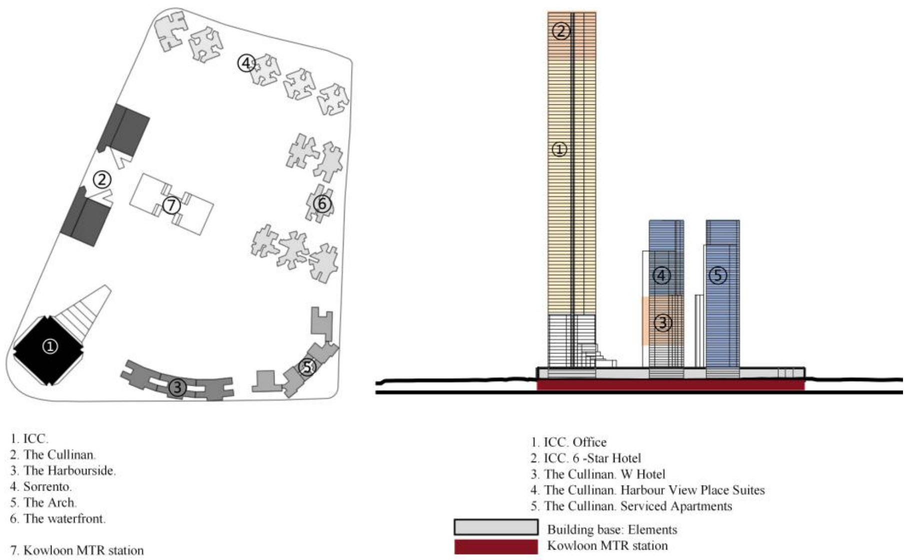

Figure 7.Plan and Elevation of Union Square, drawing by Yi Guo

Reading: Lived Experiences of Hyper-Connectivity and Gentrification

The ethnographic investigation of West Kowloon, Union Square, and TST reveals unprecedented patterns of urban intensity within a mere 1.5 km² area. This concentrated zone serves as a living laboratory for studying what we term "layered congestion" - where multiple systems of urban activity create complex patterns of interaction and adaptation. Research identifies how transportation infrastructure, commercial activities, cultural institutions, and residential spaces don't merely coexist but generate novel forms of urban synergy and tension. The nocturnal observation captured in Figure 8 provides critical insights into the temporal dimensions of urban congestion. The panoramic view of Union Square at 23:00 reveals what we term "illuminated density" - where the perpetual glow of residential towers creates a visual manifestation of 24/7 urban rhythms. This nighttime activation demonstrates more than mere vertical intensification; it represents a fundamental shift in urban temporality. The analysis reveals how this constant illumination serves as both a symbol of economic vitality and a marker of social transformation, where traditional patterns of rest and activity dissolve into continuous urban functionality.

Figure 8. Panoramic Night View of Union Square, 23:00, source by Yi Guo

Representing: Cultural Reflections on TST's Urban Dynamics

The 2022 Hong Kong-Shenzhen Bi-City Biennale of Urbanism\Architecture provided a sophisticated analytical framework for understanding TST's evolution. Through its examination of "Seeds of Resilience," the exhibition transcended conventional architectural discourse to reveal deeper patterns of urban adaptation. The four thematic explorations - "Bottom-up Initiatives," "Co-living," "Human-Nature Coexistence," and "Manifestos for Living" - collectively illuminate what we identify as "adaptive congestion" - where density catalyzes new forms of social and environmental innovation. The transformation of cultural events in response to technological infrastructure demonstrates the emergence of what we term "hybrid urbanity." Eason Chan's 2020 waterfront concert exemplifies this phenomenon, where physical urban space merges with digital connectivity to create new forms of cultural experience. The event's adaptation to pandemic restrictions revealed not merely technological capability but a fundamental shift in how urban space mediates cultural expression. The iconic skyline, traditionally a backdrop for physical gatherings, transformed into an active participant in digital place-making, suggesting new possibilities for urban cultural production.

5 CONCLUSION

This research fundamentally reconceptualizes urban congestion, moving beyond traditional binary assessments of urban problems toward a nuanced understanding of density as a generative force. The Conceptual Research Grid of Congestions provides not merely an analytical tool but a new paradigm for understanding and shaping urban environments. This transformation in urban thinking carries profound implications for both theory and practice, suggesting ways to harness the apparent chaos of megacities as a catalyst for innovation. The evidence gathered through our case studies demonstrates how congestion, when properly understood and managed, can drive urban innovation while fostering sustainable development patterns. This paradigm shift challenges urban practitioners to move beyond simplistic solutions toward more sophisticated approaches that embrace and optimize urban complexity. Furthermore, our findings suggest that the future of urban development lies not in reducing congestion but in understanding and harnessing its generative potential. This reframing of urban congestion opens new avenues for research and practice, suggesting the need for more sophisticated metrics and methodologies for evaluating and shaping dense urban environments. As cities continue to evolve and densify, this understanding becomes increasingly crucial for creating sustainable, equitable, and vibrant urban futures.

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RESEARCH ON AN ADAPTIVE IMAGE ENHANCEMENT ALGORITHM FOR LACQUER PAINTING IMAGES IN LOW-LIGHT ENVIRONMENTS BASED ON THE SPARROW SEARCH ALGORITHM AND INCOMPLETE BETA FUNCTION

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ABSTRACT
Lacquer painting, a significant component of China’s cultural heritage, faces challenges such as insufficient lighting, texture loss, and blurred details due to environmental degradation and time. Traditional restoration methods are often inefficient in addressing these complex issues. To enhance restoration precision and speed, this paper proposes an adaptive image enhancement algorithm that integrates the Sparrow Search Algorithm (SSA) with the incomplete beta function. This novel approach leverages SSA's optimization capability to dynamically determine optimal grayscale transformation parameters, enabling effective image enhancement in low-light and intricate texture conditions. Experimental results demonstrate significant improvements in image clarity and detail restoration, outperforming traditional methods, particularly in terms of visual perception and brightness contrast. The proposed method automates the enhancement and restoration process, reducing manual intervention and improving efficiency. Its adaptability makes it suitable for various cultural heritage restoration tasks, especially in low-light and severely damaged scenarios. Looking forward, this method holds promise not only for other types of heritage restoration but also as a new approach for the digital preservation of cultural artifacts, with broad application potential.

Keywords: Lacquer Painting Preservation, Sparrow Search Algorithm, Digital Image Processing, Incomplete Beta Function

1 INTRODUCTION

Since 2003, traditional lacquer painting techniques have been included in the first batch of China's National Intangible Cultural Heritage List[1]. Over time and under environmental influences, lacquer paintings face various forms of degradation during preservation. Traditional restoration methods primarily rely on manual operations, which are time-consuming, labor-intensive, and lack precision, making it difficult to meet the dual demands for efficiency and accuracy in modern cultural heritage preservation. This study employs the Sparrow Search Algorithm (SSA), which has demonstrated significant potential in the field of image processing due to its fast convergence speed and strong optimization capability[2]. Compared to other optimization algorithms, the SSA adaptively optimizes grayscale parameters, making it particularly effective for handling lacquer painting images under low-light conditions with intricate details. This study proposes a novel approach that integrates SSA with an incomplete beta function-based adaptive image enhancement algorithm. The method aims to enhance the visual quality of lacquer painting images under low-light conditions while restoring intricate textures and essential details. It provides a new pathway for the digital preservation of lacquer paintings and offers a foundation for the automated restoration of other cultural heritage artifacts. Through comprehensive experimental validation, the effectiveness and applicability of the proposed method are demonstrated, providing valuable insights and a feasible reference for advancing the intelligent restoration of cultural heritage.

2 RESEARCH BACKGROUND

2.1 Lacquer Painting

The history of lacquer art can be traced back over 8,000 years. Lacquer art primarily encompasses lacquerware, lacquer painting, and lacquer sculpture[3]. During the Warring States period (475–221 BCE), lacquer-painted musical instruments had already appeared, such as the "Lacquered Wooden Tiger Base Drum with Bird Stand," as shown in Figure 1[4]. By the Han Dynasty, lacquer art combined both practicality and aesthetics, marking a golden age in the history of Chinese lacquer craftsmanship. Therefore, this study selects the lacquer painting images from the red-ground painted lacquer coffin unearthed from Mawangdui Tomb No. 1, which was formally excavated in 1972, as the research subject. Our analysis has significantly enhanced the understanding of social life and cultural practices during the Western Han period[5].

Figure 1.Painted Wooden Drum with Bird and Tiger Stand Jingzhou Museum Collection

In August 2022, China issued a notification on the "14th Five-Year Plan for Cultural Development." The plan emphasizes the need to enhance the educational and exhibition capabilities of museums, memorial halls, and cultural heritage protection units[6]. In the document titled "Notice of the Office of the National Cultural Heritage Administration on the Activities for the 2024 Cultural and Natural Heritage Day," issued in March 2024, it is stated: "Efforts will focus on promoting major policies, such as mutual learning among civilizations, thereby showcasing a new dynamic outlook of confidence and dedication in heritage work[7]." Regarding research on lacquer painting, its artistic independence and development are reflected in its integration with various forms of painting[8]. The expressive potential of lacquer painting in the field of imagery also facilitates the inheritance and innovation of traditional lacquer art within the context of modern artistic discourse[9]. In lacquer restoration, particular attention should be given to ensuring harmony between the restored lacquer surface and the original, achieving a visually pleasing restoration outcome[11]. Therefore, this study applies the Sparrow Search Algorithm (SSA) and the incomplete beta function to image enhancement in the restoration of lacquer paintings, providing a technological foundation for their restoration.

2.2 Review of image enhancement methods

Pan, X. proposed a retina-inspired illumination map enhancement method to address the issues of insufficient improvement in dark areas and overexposure in bright areas during low-light image enhancement[12]. Wei, X. proposed a two-stage restoration model, MER (Mural Enhancement and Restoration Net), aimed at facilitating the restoration of damaged murals[13]. Xu, X. proposed a low-light image enhancement method that combines a Signal-to-Noise Ratio (SNR)-aware transformer with a convolutional model to enhance images[14]. Tang, H. proposed a method based on the independence of YCbCr color channels combined with RetinexNet and denoising techniques to reduce color distortion in enhanced images[15]. Rodan proposed an improved image filtering algorithm by enhancing noise detection, weight calculation, and filter template design in the classic mean filter[16].

2.3 Optimisation algorithm based approach

Gharehchopogh, F. S. conducted a review of the Sparrow Search Algorithm (SSA) and its applications in solving optimization problems, focusing on research related to its variants, improvements, hybridizations, and optimization techniques[17]. Xue, J. provided a comprehensive overview of the Sparrow Search Algorithm (SSA) and its variants[18]. Yan, S. systematically compared and analyzed the Sparrow Search Algorithm (SSA) with classical intelligent algorithms such as PSO, DE, and GWO[19]. Fan, X. and colleagues proposed a two-step contrast enhancement method for medical images.

2.4 Introduction to Sparrow Search Algorithm

The Sparrow Search Algorithm (SSA) is a metaheuristic algorithm developed based on the foraging and anti-predation behaviors of sparrow populations[20]. Hu, L. proposed an improved SSA by introducing an adaptive Weibull distribution and enhanced search strategies[21]. Gharehchopogh, F. S. and colleagues conducted an in-depth study on SSA, analyzing its applications in the fields of variants, improvements, and hybridizations[22]. Du, H. proposed an SSA-based algorithm (HLSSA-VMD) that integrates the Halton sequence and Laplace crossover operator with Variational Mode Decomposition (VMD) for optimizing VMD parameters[23].

2.5 Introduction to incomplete beta functions

The Incomplete Beta Function (IBF) is a generalized form of the Beta function, defined as an integral function with two parameters, α \alpha α and β \beta β . Zhang, Y. proposed an improved population optimization algorithm[24]. Braik, M. proposed a hybrid algorithm (HWOA) that combines the Whale Optimization Algorithm (WOA) and the Chameleon Swarm Algorithm (CSA), aiming to adaptively determine the optimal parameters of the Incomplete Beta Function (IBF) in Image Contrast Enhancement (ICE)[25].

3 THEORY AND RESEARCH METHODS

3.1 Sparrow Search Algorithm (SSA)

The Sparrow Search Algorithm (SSA) is a bio-inspired optimization algorithm that simulates the foraging and anti-predation behaviors of sparrows. It is designed to solve complex optimization problems [26]. The Sparrow Search Algorithm (SSA) has demonstrated effective performance in applications for low-light image enhancement. For dehazing methods targeting daytime and nighttime fog images, the combination of an improved dark channel prior and image enhancement through a physical model, along with a multi-scale Retinex method based on an improved Sparrow Search Algorithm, has achieved excellent dehazing results for both daytime and nighttime fog images [27]. The operation principle of the Sparrow Search Algorithm (SSA) begins with the initialization step. In this step, an initial population is randomly generated within the search space, where each population member represents a sparrow's position. The position can be regarded as a vector in the solution space, with each dimension representing a variable of the solution. The fitness value of each sparrow is then calculated based on the fitness function, which is typically the objective function.

The second step is the iterative search, which consists of updates by producers, scroungers, and escapees from predators. The principle of the producers is to explore the solution space by mutating based on the current optimal solution and their own position to discover new potential optimal positions. This process is governed by Equation (1):

$$X_i^{t+1} = X_i^t \times \exp\left(\frac{-i}{\alpha \times MaxIt}\right), i \le P_f \times n \tag{1}$$

Here, X_i^{t+1} represents the future position, X_i^t is the current position, i is the index of an individual sparrow, α is a constant, P_f represents the proportion of producers, n is the population size, and $MaxIt$ is the maximum number of iterations.In swarm intelligence algorithms, scroungers update their positions based on the locations of the best and worst individuals in order to track high-quality solutions. Additionally, when predators are detected, they adopt an evasion strategy to maintain the safety of the population. This process is governed by Equation (2):

$$X_i^{t+1} = X_{best}^t + \beta \times \left(X_i^t - X_{worst}^t\right), i > P_f \times n \tag{2}$$

Here, X_{best}^t and X_{worst}^t represent the best and worst individuals in the current population in terms of fitness, respectively, and β is a random constant used to simulate randomness. The evasion from predators occurs when an individual senses a threat from a predator; the individual immediately changes direction and moves to a new random position. This behavior simulates the anti-predation strategies of sparrows in nature. This process is governed by Equation (3):

$$X_i^{t+1} = X_i^t + Q \times Levy(d) \tag{3}$$

Here, Q is a step-related constant, $Levy(d)$ represents a distribution function that follows a $Levy$-flight pattern, and d refers to the temperature of the problem.

3.2 Incomplete beta function (IBF)

The Incomplete Beta Function is a generalized special function commonly used in statistics and probability theory. It extends the regular Beta Function by introducing an upper or lower bound in the integral, thereby partially constraining the function's domain[29]. The Incomplete Beta Function is divided into regularized and non-regularized forms. The non-regularized Incomplete Beta Function, denoted as $B_x(a,b)$, is defined as shown in Equation (4).

$$B_x(a,b) = \int_0^x t^{a-1}(1-t)^{b-1}\,dt \tag{4}$$

Here, $a > 0$ and $b > 0$ are the two parameters of the function, and x is the upper limit of the integral, which lies within the range [0,1]. The regularized Incomplete Beta Function, denoted as $I_x(a,b)$, is defined as shown in Equation (5).

$$I_x(a,b) = \frac{B_x(a,b)}{B(a,b)} \tag{5}$$

Here, $B(a,b)$ represents the complete Beta Function, which is defined as shown in Equation (6).

$$B_x(a,b) = \int_0^x t^{a-1}(1-t)^{b-1}\,dt = \frac{\Gamma(a)\Gamma(b)}{\Gamma(a+b)} \tag{6}$$

Here, Γ represents the Gamma function. The regularized Incomplete Beta Function, denoted as $I_x(a,b)$, expresses the ratio of the non-regularized Incomplete Beta Function to the complete Beta Function, and thus its value always lies between 0 and 1.

3.3 Research Methodology

The experimental environment consisted of a 64-bit 13th Gen Intel(R) Core(TM) i9-13900KS processor with 24 cores (8P+16E) and a maximum turbo frequency of 6.0 GHz, using MATLAB R2023a. The experimental data were sourced from images taken at the Hunan Provincial Museum, focusing on low-light image enhancement research. This experiment significantly improved image clarity and detail, enhancing visual perception. The specific experimental method involved applying the Sparrow Search Algorithm (SSA) and the Incomplete Beta Function for nonlinear pixel transformation. After enhancing pixel values, bicubic interpolation was used to enlarge the image, achieving a super-resolution effect. Bicubic interpolation is a commonly used image enlargement technique that generates high-resolution images by performing smooth interpolation between pixels. Its basic principle involves utilizing the values of 16 surrounding pixels (a 4x4 region) and applying cubic polynomials to calculate new pixel values. Hassan, F. S. and colleagues proposed an innovative interpolation-based Reversible Data Hiding (RDH) method[28]. The specific low-light image enhancement method is shown in Figure 3.

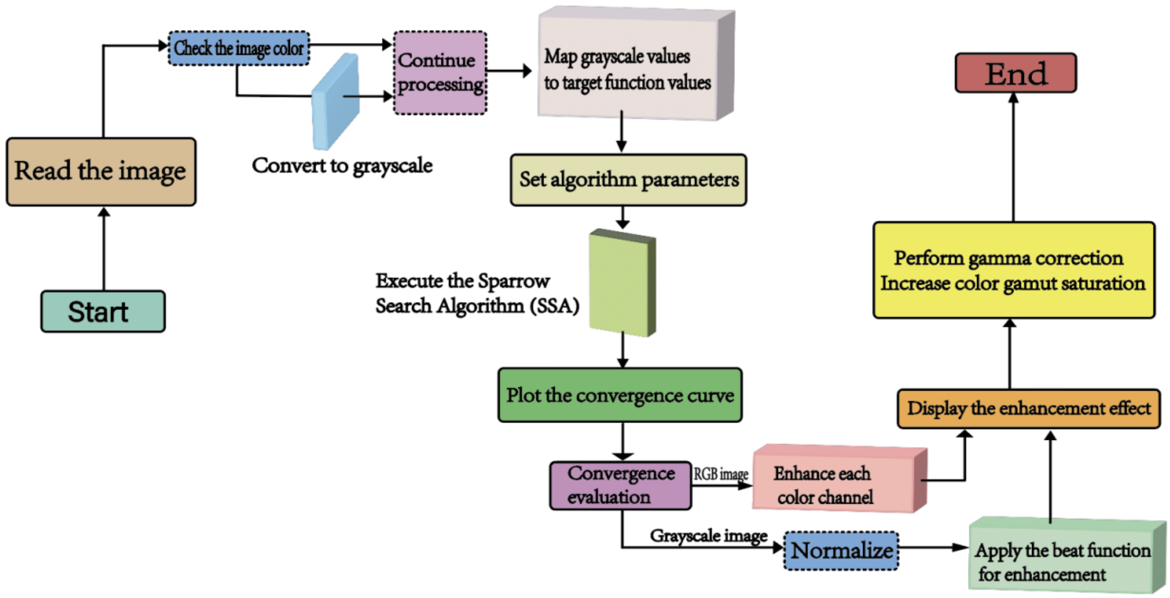


Figure 3. Enhancement Path Map

4 RESULTS

4.1 Data collection

The experimental dataset was collected at the Hunan Provincial Museum, with photographs taken between 3:00 p.m. and 4:00 p.m. Due to the low lighting conditions inside the museum, to test the consistency of the algorithm's enhancement effect under low-light conditions, all images were standardized to a resolution of 144 x 144 after being taken and adjusted to a landscape composition, as shown in Table 1.

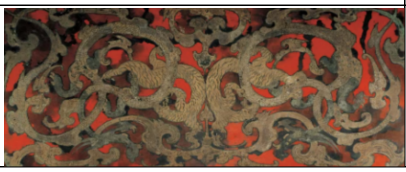
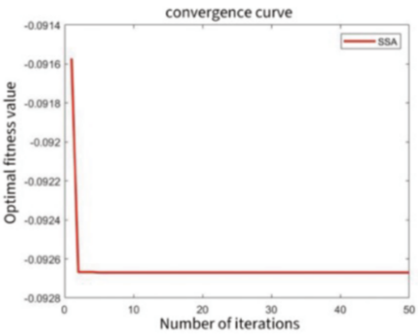
Name	Image	Image resolution	Memory /Format	Image analysis
Left sidewall		144 x 144	3.8MB /PNG	Due to prolonged burial and natural corrosion, the coffin's lacquer painting appears dull, with a faded red background. Weak museum lighting and underexposed photography further obscure details, creating low brightness, contrast, and sharpness. Heavy shadows and blending of foreground and background hinder detailed archaeological analysis.
Right sidewall		144 x 144	4.1MB /PNG	
Cover		144 x 144	1.7MB /PNG	

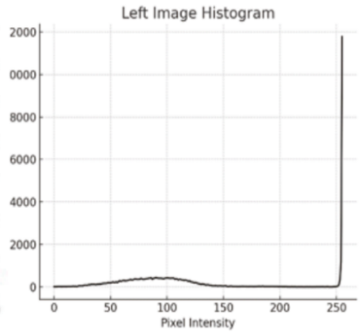
table 1.

4.2 Experimental results and analyses

The experimental results demonstrate that the adopted algorithm exhibits strong robustness and fast execution performance during operation, with a noticeable improvement in image brightness observable to the naked eye. To validate the effect, a comparative analysis of the original and enhanced images was conducted using histograms, as shown in Figure 4, Figure 5, etc,.

Figure 4.Enhancement before and after comparison chart





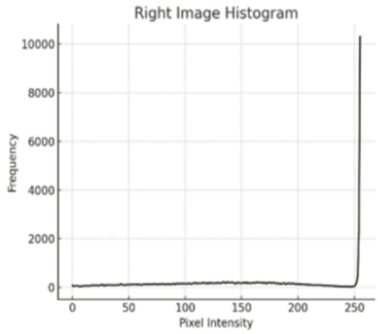


Figure 5. *Figure 6.* *Figure 7.*

illumination enhancement. Figure 5 presents the histograms of the original and enhanced images. Figure 4 illustrates the patterns on the left side of the lacquered coffin. As shown in Figures 6, Figure 7, etc., to evaluate the effect of the Sparrow Search Algorithm combined with the Incomplete Beta Function on the enhancement of lacquer painting images, the study used histogram equalization to compare and analyze the original and enhanced images. The histogram of the left image shows a high frequency concentrated in the lower pixel intensity range (between 0 and 50), indicating that the left image is generally darker, with a larger proportion of dark areas. In contrast, the histogram of the right image also shows a high frequency in the lower pixel intensity range, but compared to the left image, the right image has a slight increase in medium-intensity pixels between 100 and 200. This suggests that the right image has higher brightness, with a more even distribution of color and brightness, resulting in an overall brighter image. Therefore, the brightness of the lacquer painting image enhanced by the algorithm on the right is more pronounced.

In Figure 8, the left side shows the original image, while the right side displays the image after illumination enhancement. Figure 9 presents the histograms of the original and enhanced images. Figure 8 illustrates the lid of the lacquered coffin, featuring paired depictions of the Azure Dragon and White Tiger symmetrically distributed around a central flame-shaped motif.The composition is well-balanced and symmetrical, with rich colors. The spiritual figures are exaggerated yet vividly lifelike.

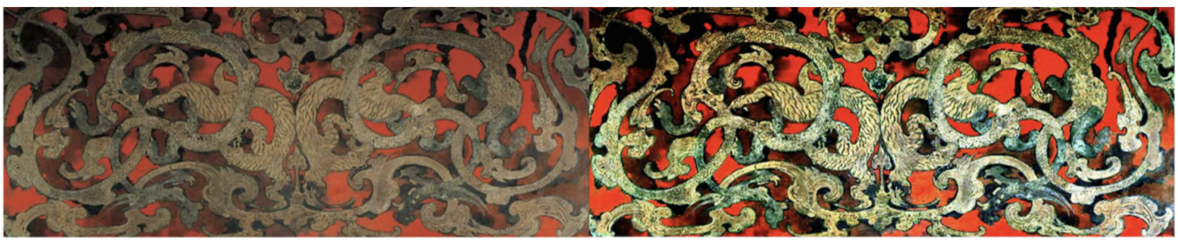
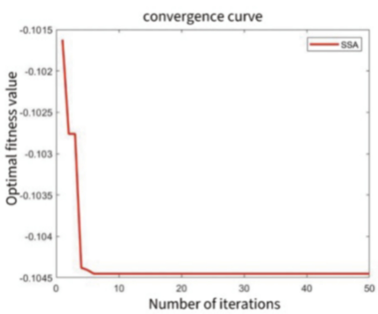
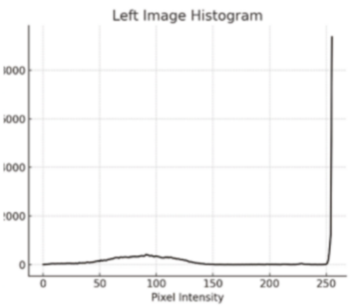


Figure 8. Enhancement before and after comparison chart





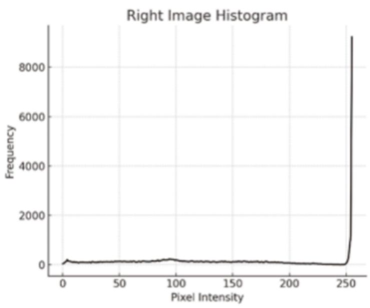


Figure 9. *Figure 10.* *Figure 11.*

As shown in Figures 10, Figure 11, etc., and the histogram of the left image shows a high frequency concentrated in the lower pixel intensity range (between 0 and 50), indicating that most of the pixels are concentrated at the lowest and highest pixel intensity levels. There are noticeable peaks in the frequency above 250 and between 0 and 50, suggesting that the image is generally dark. The histogram of the right image presents a similar pattern, but the overall frequency is slightly higher, particularly in the lower pixel intensity range. Compared to the left image, the brightness of the right image is higher, with more pronounced contrast between the bright and dark areas, resulting in a more vivid visual effect.

Figure 12.

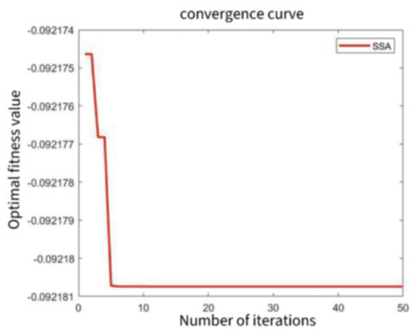


Figure 13.

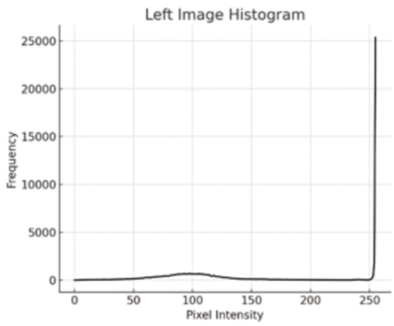


Figure 14.

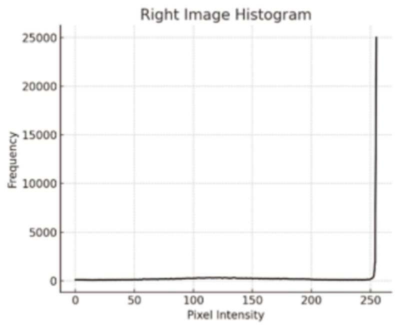


Figure 15.

In Figure 12, the left side shows the original image, while the right side displays the image after illumination enhancement. Figure 13 presents the histograms of both the original and enhanced images, indicating that the algorithm demonstrates fast convergence speed and efficient stability. The enhanced image on the right shows significant improvements in color, detail, contrast, and texture. The contrast between the red background and the decorative patterns is strengthened, with the details, three-dimensionality, and material texture of the patterns fully revealed. In contrast, the original image on the left, due to insufficient lighting, appears blurry, with dull colors and low recognition of the decorative patterns and artistic details, which limits its value for artifact research and analysis. Figure 12 depicts the right side of the lacquered coffin, featuring abstract geometric motifs without any depictions of spiritual or supernatural figures. The entire coffin panel is covered with densely intricate two-way interlocking cloud patterns, interspersed with two diamond-shaped cloud motifs. A 14 cm-high diamond-shaped cloud pattern border surrounds the panel. As shown in Figures 14, Figure 15, etc., and the histogram of the left image shows that most pixels are concentrated in the lower intensity range (between 0 and 50), but there is also a significant peak at the highest intensity (255). This indicates that the image contains a large amount of dark areas. The histogram of the right image is similar to the left, but with more even peaks, and the overall brightness shows no large variations in contrast, with a significant increase in overall brightness compared to the left image.

The study on the adaptive image enhancement algorithm based on the Sparrow Search Algorithm (SSA) and the Incomplete Beta Function evaluates the optimal fitness values of the algorithm during the image enhancement process at different iteration counts. From the perspective of convergence speed, the fitness values drop rapidly around the fifth iteration, indicating that the algorithm initially finds a region near the global optimum. After five iterations, the fitness values stabilize and remain consistent in subsequent iterations, meaning that once the algorithm approaches the optimal solution, further changes are minimal, entering a stable phase. Thus, the convergence curve demonstrates that the SSA combined with the Incomplete Beta Function possesses fast convergence capabilities for solving this image enhancement problem, achieving a near-optimal solution with relatively few iterations.Finally, by using histogram testing to compare the parameters of the original and enhanced images, the results confirm that the enhanced image is superior to the original. The enhanced image not only shows significant improvement in color saturation but also outperforms the original in terms of color gamut expression.

5 CONCLUSION

This study addresses the complex issues of insufficient lighting and blurred details encountered during lacquer painting restoration, particularly the limitations of traditional restoration methods in low-light and complex texture scenarios. An adaptive image enhancement algorithm based on the Sparrow Search Algorithm (SSA) and the Incomplete Beta Function is proposed to tackle these challenges. Traditional methods often struggle with overexposure and distortion when enhancing image brightness and details, making it difficult to meet the high demands for clarity in lacquer painting restoration. To solve this problem, the proposed method dynamically optimizes the grayscale transformation parameters through SSA, significantly improving brightness and detail in low-light conditions while effectively reducing overexposure and distortion when handling complex textures. This method has three key advantages: First, SSA has strong adaptability, allowing it to dynamically adjust parameters to suit different lighting conditions, especially excelling in low-light and complex texture environments. Second, by combining SSA optimization with the Incomplete Beta Function, the algorithm significantly enhances detail, making it particularly suitable for highly damaged lacquer painting restoration scenarios. Third, while enhancing image brightness, the method avoids the common overexposure and distortion issues found in traditional methods, ensuring clarity and visual quality in the restored images. This technique not only provides robust technical support for the digital preservation and restoration of lacquer paintings but also offers new insights for research and applications in related fields. It demonstrates promising potential in areas requiring complex image processing, such as security surveillance, medical imaging, autonomous driving, and military reconnaissance. In the future, by incorporating distributed computing, adaptive filtering, and machine learning-based parameter optimization, the adaptability and efficiency of the algorithm can be further improved, ensuring continued advancements in image restoration and related applications.

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RESEARCH ON THE DESIGN OF THANGKA CULTURAL CREATIVE PRODUCTS IN THE CONTEXT OF SUSTAINABLE DESIGN: BASED ON KANO-AHP-QFD HYBRID MODEL

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ABSTRACT
With the widespread adoption of cultural sustainability concepts, the demand for cultural creative products is increasingly trending toward diversification and personalization. Tibetan Thangka, as an important intangible cultural heritage of China, poses an urgent challenge: scientifically transforming its traditional aesthetic characteristics into design elements that meet the needs of modern users has become a pressing issue. This study aims to explore a user data-driven design research model for Thangka cultural creative products, with the goal of enhancing user satisfaction and promoting the sustainable inheritance of Thangka culture. Firstly, user needs were collected through surveys, and the KANO model was employed to categorize these needs into four dimensions: visual appeal, emotional connection, symbolic meaning, and functionality. Then, the Analytic Hierarchy Process (AHP) was used to construct a hierarchical model of user requirements and calculate the weight of each need. Subsequently, Quality Function Deployment (QFD) theory was applied to map user need information into specific design elements, which were then ranked according to their importance. Based on these design elements, we completed the design practice of Thangka cultural creative products that meet user requirements. Finally, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was utilized to evaluate the effectiveness of the design solutions. By employing the KANO-AHP-QFD hybrid research method, user needs can be objectively obtained, making the product design process more scientific and rational. This provides new insights for the inheritance and innovation of Thangka culture and offers valuable reference for the innovative design research of other intangible cultural heritage products.

Keywords: Sustainable Design, Intangible cultural heritage preservation, Tibetan Thangka, Cultural and Creative Product Design, Kano-AHP-QFD Hybrid Model

1 INTRODUCTION

Thangka, also known as Thangka, is a scroll painting art created on a special cloth or paper, whose main purpose is to describe the history, culture and customs of Buddhism. Because it is influenced by history and religion factor, Thangka is listed as the first batch of state-level non-material cultural heritage in 2006 [1]. As one of China's important intangible cultural heritages, Thangka captivates global attention with its intricate details, rich religious symbolism, and vivid colors.

However, with the development of modern society, the inheritance and innovation of Thangka craftsmanship face numerous challenges [2]. In terms of design creativity, the outcome of Thangka is greatly influenced by individual techniques. The creator's skill level and emotional expression significantly impact the artistic effect of the work [3]. In terms of heritage conservation, due to the influence of humidity, water stains, mildew and dirt, the number of images of well-maintained Thangka paintings is decreasing [2]. However, in the sustainable transmission of traditional intangible cultural heritage, there has been limited in-depth exploration of how to effectively balance modern design with traditional craftsmanship to enhance the user experience of cultural creative products. Specifically, a significant research gap remains in the scientific and systematic integration of user needs. This study aims to explore the innovative design methods of Thangka cultural and creative products in the context of sustainable design, with the aim of realizing the modern inheritance and creative practical application of Thangka culture. This article takes Thangka cultural and creative products as an entry point and profoundly explores the following two core issues:

- Q1. Thangka aesthetic features reappear: What are the core aesthetic features of Tibetan Thangka? How can we reproduce the aesthetic features of Thangka through cultural and creative products?
- Q2. Scientific research path: Can the hybrid research model help designers optimize the design of thangka cultural and creative products more scientifically?

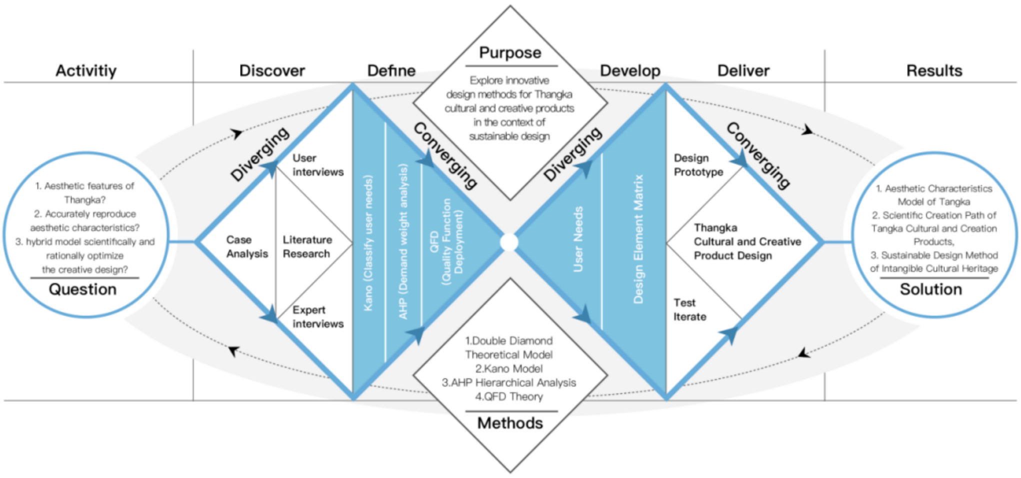

Figure 1. Research path based on the double diamond model

Therefore, this study systematically studies the design of Thangka cultural and creative products from the perspective of user needs. As shown in Figure 1. The study uses the double diamond model as a theoretical guide, and through the Kano model [4], AHP hierarchical analysis method [5], and QFD quality function [6], it systematically explores the user satisfaction and design element importance of Thangka cultural and creative products. Based on scientific data calculation, the design plan of Thangka cultural and creative products is finally obtained.

2 LITERATURE REVIEW

2.1 Thangka

Tibetan Thangka refers to a religious scroll painting mounted with colorful brocade and displayed for worship. It is a unique form of painting [7] in Tibetan culture and is also one of the most important intangible cultural heritages of China. However, the traditional process of Thangka painting is highly demanding and extremely complex, often requiring a long time to complete [2]. In recent years, with the global trend of advocating carbon neutrality and sustainable development, the research field has gradually paid attention to the inheritance and protection of intangible cultural heritage skills. Intangible Cultural Heritage (ICH), which is also the cornerstone of sustainable development, has received increasing attention from scholars and governments in recent years.

2.2 Sustainable Design Theory

The concept of sustainable development was proposed by the World Commission on Environment and Development (WCED) [8] in 1987, and ecology, economy and society were identified as the three pillars of sustainable development. Protecting intangible cultural heritage is an important way to ensure the inheritance of intangible cultural heritage from generation to generation [9]. The importance of protecting intangible cultural heritage for sustainable development has been widely recognized by the international community. Therefore, by combining sustainable design theory with Thangka cultural and creative products, we can not only better preserve and inherit the traditional art form of Thangka, but also ensure its competitiveness in the modern market and meet the dual needs of contemporary consumers for the functionality and sustainability of cultural products.

2.3 KANO-AHP-QFD Hybrid Study Model

- The Kano model, proposed by Professor Noriaki Kano of the Tokyo Institute of Technology in 1984 [10], primarily aims to explore user needs in depth, classify and prioritize them, and evaluate user satisfaction levels with specific product attributes.

- The Analytic Hierarchy Process (AHP), developed by American management scientist Thomas L. Saaty in the 1970s [11], is a widely used decision-making method. AHP is a decision support tool used to address decision-making problems with multiple levels and criteria. Its core involves using expert subjective judgment or experiential evaluation to determine the relative importance of these criteria.
- Quality Function Deployment (QFD) was introduced by Japanese scholars Yoji Akao and Shigeru Mizuno in the 1960s [12]. QFD transforms customer requirements into specific technical characteristics, aligning them with product design, engineering, and manufacturing processes. This approach ultimately enhances customer satisfaction, increases product competitiveness in the market, shortens development cycles, and reduces development costs.

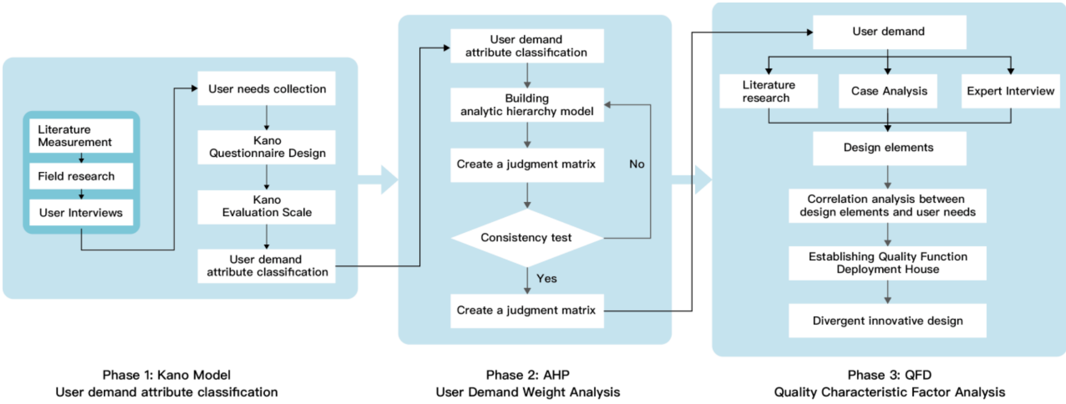

Figure 2. Kano-AHP-QFD hybrid model Research framework

As shown in Figure 2, the hybrid model combines the strengths of these three methodologies, providing a systematic framework for understanding, prioritizing, and translating user needs into sustainable product designs. It scientifically enhances the accuracy and effectiveness of addressing user needs in the design process of Thangka cultural creative products, contributing to the modernization and transmission of Thangka craftsmanship and the promotion of design practices.

3 RESEARCH METHODS

3.1 KANO-User demand acquisition and classification

First, we conducted a field investigation and research in the Tibet Autonomous Region, the main production area of Thangka, to truly understand the development status and innovative inheritance of Thangka. Secondly, during the survey process, the research team randomly selected 20 tourists and thangka collectors who had purchased thangkas for semi-structured interviews. Through coding analysis of the interview texts, they initially obtained 39 consumer demand factors. Third, due to the limited number of interview samples, we supplemented the analysis by using bibliometric methods to review relevant data on Thangka cultural creative products from Web of Science and CNKI databases. Finally, to ensure the scientific validity and rationality of the user needs, we consulted six designers specializing in intangible cultural heritage products, three professors focused on brand design, and one Thangka intangible cultural heritage creator. They reviewed, consolidated, and categorized 39 user needs. As shown in Table 1, 18 core user requirement elements were identified across four dimensions: symbolism, visual aesthetics, emotional value, and functionality.

Table 1. Initial user needs of Thangka cultural and creative products

Level 1 user needs	Level 2 user needs
A. Meaning	A1.Religious Symbols, A2.Cultural Heritage A3.Inspiration, A4.Blessing Attributes
B. Visual Perception	B1.Vivid Colors, B2.Simplicity B3.Regional Characteristics, B4.Creativity B5.Abstraction, B6.Detailing Precision B7.Visual Hierarchy
C. Emotional Experience	C1.Cultural Affiliation, C2.Cultural Depth C3.Spiritual Healing, C4.Resonance

D. Functionality	D1.Decoration, D2.Collectibility, D3.Sustainability

According to the questionnaire design principles of the KANO model, a KANO two-factor five-point Likert questionnaire scale was created. The score range is 1 to 5, with 1 representing the lowest level of importance and 5 representing the highest. Respondents were asked to rate the importance of each requirement element from both positive and negative dimensions. To obtain more accurate user needs and effective information, a combination of online and offline methods was used for the survey. A total of 97 questionnaires were distributed, with 83 returned and 76 valid responses, resulting in an effective response rate of 91.56%. Among them, 50 questionnaires were distributed online SoJump, and 47 were distributed offline in the Barkhor Street commercial district in Lhasa, Tibet. The survey primarily targeted younger and middle-aged groups, with 29.7% aged 18-30, 43.6% aged 30-40, and 17.2% aged 40-50. Respondents included university students, cultural artifact enthusiasts, art professionals, and business people, accounting for 73% of the sample. Based on the results of the dual-factor user needs survey, the K_A, K_O, K_M, K_I, K_R and K_Q values for each requirement indicator were calculated. The results are shown in Table 2.

Table 2. KANO questionnaire analysis table

User needs	K_A	K_O	K_M	K_I	K_R	K_Q	Requirement Type
A1.Religious Symbols	40.9%	5.6%	9.3%	39.5%	3.9%	0.8%	A
A2.Cultural Heritage	14.6%	12.6%	58.9%	10.2%	3.5%	0.2%	M
A3.Inspiration	20.4%	38.9%	9.7%	20.9%	8.4%	1.7%	O
A4.Blessing Attributes	18.9%	9.3%	44.7%	17.3%	9.8%	0%	M
B1.Vivid Colors	5.3%	10.7%	66.3%	11.3%	6.4%	0%	M
B2.Simplicity	16.1%	7.9%	57.7%	6.4%	11.9%	0%	M
B3.Regional Characteristics	7.6%	5.7%	53.3%	13%	19.2%	1.2%	M
B4.Creativity	57.9%	13.1%	10.5%	10.7%	7.8%	0%	A
B5.Abstraction	23.2%	39.7%	5.4%	18.4%	9.8%	3.5%	O
B6.Detailing Precision	14.7%	6.8%	58.3%	12.4%	7.8%	0%	M
B7.Visual Hierarchy	6.7%	17.1%	59.9%	11.6%	4.7%	0%	M
C1.Cultural Affiliation	39.4%	12.8%	19.1%	13.4%	13.9%	1.4%	A
C2.Cultural Depth	17.2%	37.5%	4.8%	29.9%	7.6%	3%	O
C3.Spiritual Healing	23.1%	39.2%	4.7%	20.4%	9.9%	2.7%	O
C4.Resonance	3.9%	16.9%	9.1%	58.7%	11.4%	0%	I
D1.Decoration	21.6%	45.4%	4.2%	18.2%	10.6%	0%	O
D2.Collectibility	16.1%	15.4%	51.7%	11.3%	5.5%	0%	M
D3.Sustainability	8.9%	10.2%	10.4%	59.2%	9.6%	1.7%	I

As shown in Figure 2, A2. Cultural heritage, A4. Blessing function, B1. Vibrant colors, B2. Simplicity, B3. Regional characteristics, B6. Fine details, B7. Visual layering, and D2. Collectibility as a must-have attribute (M) are the eight needs that should be prioritized in the design process. A3. Inspiration, B5. Abstraction, C3. Spiritual healing, C4. Sense of resonance, and D1. Decoration are classified as one-dimensional requirements (O). Meeting these five needs in the design will enhance user satisfaction, while failing to meet them will result in decreased satisfaction. A1. Religious symbolism, B4. Creativity, and C1. Cultural belonging are classified as attractive requirements (A). Meeting these three needs in the design of Thangka cultural creative products can significantly enhance consumer satisfaction, while failing to meet them will not decrease satisfaction.

3.2 AHP-User Demand Weight Analysis

After categorizing user needs using the Kano model, this study applies the AHP (Analytic Hierarchy Process), known for its strong logical decision-making capabilities, to scientifically analyze complex elements and calculate the weight of each user need [13]. This approach clarifies the importance of each need and highlights the key focus areas in the subsequent design process of Thangka cultural creative products. First, a hierarchical model for Thangka cultural creative products is constructed. Second, the demand elements within the criteria and sub-criteria layers are compared pairwise and scored to establish the corresponding judgment matrix. Third, the weights of the elements in the sub-criteria layer are calculated and ranked. Finally, a consistency check and analysis are performed on the target weight results.

As shown in Figure 3. Based on the preliminary classification of user need types, an AHP-based hierarchical model of user needs for Thangka cultural creative products is established. The goal layer represents the design of Thangka cultural creative products. The criteria layer consists of four dimensions of needs: symbolism A, visual aesthetics B, emotional value C, and functionality D. The sub-criteria layer is composed of 16 sub-elements, categorized as must-be requirements, one-dimensional requirements, and attractive requirements, identified through the Kano model analysis.

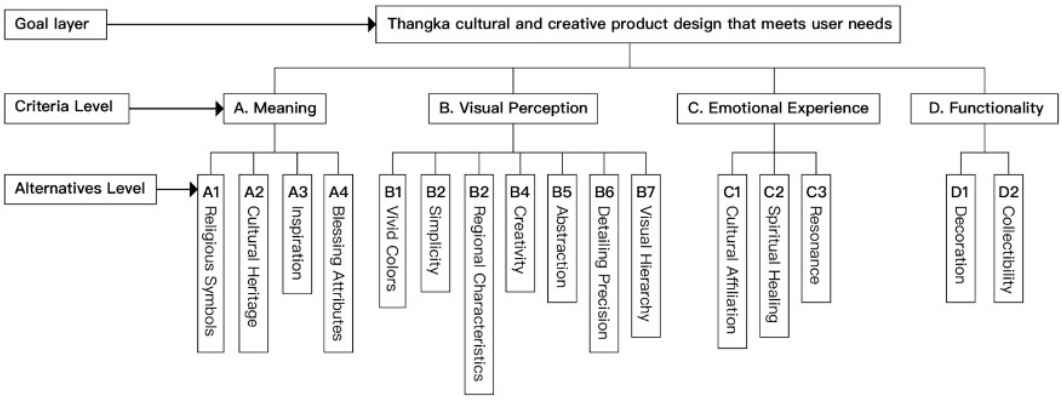

Figure 3. A Hierarchical Analysis Model for Thangka Cultural and Creative Product Design

To ensure the scientific rigor and objectivity of the user need weighting results, this study invited 15 experts in Thangka culture and related fields to participate in the survey. Experts performed pairwise comparisons and assigned scores to different levels of user needs for Thangka cultural creative products using the 1-9 scale method. The arithmetic mean of their evaluations served as the basis for calculating weights, creating the judgment matrix for each level. The geometric mean method [13] was then applied to calculate user need weights, followed by consistency checks on the judgment matrix scores. Detailed results are shown in Table 3, Table 4, etc.

Table 3. Criterion level weight

Index	A	B	C	D	Weight value	I_{CR}
A	1	0.75	1.25	1.5	0.2654	0.0008
B	1.3333	1	1.5	1.75	0.3334	
C	0.8	0.6667	1	1.25	0.2201	
D	0.6667	0.5714	0.8	1	0.1811	

Table 4. Sub-Criterion level weight

First-level indicators	Second-level indicators	Judgment Matrix							Weight value	I_{CR}
A	A1	1	1.25	2	1.75	/			0.3477	0.0011
	A2	0.8	1	1.75	1.25				0.2763	
	A3	0.5	0.571	1	0.75				0.1635	
	A4	0.571	0.8	1.333	1				0.2124	
B	B1	1	1.75	0.75	0.5	1.25	1.5	2	0.1424	0.0471
	B2	0.571	1	0.125	0.1	0.5	0.75	0.2	0.0469	
	B3	1.333	8	1	0.75	1.25	1.75	2	0.2077	
	B4	2	10	1.333	1	1.5	1.75	2	0.2558	
	B5	0.8	2	0.8	0.667	1	1.25	1.5	0.1318	
	B6	0.667	1.333	0.571	0.571	0.8	1	1.25	0.1044	
	B7	0.5	5	0.5	0.5	0.667	0.8	1	0.111	
C	C1	1	0.25	0.5	/				0.1463	0.0088
	C2	4	1	1.5					0.5317	
	C3	2	0.667	1					0.322	
D	D1	1	1.25	/					0.5556	0.0023
	D2	0.8	1						0.4444	

Finally, a consistency test is needed to determine the validity of the matrix. When $I_{CR} \leqq 0.1$, the consistency test passes, otherwise it fails. The calculation formulas are shown in formula (1) and formula (2). The results of the consistency check (I_{CI}) are as follows:

$$I_{CI} = (\lambda_{max} - n)/(n-1) \tag{1}$$

$$I_{CI} = I_{CR} / I_{RI} \tag{2}$$

The criterion layer $I_{CR}=0.0008 \leqq 0.1$, and the sub-criterion layer I_{CR} are 0.0011, 0.0471, 0.0088, and 0.0023, respectively, all less than 0.1, and the consistency test passes.

Table 5. Relative weight calculation ranking table

Relative weight ranking	A1	A2	A3	A4	B1	B2	B3	B4
	3	6	12	9	10	16	8	4
	0.0923	0.733	0.0434	0.0564	0.0475	0.0156	0.0693	0.0853
	B5	B6	B7	C1	C2	C3	D1	D2
	11	14	13	15	1	7	2	5
	0.0439	0.0348	0.037	0.0322	0.117	0.0709	0.1006	0.0805

The results are shown in Table 5. Among the four criteria layer indicators, visual needs (B) have the highest weight. In the sub-criteria layer, the relative weight of demand elements from highest to lowest is as follows: C2 Cultural connotation, D1 Decoration, A1 Religious symbolism, B4 Creativity, D2 Collectibility, A2 Cultural heritage, C3 Spiritual healing, B3 Regional characteristics, A4 Blessing function, B1 Vibrant colors, B5 Abstraction, A3 Inspiration, B7 Visual layering, B6 Detail refinement, C1 Cultural belonging, and B2 Simplicity.

3.3 QFD-User Requirements Design Factor Mapping

QFD (Quality Function Deployment) is an effective method for translating user needs into design elements. By quantitatively analyzing the relationship between user needs and design elements, QFD outputs the weight of design elements. In this study, following the AHP (Analytic Hierarchy Process), QFD is applied to construct a relationship matrix between user needs and design elements using the House of Quality [14]. This process clarifies the weight of each design element, leading to the identification of the final design elements. It provides evaluative factors for optimizing the design scheme and offers more precise technical support and constraint guidance for the design process [15].

Table 6. Mapping results of user requirements and design elements.

User needs A	Design elements D
C2. Cultural Depth	D1. Swastikas, auspicious clouds, and eight auspicious symbols
D1. Decoration	D2. Floral patterns, spiral cloud patterns, and golden thread depictions
A1. Religious Symbols	D3. Buddhist symbols such as the Dharma wheel, lotus, Buddha hand gestures, and protective deities
B4. Creativity	D4. Traditional artistic techniques combined with modern methods
D2. Collectibility	D5. High-quality textiles and mineral materials
A2. Cultural Heritage	D6. Hand-painting techniques with intricate details and layered textures
C3. Spiritual Healing	D7. Symmetrical compositions and tranquil scenes
B3. Regional Characteristics	D8. Natural landscapes and ethnic clothing
A4. Blessing Attributes	D9. Design of auspicious symbols
B1. Vivid Colors	D10. Red and gold, blue and green color combinations
B5.Abstraction	D11. Abstract geometric patterns
A3. Inspiration	D12. Buddhist scenes and stories
B7. Visual Hierarchy	D13. Visual layering effect
B6. Detailing Precision	D14. Delicate brushwork and complex patterns
C1. Cultural Affiliation	D15. Traditional Tibetan symbols

B2. Simplicity	D16. Simple and concise patterns

As shown in Table 6. First, by studying the cultural background of Thangka and related literature on cultural creative products, and analyzing successful cases of Thangka cultural creative products, the initial user needs were translated into functional requirements. Nine experts were then invited to provide feedback on the preliminary design parameters, including six cultural creative product designers and three professors specializing in product design and visual communication. Through three rounds of summarizing, revising, and re-evaluating, the mapping from user needs to design elements D was finalized.

User		Design Elements															
Needs	Weight	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16
C2	0.117	★	○	★	■	●	○	○	○	○	○	○	■	○	○	★	○
D1	0.1006	★	●	○	○	○	○	○	○	■	○	○	○	○	○	■	●
A1	0.0923	●	●	○	○	○	○	○	○	●	○	○	★	○	○	★	○
B4	0.0853	○	○	○	○	○	★	★	○	○	○	★	○	■	○	○	■
D2	0.0805	○	○	○	○	★	○	○	○	■	○	○	○	○	○	○	○
A2	0.0733	○	★	★	○	○	○	○	■	★	○	○	○	○	○	★	○
C3	0.0709	○	○	○	○	○	○	★	○	○	○	○	★	○	○	○	○
B3	0.0693	●	●	●	★	○	○	○	●	★	○	○	○	○	●	○	○
A4	0.0564	○	■	●	■	○	○	○	○	★	○	○	○	○	○	○	○
B1	0.0475	○	○	○	○	○	○	○	○	○	■	○	○	★	○	○	○
B5	0.0439	○	○	○	○	○	○	○	●	○	○	★	○	○	○	○	★
A3	0.0434	■	●	■	○	○	○	○	○	★	○	○	●	○	○	○	○
B7	0.037	○	○	○	○	○	■	○	○	○	○	★	○	★	■	○	○
B6	0.0348	○	○	○	●	○	★	○	○	○	○	○	○	■	★	○	○
C1	0.0322	★	■	★	○	○	○	○	○	○	○	○	●	○	○	★	○
B2	0.0156	○	○	○	○	○	■	○	○	○	○	○	○	●	○	○	★
SUM		0.5884	0.5219	0.5115	0.3468	0.2377	0.2432	0.2343	0.2011	0.6732	0.057	0.2498	0.4604	0.2871	0.1659	0.5929	0.2923
Ranking		3	4	5	7	12	11	13	14	1	16	10	6	9	15	2	8

Figure 4. Quality house of QFD

As shown in Figure 4, constructing the House of Quality is central to the Quality Function Deployment (QFD) process. Using the Kano model and Analytic Hierarchy Process (AHP), user need elements and design parameters are established to form the House of Quality. User need weights are placed in the left wall, while design elements form the ceiling. Relationships between user needs and design elements are indicated by symbols ★, ■, and ●, representing weights of 1.5, 1.2, and 1, respectively. Final design element weights are calculated by summing the total weighted needs under each design element, adjusted by the relationship weight. These weights are normalized and ranked by importance. Based on Figure 4, the ranking order of design elements is: D8 > D15 > D1 > D2 > D3 > D12 > D4 > D16 > D13 > D11 > D6 > D5 > D7 > D14 > D10. Key design elements—such as auspicious symbols, traditional Tibetan motifs, cloud patterns, floral designs, Buddhist narratives, and modern interpretations—were selected for further development in sustainable Thangka cultural product design.

4 THANGKA CULTURAL CREATIVE PRODUCT DESIGN PRACTICE

4.1 Thangka cultural and creative product design practice

This chapter provides a detailed overview of the innovative design practices of Shu embroidery based on the Kano-AHP-QFD hybrid model. The Thangka cultural products are ultimately created as "Puzzle Magic Cube Designs" and "Collectible Stamp Designs." Firstly, the Thangka Magic Cube is designed in a 3x3 specification, where each face's patterns and graphic elements are thoroughly contemplated. The design incorporates 20 classic "Tibetan traditional symbols, auspicious clouds, spiral cloud patterns, and floral motifs [16]" By simplifying graphics, enhancing visual hierarchy, and abstracting patterns into geometric forms, the design aims to stimulate youth interest in the preservation of intangible cultural heritage through playfulness and interactivity. By rotating the magic cube, young individuals can appreciate the aesthetic allure of Thangka art while inadvertently deepening their understanding of Thangka culture. As shown in Figure 5. Additionally, the design of Thangka postcards has been selected based on the preferences and highest acceptance rates among non-local tourists. The front of the postcards features classic Thangka patterns, including Buddhist figures, mandalas, and natural landscapes.

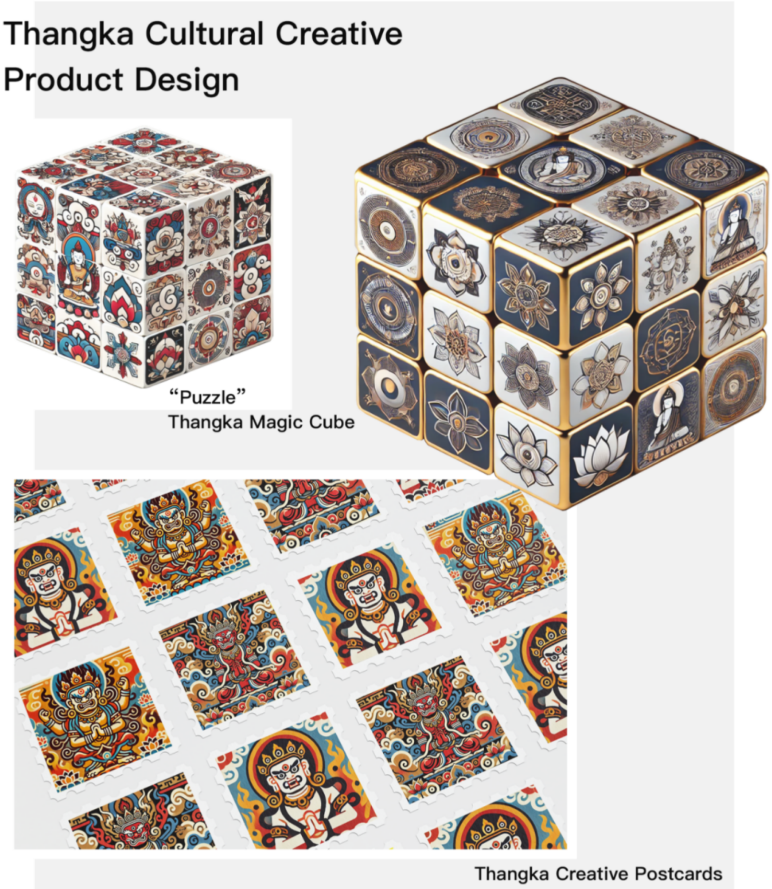

Figure 5. Thangka cultural creative product design

4.2 Design Evaluation

To evaluate whether the conceptual design of the Thangka cultural creative products effectively meets user needs, this study invited intangible cultural heritage inheritors and Thangka enthusiasts who had previously participated in user surveys. Using the TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution), a comprehensive analysis and evaluation were conducted on Thangka-themed cultural products available on the market, including a Thangka pillow (Sample 1), Thangka tote bag (Sample 2), Thangka postcards (Sample 3), and the proposed conceptual design of the Thangka product. As shown in Table 7.

Table 7. Thangka cultural and creative concept design plan and sample analysis.

Thangka Conceptual Design	Thangka Sample 1	Thangka Sample 2	Thangka Sample 3
			

The evaluation criteria consist of 16 user requirements that were filtered using the KANO model and AHP (Analytic Hierarchy Process). A total of 11 participants from the previous user survey were invited to rate each design based on the Thangka cultural creative product user requirement index system. The ratings were conducted using a 7-point Likert scale, and the raw scoring data for the evaluation criteria are shown in Table 8.

Table 8. Initial evaluation matrix.

Design plan	User demand evaluation indicators															
	A1	A2	A3	A4	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	D1	D2
Concept plan	5.2	4.4	4.9	5.1	5.3	4.7	5	5	5.3	5.5	4.6	4.9	5.8	4.7	5.5	5
Sample 1	2.9	3	2.9	3.5	3.3	4.1	3	2.5	3	3.1	3.4	3.3	2.5	3.4	3.1	2.8
Sample 2	3.7	3.9	4.1	3.2	3.7	4.1	3	3.4	3.7	3.3	3.9	4	2.9	2.6	3.8	2.7
Sample 3	2.5	3.7	2.1	3	2.9	2.7	2.4	2.8	2.9	3.3	2.8	2.6	2.7	3.4	3	2.5

As all evaluation criteria are maximization indicators, no positive transformation is needed. After performing dimensionless normalization on the criteria, the initial evaluation data were obtained. These data were then weighted using the relative weights from Table 6, resulting in the calculation of weighted standardized data, as shown in Table 9.

Table 9. Weighted standardized evaluation matrix.

Design plan	Evaluation indicators							
	A1	A2	A3	A4	B1	B2	B3	B4
	B5	B6	B7	C1	C2	C3	D1	D2
Concept plan	0.064	0.043	0.029	0.038	0.032	0.009	0.05	0.06
	0.03	0.024	0.023	0.02	0.091	0.046	0.07	0.059
Sample 1	0.036	0.029	0.017	0.026	0.02	0.008	0.03	0.03
	0.017	0.014	0.017	0.014	0.039	0.033	0.039	0.033
Sample 2	0.045	0.038	0.024	0.029	0.022	0.008	0.03	0.04
	0.021	0.015	0.019	0.017	0.045	0.025	0.048	0.031
Sample 3	0.031	0.036	0.012	0.022	0.018	0.005	0.029	0.036
	0.017	0.015	0.014	0.011	0.042	0.033	0.038	0.03

Table 10. Euclidean distance and relative post progress.

Design plan	S_i^+	S_i^-	C_i	Ranking
Concept design	0	0.095	1	1
Sample 1	0.087	0.014	0.141	3
Sample 2	0.073	0.029	0.286	2
Sample 3	0.09	0.011	0.113	4

As shown in Table 10. Based on the closeness coefficients of the solutions, the ranking is as follows: conceptual design > Sample 2(0.286) > Sample 1(0.141) > Sample 3(0.113). This indicates that the conceptual design of the Thangka cultural creative products, guided by the KANO, AHP, and QFD hybrid model, demonstrates higher satisfaction and overall acceptance, suggesting that it meets user needs to a considerable extent.

5 CONCLUSION

In terms of research conclusions, this study has innovatively applied the KANO-AHP-QFD hybrid model to the design of Thangka cultural and creative products, offering a scientific approach to capture user needs and translate them into design elements. This model significantly enhances precision in designing Thangka cultural products and provides a novel pathway for the development of cultural and creative products. Additionally, the research enriches approaches to modernizing intangible cultural heritage. Through design practices such as the Thangka cube and postcards, this study demonstrates how modern design techniques can be employed to make traditional art forms more appealing, providing direction for innovation in other intangible cultural heritage products. Lastly, an adaptable model framework is proposed: while focused on Thangka product development, the KANO-AHP-QFD hybrid model exhibits broad applicability, providing a valuable reference framework for other intangible cultural heritage products and demonstrating the model’s flexibility in addressing user needs across diverse cultural contexts.

Future research could further expand and optimize this model’s application across several areas. Firstly, the model’s applicability across other forms of intangible cultural heritage could be explored to verify its generalizability and adaptability. Secondly, integrating additional methodological tools, such as text mining, deep learning, and real-time feedback systems, could enhance the model’s scientific rigor, accuracy, and dynamism. Additionally, design practices could be extended to include digital products and household items, thus attracting a broader audience. Finally, user feedback and satisfaction data from the actual market could validate the model’s effectiveness, establishing a feedback-driven, iterative design process to continuously optimize cultural and creative product design and user experience.

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THE CONSTRUCTION AND DESIGN OF A TRADITIONAL CERAMIC CULTURE DATABASE ALONG THE SILK ROAD

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ABSTRACT
Based on the contemporary development of design innovation and the demand for the preservation of traditional culture, the integration of culture and technology, digital media, and art has become a significant interdisciplinary research direction. This paper focuses on ceramic artifacts from the northwestern region of China along the Silk Road. Using data collection and re-measurement of these artifacts, we completed the systematic organization, digitization, and visualization of traditional culture. Additionally, we analyzed the contemporary needs for design innovation and subsequently constructed a database for the innovative design of ceramic culture. This database offers design materials and innovative insights for the preservation of existing traditional ceramic culture along the Silk Road and for future design innovations based on this heritage.

Keywords: Industrial Design, Silk Road, Ceramic Culture, Cultural Digitization, Design Innovation, Database

INTRODUCTION

For millennia, the civilizations along the Silk Road have been intertwined, creating a unique cultural landscape that has significantly influenced the development of the regions and countries along its path [1]. Currently, research on the Silk Road, particularly within China, benefits from abundant resources, such as artifacts, literature, and well-documented field investigations, particularly in the realms of culture, art, and folklore.

Among these, ceramics—one of humanity's greatest inventions—have played a vital role in both production and daily life since their inception. Ceramic vessels, initially designed to meet functional needs, reflect various aspects of life, including folk customs, production techniques, culinary traditions, lifestyle, environmental adaptation, and aesthetic preferences.

1 OVERVIEW OF TRADITIONAL CERAMIC CULTURE ALONG THE SILK ROAD

Since ancient times, the Silk Road has served as a crucial bridge for cultural exchange between Eastern and Western civilizations. The cultural interactions along the Silk Road have continually fostered the development of diverse regional cultures. The selection of research areas along the Silk Road generally corresponds to the regions traversed by the traditional overland routes. Within China, this primarily includes the provinces and regions of Shaanxi, Inner Mongolia, Gansu, Ningxia, Qinghai, and Xinjiang. Internationally, it extends to include the five Central Asian countries, as well as regions such as Russia, Ukraine, and various countries in Western Asia. This study is based on the overland Silk Road regions within China, with some expansions into additional areas.

Research on the ceramic culture along the Silk Road currently encompasses several academic perspectives [2]. From an art historical standpoint, studies analyze the craftsmanship, forms, decorations, and aesthetic design concepts associated with these artifacts. Archaeologically, the research has developed mature classifications for these artifacts and examined their current state of preservation. Historically, there is an exploration of these objects as practical items used in daily life, with a comprehensive analysis of their social context. In the field of design studies, however, it is crucial to consider the historical evolution of individual artifacts in conjunction with the comprehensive factors

that influence their design. Such a unified approach enables a deeper understanding of both the material and spiritual cultural dimensions, facilitating effective design development.
Thus, the study of ceramic artifact evolution is essentially an exploration of the processes through which objects are culturally crafted, form distinct cultural identities, engage in cultural exchanges, and undergo self-evolution [3]. It also involves a holistic examination of related aspects such as dining customs, modes of transmission, interaction patterns, and the social and spiritual aspects of daily life.

2 CURRENT STATUS OF DESIGN RESEARCH ON TRADITIONAL CERAMIC CULTURE INNOVATION

With the rise of the cultural and creative industries, design innovation in traditional craftsmanship is continually advancing. Theoretically, scholars focus on extracting and reconstructing elements from ceramic artifacts, such as decorative patterns[4]and shapes[5], for application in modern design. They also explore ceramics-related cultural product design methodologies based on theories like Kansei Engineering[6]and user experience[7], addressing the emotional needs of users. Practically, researchers emphasize integrating elements with regional cultural characteristics[8]and ethnic cultural symbols[9]in product design. They also leverage digital tools, such as mobile applications and digital exhibition halls, to introduce craftsmanship[10], display[11], and encourage public interaction with collections[12].
The existing body of research comprehensively demonstrates the interdisciplinary inclusiveness of design studies, adeptly using emerging research tools and advanced methodologies to facilitate multi-level, multi-perspective, and holistic design innovation transformations[13]. However, there are still some notable challenges:

1) Current ceramic artifact design innovations often focus on visual design elements (such as shapes, patterns, and colors) gathered from archaeological literature. This approach typically lacks a comprehensive consideration of factors such as typological accuracy, cultural authenticity, holistic data analysis of artifacts, and context-specific usage. As a result, design practices predominantly emphasize individual artifact design, with less emphasis on the lifestyles and artifact-making philosophies that the objects reflect.
2) Due to the lack of quantitative standards addressing the differences between professional and general public needs in ceramic artifact design, there is often a mismatch between supply and demand. Many cultural products fall short of meeting the personalized needs of contemporary users, leading to limited industrial transformation of cultural heritage resources.

Therefore, establishing a database for ceramic culture design innovation bridges the gap between archaeology and design. This enables the sharing of research data, resources, and findings while facilitating direct practical applications. Additionally, by leveraging quantitative data on design elements, this database can enhance the understanding of distinctions between cultural disseminators and consumers, ultimately supporting the consumer-driven transformation of design.

3 CONSTRUCTION IDEAS FOR A CERAMIC CULTURE DESIGN INNOVATION DATABASE

3.1 Overall Construction Framework for the Ceramic Culture Design Innovation Database

The Ceramic Culture Design Innovation Database includes both original relic data and design innovation materials. The original relic data encompasses the classification, sequencing, and analysis of relationships between different types of artifacts. The design innovation materials are derived from both the public and expert communities, where qualitative perceptions are transformed into more precise data through data filtering and processing (see Figure 1 for the framework).

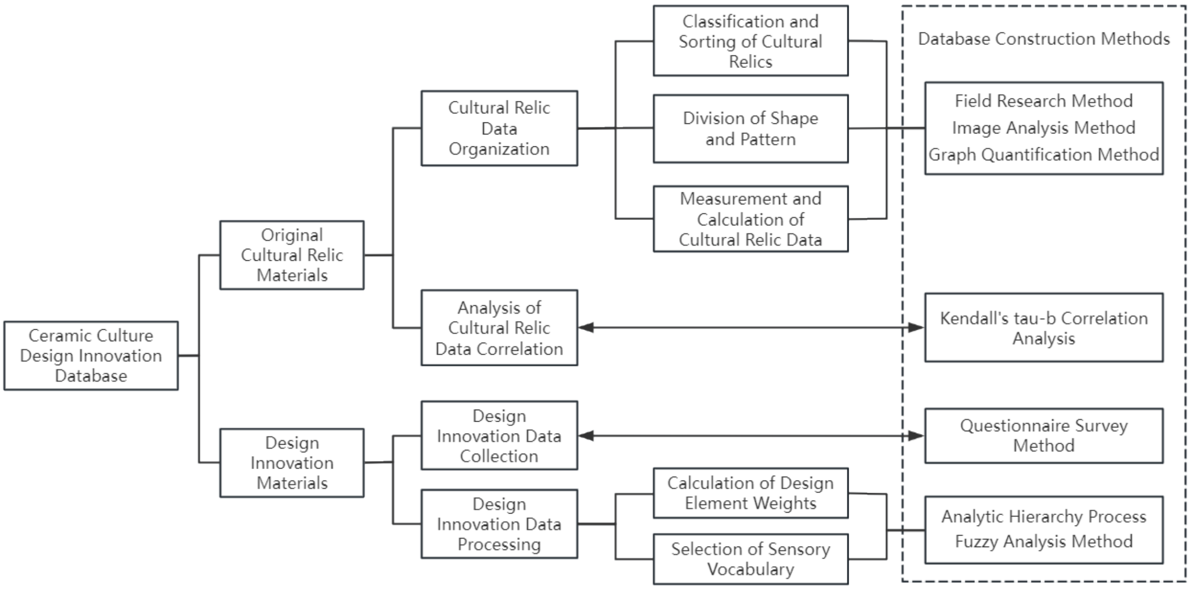


Figure 1 Ceramic Culture Design Innovation Database Structure

3.2 Original Relic Materials

3.2.1 Cataloging of Cultural Relics Materials

(1) Classification and Arrangement of Cultural Relics and Style Division

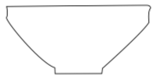
Firstly, the classification, ordering, and pattern division of artifacts are based on established archaeological typology, using the typographic quantification method in conjunction with design requirements. The typographic quantification method is rooted in archaeological typology, categorizing samples into distinct types, each characterized by features that distinguish it from other types. For a type to be clearly differentiated, it must be exclusively defined, ensuring it can be systematically separated from others[14]. This method serves as a fundamental approach for collecting data on ceramic dining vessels along the Silk Road, allowing a clear understanding of both the functional types of ceramic vessels and the main types suited to specific functions.

Based on this method, the classification of Silk Road ceramic vessels is organized according to functional characteristics and the primary interaction interfaces relevant to design use (for instance, cups and bowls are categorized by rim shape; large containers by their body shape; and pitchers by their handle design). Ultimately, the database of ceramic artifact data relies on a scientific archaeological classification system, integrating functional use and interaction points during use, aligning archaeological classifications with design application needs to emphasize the design focus of each artifact.

Secondly, using the typographic quantification method and considering the quantity of each type of artifact, the classification and ordering of vessel types are completed. The vessel types include twelve categories: chicken-leg vase, ewer, bowl, handle cup, tea cup, plate, cockscomb pot, phoenix-head pot, tied jar, jade pot, high-foot cup, and flat pot. Secondly, the classification of styles is carried out based on the changes in the functional use and usage patterns of each vessel type, as shown in Table 1.

Table 1 Classification and Categorization of Ceramic Relics (Partial)

Type	Quantity	Subcategory	Illustration	
Tea Cups	60	Narrow-Mouthed		

		Wide-Mouthed		
		Constricted-Mouthed		
Stem Cups	63	Flared-mouth style		
		Open-mouth style		
		Straight-mouth style		
Ewers	117	Short straight-spout style with a bulging belly		
		Long curved spout style with a bulging belly		
		Cylindrical body with a short straight spout		
		Flat, rounded body with a long curved spout		
		Gourd-shaped body with a short straight spout		

In the Spring and Autumn Period, tea bowls appeared as vessels for eating, as introduced in the *Comprehensive Dictionary of Ancient Chinese Vessels*. The early bowls from the Spring and Autumn and early Warring States periods were made of bronze or gold, had shallow bodies, three feet, and lids, resembling a basin. During the Three Kingdoms, Jin, and Northern and Southern Dynasties periods, the custom of tea drinking had not yet spread nationwide, with the northern regions primarily consuming "fermented milk." At this time, tea utensils were not distinctly separate from wine vessels, and wide-mouthed bowls were commonly shared for both purposes. Initially, tea bowls appeared as food vessels, made of bronze or gold, and later evolved into an elliptical shape. During the Warring States, Qin, and Han periods, some bowls were made of lacquer. By the Eastern Han dynasty, porcelain tea bowls were produced, which subsequently became mainstream, serving as essential vessels for both tea and wine.

The ceramic tea bowls unearthed along the Silk Road are mainly concentrated from the Sui, Tang, and Song dynasties, with distinct changes in the shape and form across these three periods. Tang Dynasty tea bowls were more open and shallow compared to those from the Song Dynasty. Their basic features included a wide mouth, slanting straight walls, and a jade bi-disc base. The shape of the tea bowl was larger than the tea saucer and often featured lotus petal or lotus flower designs. The saucer's rim, typically lower, was curled into a lotus leaf shape. During the Song Dynasty, tea bowls came in many styles, including those with constricted or flared mouths and deeper bowls, developed for the practices of tea fighting and tea whisking.

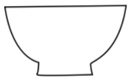
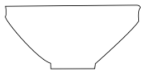
(2) Measurement and Calculation of Cultural Relic Data

In the process of data measurement, the 12 types of cultural relics include data on height, center of gravity, volume, and complexity of form. Additionally, depending on the specific design components of each artifact, further measurements are taken. These include the spout angle and handle interior space for ewers; the diameter of the body, base, and mouth for chicken-leg vases, flat pots, phoenix-head pots, jade pots, and tied jars; the hole types and handle interior space for cockscomb pots; the base and mouth diameters for bowls and plates; the handle interior space, base, and mouth diameters for handled cups; the ratio of bowl to saucer for tea bowls; and the ratio of the foot to the overall height and the rim inclination for high-footed cups.

The complexity of form is assessed based on image elements drawn from quantitative image mapping, which classifies the complexity into four levels (ranging from level 1 to level 4, from least to most complex). For example, the data measurements for tea bowls include height, center of gravity, volume, and complexity of form (some relic data are shown in Table 2).

Table 2 Data Sorting of Tea Cups (Partial)

Subcategory		Images and outlines	Data			
			Height (cm)	Center of Gravity (cm)	Volume (cm^3)	Shape complexity
Narrow-Mouthed	Slanting curved body style		4.3	2.68	149.7	2
			5.7	3.16	398.1	1
	Slanting straight body style		1.9	0.90	21.6	2
Wide-Mouthed	Slanting straight body style		5.1	2.83	303.6	2
	Slanting curved		6.4	3.76	966.7	3

body style			4.6	2.70	144.3	2
Constricted -Mouthed			8	4.44	764.2	3

3.2.2 Correlation Analysis of Cultural Relic Data

Kendall's tau-b correlation analysis is used for the correlation analysis of artifact data. Kendall's tau-b is a method suitable for analyzing the correlation between pairs of ordinal variables without requiring them to follow a normal distribution. When all variables are ordinal, Kendall's tau-b coefficient can be applied to assess correlations. This method is used to analyze the correlations between various components and measurements of ceramic artifacts, such as volume, total height and center of gravity, total height and shoulder height, total height and maximum belly width, total height and rim circumference, handle area, spout inclination, usage method, and shape complexity. By comparing these data points, a correlation heat map can reveal the relational strength among design elements in each component, allowing for a rapid understanding of key design features across different artifacts and the relative importance of components in various functional items.

For example, a correlation analysis was conducted on a sample of 60 tea cups (48 from the Song Dynasty, 6 from the Liao Dynasty, and 6 from the Jin Dynasty). Measurements such as height, diameter, and base diameter were taken, along with calculations for the center of gravity height from the ground and the volume of each cup. The 60 artifacts were arranged by dynasty and height for analysis. Using the data from these tea cups, a comprehensive analysis was performed across all types, resulting in a correlation coefficient table, as shown in Table 3.

Table 3 Kendall's Tau-b Correlation Coefficient Table for the Tea Bowls

	Height	Diameter (specifically referring to the opening)	Base Diameter	Center of Gravity (Height Above Ground)	Volume	Shape Complexity
Height	1(0.000***)	0.611(0.000***)	0.298(0.001***)	0.846(0.000***)	0.735(0.000***)	0.138(0.166)
Diameter (specifically referring to the opening)	0.611(0.000***)	1(0.000***)	0.498(0.000***)	0.542(0.000***)	0.845(0.000***)	0.229(0.021**)
Base Diameter	0.298(0.001***)	0.498(0.000***)	1(0.000***)	0.259(0.004***)	0.503(0.000***)	0.033(0.739)
Center of Gravity (Height Above Ground)	0.846(0.000***)	0.542(0.000***)	0.259(0.004***)	1(0.000***)	0.656(0.000***)	0.143(0.152)
Volume	0.735(0.000***)	0.845(0.000***)	0.503(0.000***)	0.656(0.000***)	1(0.000***)	0.167(0.090*)
Shape Complexity	0.138(0.166)	0.229(0.021**)	0.033(0.739)	-0.143(0.152)	0.167(0.090*)	1(0.000***)

Note: ***, **, and * correspond to significance levels of 1%, 5%, and 10%, respectively.

In the correlation coefficient table, results marked with ***, **, and * indicate significance. A significant correlation between two variables suggests a relationship, while a lack of significance indicates no correlation. Specifically, ***, **, and * correspond to significance levels of 1%, 5%, and 10%, respectively; a higher significance level indicates a stronger correlation.
According to the correlation coefficient table for the 60 tea bowls (Table 3), the relationships among the tea bowl characteristics are ranked from high to low in terms of correlation strength as follows: height and center of gravity, mouth diameter and volume, height and volume, volume and center of gravity, height and mouth diameter, mouth diameter and center of gravity, foot diameter and volume, mouth diameter and foot diameter, height and foot diameter, foot diameter and center of gravity, and mouth diameter and complexity of form. There is no correlation between the complexity of form and the relationships involving height, foot diameter, center of gravity, and volume.
Discussion:

1. Among the tea bowls, the elements of height, mouth diameter, foot diameter, center of gravity, and volume are closely related and should be considered comprehensively. The primary consideration should be the relationship between height and center of gravity.
2. The factors that show no correlation among the tea bowls are the relationships between the complexity of form and height, foot diameter, center of gravity, and volume. These four relationships can serve as a starting point for seeking design innovations.

3.3 Design Innovation Materials

3.3.1 Data Collection for Design Innovation

Firstly, the Analytic Hierarchy Process (AHP) is used to collect data for design innovation. AHP is a decision-making method that combines qualitative and quantitative analysis to solve complex multi-objective problems. This method is applied to analyze design elements with the goal of meeting public needs and involves pairwise comparisons to determine the relative importance of each design element, ultimately establishing weight indicators for each element of the artifact. For example, by constructing six design evaluation elements—characteristics, function, shape, color, cultural type, and pattern—and conducting pairwise comparisons, the elements are ranked according to their weights. This provides insights into the perceived importance of each design element among the public, guiding designers in their design innovation efforts.
For instance, a questionnaire survey is conducted among the public and experts regarding ceramic artifacts, covering information on six design elements of the artifacts as well as emotional perceptions toward them. The six design elements involve breaking down each artifact into the following components: functionality (whether the artifact has practical use), characteristics (whether the artifact possesses distinctive features in certain aspects), cultural type (including Central Plains culture, ethnic minority culture, foreign culture, and multiculturalism), shape (the external contour and form of the artifact), color (glaze colors such as white, celadon, black, floral, brown, etc.), and patterns (including geometric patterns, floral patterns, animal motifs, and narrative patterns). Each element will be subject to specific questions. Regarding subjective perception, respondents will be provided with descriptive terms (e.g., generous, simple, luxurious, exquisite, minimalist, practical, etc.) to choose from, and they can also fill in other terms they find appropriate. Taking the Tang Dynasty "Dazhong Yuan Nian" engraved floral ewer as an example, a total of 7 questions will be posed regarding this artifact for both the general public and experts, as shown in Table 4.

Table 4 Questionnaire for the Tang Dynasty "Dazhong Yuan Nian" Inscribed Floral Pattern Teapot

Type	Question	Personal Status				
		Completely unaware/ Completely lacks characteristics/ Completely unacceptable	Not very sure/ No characteristics/ Not very acceptable	Have seen/ Aver age	Aware/ Has some characteristics / It's okay	Familiar/ Very distinctive / Relatively like

	（1）Do you know what the specific function is? （2）Does it have certain characteristics? （3）Are you aware of which cultural type it belongs to? （4）Do you like this shape? （5）Do you like this color? （6）Do you like this pattern?	/
	（7）Which words do you think can describe it?	Luxurious/ Opulent/ Hefty/ Practical/ Elegant/Attractive/ Delicate/ Simple/ Innovative/ Interesting/ Durable/ Rugged/ Minimalist/ Compact

After distributing and collecting the questionnaires, a total of 89 responses were gathered for this artifact. Three invalid questionnaires, which were completed in an excessively short time, were excluded, resulting in 86 valid questionnaires.

3.3.2 Processing of Design Innovation Data

(1) Calculation of Design Element Weights

First, the survey results for the six design elements were analyzed using the Analytic Hierarchy Process (AHP) to perform pairwise comparisons among the elements, ultimately deriving the weight of each element. The specific steps are as follows: First, the responses from the survey participants were converted into a Likert scale format[15]to facilitate subsequent calculations. Next, for a selected artifact, the answers from one respondent were converted into the Likert scale, and the values for each element were compared pairwise, resulting in a judgment matrix. Subsequently, the weight values for each indicator were calculated using the square root method based on the constructed judgment matrix. After that, the consistency of the judgment matrix was tested to determine the validity of the results. Finally, the results were presented in the form of a radar chart to analyze the interrelationships among the various elements.

Using the aforementioned ewer as an example, the answers of 15 respondents to the six questions regarding functionality, characteristics, cultural type, shape, color, and patterns were converted into a Likert scale, as shown in Table 5. Based on the results presented in the Likert scale, the answers were transformed into 15 judgment matrices, one of which is shown in Table 6.

Table 5 Likert Scale for the Questionnaire on the Tang Dynasty "Dazhong Yuan Nian" Inscribed Floral Pattern Teapot

Serial Number	Function	Characteristics	Cultural Type	Shape	Color	Pattern
1	9	7	9	7	7	5
2	1	5	1	3	3	5
3	5	5	3	5	5	7
4	5	5	5	5	5	5

5	5	5	5	7	5	5
6	5	5	3	7	7	7
7	3	5	5	7	5	5
8	1	7	1	7	9	7
9	7	7	1	3	7	9
10	3	5	3	7	7	7
11	3	7	3	5	7	5
12	7	7	7	7	7	7
13	9	7	3	7	5	9
14	5	5	5	5	7	9
15	7	7	5	9	7	9

Table 6 Evaluation Matrix for the Six Key Elements (Partial)

Index	Function	Characteristics	Cultural Type	Shape	Color	Pattern
Function	1	9/7	1	9/7	9/7	9/5
Characteristics	7/9	1	7/9	1	1	7/5
Cultural Type	1	9/7	1	9/7	9/7	9/5
Shape	7/9	1	7/9	1	1	7/5
Color	7/9	1	7/9	1	1	7/5
Pattern	5/9	5/7	5/9	5/7	5/7	1

Based on the judgment matrix, the weight characteristic vector was further derived. The approximate value of the eigenvector of the judgment matrix was calculated using the square root method, denoted as ω, with calculations shown in Equation (1). After obtaining the average value of the 15 eigenvectors, the average eigenvector was then used to calculate the weight values, yielding the average weights for the six main elements of the artifact, as indicated in Equation (2). Finally, a radar chart was created based on the weight calculation results, as shown in Table 7. The distribution of the radar chart indicates that for the Tang Dynasty "Dazhong Yuan Nian" engraved floral ewer, color, shape, pattern, and characteristics are the more important design elements.

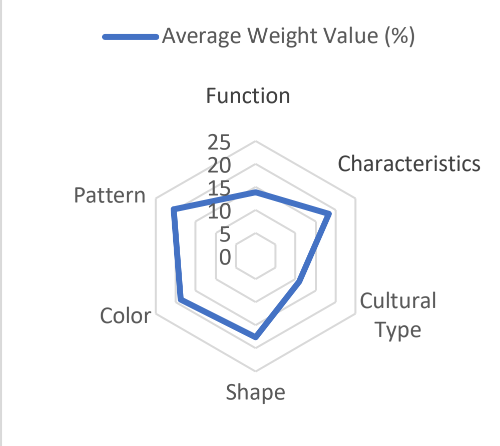
$$\bar{\omega}_i = \sqrt[m]{\prod_{j=1}^{m} a_{ij}} \tag{1}$$

$$\omega_i = \frac{\bar{\omega}_i}{\sum_{j=1}^{m} \bar{\omega}_j} \tag{2}$$

Table 7 Calculation Results of Average Weight Values for the Tang Dynasty "Dazhong Yuan Nian" Inscribed Floral Pattern Teapot

Index	Average Eigenvector	Average Weight Value (%)	Radar Chart Drawing

Function	0.9	13.89
Characteristics	1.19	18.33
Cultural Type	0.71	10.94
Shape	1.14	17.56
Color	1.22	18.79
Pattern	1.33	20.49



After the weight calculations were completed, a consistency test was conducted on the constructed judgment matrix to ensure its accuracy. This involved solving for the maximum eigenvalue and the consistency index (CI) to calculate the consistency ratio (CR), thereby verifying its consistency, as shown in Equations (3)-(5). The calculation results are presented in Table 8.

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(AW)_i}{W_i} \tag{3}$$

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{4}$$

$$CR = \frac{CI}{RI} \tag{5}$$

Table 8 Consistency Test Results for the Tang Dynasty "Dazhong Yuan Nian" Inscribed Floral Pattern Teapot

Maximum Eigenvalue	CI Value	RI Value	CR Value	Consistency Test Results
6	0	1.25	0	Pass

The calculation results show that the maximum eigenvalue is 6.0. According to the RI table, the corresponding RI value is 1.25. Therefore, the consistency ratio (CR) is calculated as CR=CI/RI=0.0 ＜0.1, indicating that the consistency test has been passed successfully.

（2）Emotional Word Selection

Based on the frequency of responses in the questionnaire, the three most commonly selected emotional adjectives were used to represent the artifact's general design style. Based on the concentration or dispersion of the selected vocabulary, the typicality of its design style can be assessed. For example, analyzing the questionnaire responses regarding the aforementioned teapot, the three most frequent terms revealed that the public's affective evaluation of this teapot is concentrated around "simple," "generous," and "practical," as illustrated in Figure 2.

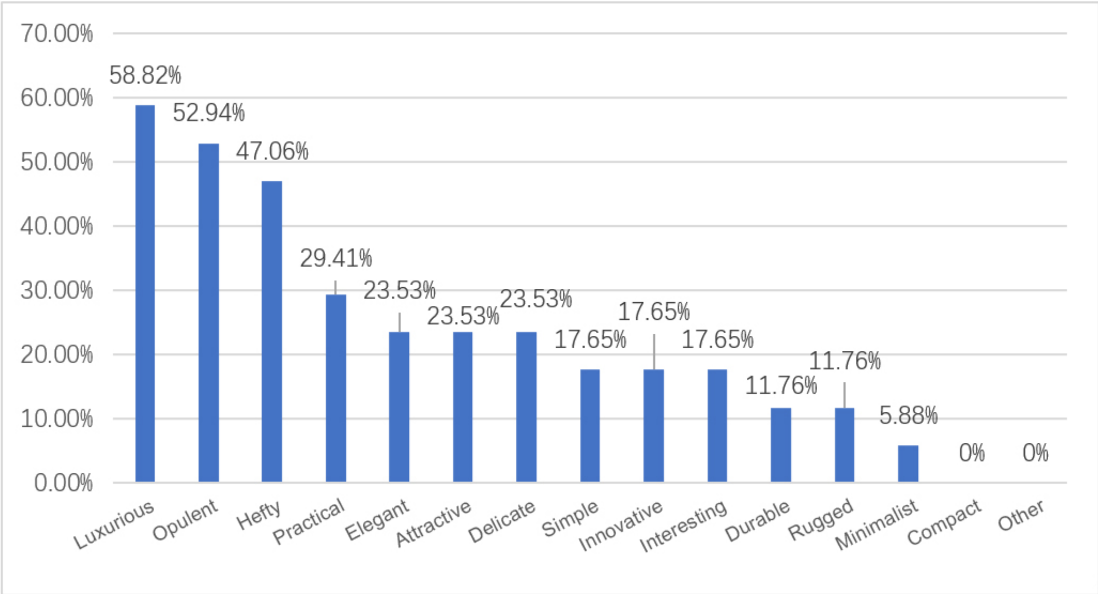


Figure 2: Questionnaire Survey Results for the Tang Dynasty "Dazhong Yuan Nian" Inscribed Floral Pattern Teapot

4 CERAMIC CULTURAL INNOVATION DESIGN STRATEGIES BASED ON DATABASES

4.1 Design Innovation References Based on Original Materials of Cultural Relics

First, the types of artifacts in the database are arranged based on the actual quantity of unearthed relics, and styles are categorized according to important functional components used in practical applications, which provides both typical and widespread representation. Second, by integrating measurement data and correlation analyses of various artifacts, the physical data range for design innovation in vessel types can be clarified, facilitating the search for suitable design reference objects according to design requirements. Therefore, using artifact types as a foundation, along with data measurement and correlation analysis of components, helps designers intuitively grasp the design focus of artifacts and the relationships among different design priorities, allowing for design innovation within reasonable limits.

4.2 Design Value Transformation Based on the Weights of Design Elements

The six design elements reflected in the database represent the recognition level of various artifacts among the public. A higher weight among the six elements indicates a greater recognition among the public, leading to stronger consensus for design innovation and higher market acceptance of the products. Thus, the weight relationships of the six design elements can provide a clearer design direction, aiding in the transformation of design value for ceramic relics. For example, if the weights of shape and functionality are extremely low, the design innovation for that artifact should focus on decorative patterns, cultural types, and color aspects.

4.3 Determination of Design Style Based on the Selection of Affective Vocabulary

The collection of affective vocabulary in the database serves two purposes: first, it presents the top three most commonly chosen words among the public for a particular artifact; second, it reflects the concentration and dispersion of the affective vocabulary. Consequently, the selection of affective vocabulary demonstrates the modern aesthetic characteristics of the ceramic artifact, helping designers determine the design style that meets public demand while also indicating whether potential design styles may exist based on the degree of dispersion.

5 CONCLUSION

Database-driven design innovation in ceramic culture not only facilitates a contemporary inheritance of traditional cultural connotations through an in-depth understanding of these traditions but also aids designers in comprehensively referencing existing archaeological research findings. Ancient ceramic forms serve as crucial vessels for the continuation of ceramic culture in contemporary daily life. Only by integrating artifact data with modern aesthetic demands can we reflect a shared historical memory in design. The ceramic culture design innovation database provides feasible data references for the transformation of design needs in this field. Furthermore, the scientific and artistic framework of the database significantly impacts the mutual reinforcement between research achievements in design studies and archaeology. The statistical data contained in the database greatly facilitates the exploration of the reasons behind the overall design changes of artifacts. Additionally, the scientifically comprehensive analysis of elements and design innovation data also inspires modern design innovations for typical cultures along the Silk Road. Through data organization, traditional culture, ethnic aesthetics, regional culture, and daily life can be utilized as complete scientific resources for design innovation, ultimately achieving the transformation of cultural heritage resources into modern industrial design and production.

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STORY-MAKING: A COMPLEX METHOD BASED ON ARTS-BASED RESEARCH IN SOCIAL DESIGN

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ABSTRACT
The study explores how the combination of visual art making, in this case, textile making, and storytelling can enable story-making to express research participants' inner worlds and world views in social design practices. Arts-based research (ABR) can address the limitations of conventional methods of practice and research in social design to elicit more profound and often unexpected responses from participants, leading to compelling reflections that can influence interview processes and the connections they involve. ABR's potential for unforeseen insights opens new possibilities for methodological explorations, specifically applying complex methodologies, by tackling the limitations of conventional research methods in social design. Using a socially constructivist approach, this inquiry into social design used ABR and cultural probes by combining textile making and storytelling. Analysis by the two participant-authors generated different interpretations of the participants' expressions. The study finds that the ABR story-making method can deepen insights into the participants' life experiences to uncover social aspects that can foster and strengthen new connections through design.

Keywords: Social Design, Arts-based Research, Story-making, Collaborative Visual Analysis

1 INTRODUCTION

ABR has the transformative power to support critical thinking and enhance creative and multifaceted communication while driving cultural and social change, making ABR so engaging and exciting for researchers and practitioners. This study will investigate the combined use of textiles and storytelling, paired with collaborative visual analysis, in a methodologically complex [1] method called 'story-making'. This method can elicit expression, reflection and analysis of life situations. This study aims to understand how story-making contributes to generative mindsets in the research field to enhance ABR's unstructured and exploratory knowledge generation in social design research and practice. In this article, social design is understood as creating designs for stimulating change that involves developing new ideas, solutions, and scaffolds to address social needs and reforms to foster stronger social connections [2], [3]. Scaling social design interventions should involve reshaping and strengthening the networks that support community members by enhancing and integrating social elements logically and effectively [4]. However, uncovering these social elements remains challenging and deep-seated and underlying issues are often hidden by more apparent challenges.

Drawing from stories as the essence of social fabrics [5], this study enquires how story-making can generate an understanding of these deep-seated unknowns and silences within society's ambiguous settings that social designers and practitioners have to deal with. The study asks: "How can the multi-method approach of story-making contribute to social design and practice as an exploratory and plural method?" When story-making is applied collaboratively and practised with care, open, transportive and improvisatory processes can emerge and stimulate engagement and empathy [6], [7]. Improvisation, as such, has a connective function, drawing from the affordances provided within specific settings and environments [6]; thus, its importance in social design cannot be sufficiently emphasised.

The exploratory method, story-making, creates understanding through reflective textile making and storytelling. This method, situated in an ABR strategy, can serve communities as a meaning-making process essential for uncovering hidden aspects of the societal challenges they face. McNiff [8, p.28] provides a comprehensive definition of ABR as 'the systematic use of the artistic process, the actual making of artistic expressions in all forms of the arts, as a primary way of understanding and examining experience by both researchers and the people they involve in the study'. The qualities of ABR, mainly its focus on questioning life experiences, hold immense promise for social design.

The study follows a socially constructivist approach and ABR [9], in addition to cultural probes and storytelling. Using ABR as a research strategy, textile art and storytelling were used as empathy-building activities during an international exchange between university students and academic tutors from Estonia and Japan, of which only ten individuals, half of the participants, engaged in the ABR activities. The findings will reveal how story-making and analysis are underpinned by art thinking as a generative and exploratory mindset to create diverse insights into the participants' memories, life experiences, resolutions, and unanswered questions. This study's value is to promote combining arts-based methods (ABMs) and other research methods to generate rich data from explorative art thinking. The generative ability of ABR is valuable in social design research and practice as it enables far broader means of expression, discovery, questioning and sense-making for working through life experiences, reflecting on complex situations, and creating and recreating associations that can impact on life realities. In addition, the value of this study, as Huss [10] explains, is that arts-based approaches and artistic outcomes should not be viewed not as the ultimate objectives of the research but rather as a means to acquire new knowledge to foster social and political change. These approaches ask for transformative processes supported by methods and tools. These present new opportunities for social designers to create new toolsets that integrate exploratory arts practices with transformative design approaches for their fields of practice.

2 THEORETICAL FRAMEWORK

This theoretical framework sets the foundation and elaborates on using ABR and storytelling in social design. The framework discusses the tenets of ABR and its role in social design while also elaborating on the roles of stories and storytelling. ABMs are used in various fields, especially those perhaps closer related to the arts, such as creative arts and music therapies [11], socially engaged art practices [12], participatory research [13], and social work [10]. Understanding societal behaviour and identifying elements that can lead to positive outcomes is key to enhancing well-being. Non-economic factors such as social capital, democratic governance, and human rights significantly influence a society's well-being. Strong social relationships are vital to well-being and significantly affect policy development [14].

2.1 Arts-based research in social design

ABR has been used in diverse research settings with marginalised communities [15]. By combining visual art and storytelling, ABR has effectively generated profound narrative responses and empathic socially focused research processes in marginalised settings (see [10], [7]). The values researchers seek to bring about in ABR are to facilitate the varied ways communities prefer to explore issues pertinent to their needs. In research contexts, ABR does not necessarily focus on solutions but instead explores new possibilities. This research approach can cultivate self-reflection and disrupt dominant narratives [15]. The value of ABMs has been recognised to encourage more horizontal and democratic research practices for decolonising participatory research [13]. ABR is steered by a moral commitment to the participating communities [16]. In these research processes, personal and community transformation is often experienced.

ABR can effectively unite diverse groups, as different cultural, social or spiritual experiences can be shared through visual, performative or digital expression and artmaking. Responses elicited during ABR can be emotional, intuitive, or psychological but not necessarily intellectual [17]. ABMs can be culturally modified to accommodate participants' values and beliefs as they can cultivate connection and empathy between researchers and participants to engage in research problems [17]. ABR's role in identity expression [18], through its ability to challenge dominant ideologies and include marginalised voices, enables participants and researchers alike to experience, think, and express differently [15].

Enabled by ABMs' fluidity, flexibility and adaptability, arts-based researchers often use methodological complexity [1] in data collection, documentation and content generation. Arts-based researchers concern themselves with knowledge transfer and translation by diverse means for alternatively collecting, analysing, and disseminating data [9]. ABR enables the coexistence of multiple and opposite perspectives [13], and the opening of spaces between self and others. Through ABR, research participants can engage in embodied processes to uncover inner or shared worlds through creative participation. ABR's value for generating empathy in the fuzzy front end of service design processes has been established [7]. However, the role and impact of ABR received little attention in social design. However, the role of ABR in generating empathy within communities has been established [7]. In summary, ABR can enable knowledge transfer to generate an understanding of communities' historical, social, economic, and environmental contexts as they provoke and transport ideas, as well as cognitive and emotional empathy and compassion.

2.2 Storytelling

Stories are affirmations of the ‘cleverness necessary to get on in the world, the kind of humour required to persevere’ [18:110]. Frank [18:110] further explains how stories can create the ‘the moment and the story–how well the transition was made–and how effectively the telling of the story focused attention’. Storytelling can be applied through performance and dialogue or creative writing. Storytelling and art-making, or story-making, can enable new dialogues and participation, underpinning their value in representation and visual dissemination for impactful research [19]. Story-making necessarily represents fabrication as it is based on personal life histories [20], experiences and memories that are reconnected and expressed through storylines and voice [21]. ‘Story is how we package and present the lived experience’, says Tordzro [21:1]. Therefore, the fabrication of such histories is itself generative and explorative. The narrative potential of stories embedded in artefacts to narrate meaning independent from the designer-maker’s intention has been established [22]. Narrative potential can illuminate participants' unconscious fears, reasoning and emotions.

Individual and collective storytelling is integral to arts-based approaches. Still, the most significant social impact of the arts is that it enables people to think critically about their experiences and those of others [23]. Storytelling creates authenticity [18:109]. According to Frank [18:109], authenticity is not a precondition of storytelling as it comes through the process. Stories can help people to explore the ‘world as a narratable place; that is, a place that stories can make sense of’, explains Frank [18:111], as they can ‘guide what to do next and how to live now’ [18:112]. Both storytelling and artmaking can help make sense of challenging and complex realities. Therefore, story-making is a performative, complex, and explorative cognitive-embodied process of remembering, discovery, and sense-making based on creative expression in various forms and materialities.

Research by Bloome et al. [24:45] illustrated the effect of story-making in adopting and adapting ‘extant stories and recounts of experiences to accomplish a broad range of in situ social goals and develop a repertoire of narrative styles and structures’. Such practices require creativity and divergent approaches that may be likened to art thinking, which requires emotional and cognitive capacities to transport participants using their skills, imagination, and creative competencies. Participants can explore and expand story-making to express and possibly gain insights into their life experiences.

In social and learning contexts, Gudmundsdottir [25] writes about story-makers when they transfer essential histories for learning, for example, to stimulate interest in learning topics and create a contextual understanding of the story’s people, places, and culture. At the same time, story-makers can knowingly and unknowingly contribute to strengthening negative and dominant narratives about people, places, and culture. For this reason, the ethical implications of story-making are important, requiring care and reflexivity of story-makers to create stories mindfully of existing dominant narratives. Frank [18:111] reminds us about the importance of ‘narrative revisionism’ for shaping morality that needs constant revision through ‘subsequent stories, including retellings that put different emphases on old stories’. Narrative revisionism is an essential element of storytelling, making processes and creativity that social designers should adopt in their community practices. It opens locally situated opportunities for reflection, improvisatory processes, re-learning and re-telling for reform, shaping the social connections that social design methods hope to target.

3 METHODS

This study adopted an ABR strategy, using textile making and storytelling as key methods for producing visual and textual data. The textile-making served as cultural probes to elicit storytelling and discussion amongst the participants and author-participants. The analytical approach used was collaborative visual analysis [26:3131].

3.1 Research participants

As an alternative to standard research methods in research and practice, textile art and storytelling were combined to explore the participants' life experiences during a two-day visit to Yabakei, a culturally and environmentally significant village in Oita prefecture in Japan. The ten participants, aged between 21 and 53, included international and local students and tutors. Both authors participated in this activity, while the remaining participants and institutions were anonymised for privacy reasons. Participants were asked to provide a written story accompanying their textile art as an additional method. Participants were invited to use objects or inspiration found in their environment in Yabakei. All participants provided informed consent before the activity to adhere to ethical requirements.

3.2 Cultural probes

1. Scar Stories. It is said that every scar is a story—a story of adventure, perseverance, overcoming an obstacle, and taking risks.

2. Grow like tree rings. For me, loneliness happens when I feel ignored or misunderstood by people I love. It reveals my deep fears and vulnerabilities, as well as the desire for connections with others, like a brief death. However, loneliness also made me see myself and build a relationship with myself, which fosters personal growth akin to the growth of tree rings.

3. Holding Traditions. In small communities, knowledge, traditions, and skills are quick to fade if no one wants to learn them. Everyone can do something to fix this.

4. Rice plant with the sun in the background. It was my first time visiting Japan, and the last thing I saw was the bright sun. The first thing I ate was Onigiri.

5. Shared Moments. On my first day in Japan, I met this man in a bookstore who gave me an amulet with an engraved angel. This gift was meant to bring good luck and protection. This embroidery of an angel reaching out with her hands symbolises the power of shared moments and the universal desire for happiness and well-being.

6. Loss of connection. My grandma taught me these three techniques when I was four years old. Her health is deteriorating, and soon, I'll lose her, which for me means losing connection with my past and future. I express the feelings of end and loss by depicting cultural folk symbols once instead of in traditional repeated sequences.

7. Making decisions. Making decisions will leave a different mark on your life. Some are more noticeable, some less, some take away from you, some add, some will mend broken parts, and some leave you fragile.

8. All together. Someone once wrote, "We are all alone together". So, loneliness is often a blessing, and it is my quiet time. I am lonely when I get busy.

Figure 1. The eight purposively selected textile arts and stories of the participants. Photography by M. Sarantou (2024).

Cultural probing involves using a set of stimulating tools and materials that may offer a strategy for exploration [27]. Participants received a probing kit with a 10 x 10-centimetre linen textile, thread, needles, and paper clips as materials to engage in the story-making and create the textile art. Besides the cultural probing kit [28], no creative specifications were delivered to each participant. The strength of the cultural probing method is that it aids the exploration of people, agency and the environment within a specific context [27:29]. Eight textiles and stories were purposively selected for the collective visual analysis conducted by both authors. The data collected from this stage of the ABR were the textile artworks and hand-written stories on paper transcribed and presented below in Figure 1.

The following subsections will explain the theoretical considerations for the methods used: cultural probes, probing kits, storytelling, and analysis. Next, the implementation of the analysis as the author-participants attempted to use generative art thinking to identify various ways of story-making will be elaborated on.

3.3 Analysis

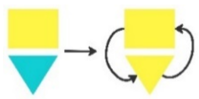
Collaborative visual analysis is an analytical approach to 'enable distributed exploration and evidence gathering, allowing many users to pool their effort as they discuss and analyse the data' [26:3131]. This analytical approach has been used alongside arts-based methods [29], drawing from storytelling, visual data, and reflective processes to enable dialogical analytical processes in which two or more researchers facilitate the analytical process. The literature has given limited attention to analysis in ABR. Focus group discussion, storytelling, sketching, note-taking, and idea-sharing can be used as methods for story-making. Collaborative visual analysis aims to shift from personal to group agency [26], yet it is based on individual and collaborative interpretations; it is a subjective approach that draws on personal experience and is supported by narrative accounts and reflections generated through discussion within a group [29]. Due to this method's collective and reflective approach, each analyser's findings and subjective analysis must be negotiated within the group of two or more participants. The more participants, the broader the distribution and interpretation, which may prevent power imbalances, especially between researchers and participants [26]. Negotiation results in the research being non-exploitative and accessible while retaining self-interrogation [29].
The study outcomes were analysed by the authors using collaborative analysis. The author-participants' analysis of the eight purposively selected textile arts and stories was facilitated on the digital Miro whiteboard platform. The images and stories were collected, grouped and analysed using the platform's sticky note function. Three one-hour sessions, one online discussion and two in situ assisted in refining the visual analysis collaboratively. The data generated from the collaborative visual analysis included transcribed focus group data, mapping, and note-taking. The discussions were recorded and transcribed using the digital Zoom meeting platform, which supported the theorisation. Selected findings present the inter-subjective insights of the collaborative analysis, in which the authors seek to illustrate the generative and diverting potential of art thinking, which will be presented hereafter.
Knowledge translation in ABR generates diverse insights, and the generative ability of ABR continues to motivate practitioners and researchers to challenge existing research methods and formats. The analysis by the author-participants revealed the interpretive process of generating understanding from the artworks and stories. The numbers allocated to the artworks and stories also correspond to the numbers in Table 1. Reflections from the analysis are:

> *When I see these artworks, it is how I read them; I see some differences. In the beginning, I was reading the keywords. When I was reading, what was the story? I was confused. Then, I turned to the artwork and tried to feel it directly. And then I felt something different - harmony. So, I then went back to the words and expressions. Then I felt like I understood. The purpose of the artwork is to understand, and the artwork helped me to reflect on my views. (Author-participant 1, 2024)*

Drawing from such examples, the analysis used different shapes and colours to express the relationship between the artwork and the story. The positive triangle represents an artwork (A), and the inverted triangle represents a story (S). The same yellow colour refers to feelings of deep connection between artwork and story. The colour blue refers to when a story feels different from the artwork. The use of the different colours and shapes is illustrated in Table 1.

Table 1. Analysing Story-making: The relationship between the artwork and the story.

Symbols	Analysis
LEGEND 	*Stories, Artwork and Storymaker. The identities of the participants are protected, yet we create clarity for the reader by coding and distinguishing the eight stories, artwork and storymakers using numbers, e.g., story 1, 2. 3, to 8, artwork 1, 2. 3, to 8 and storymaker 1, 2. 3, to 8.*
	This symbol represents the equal impact of the artwork and story. This implies that the artwork vividly and concretely reflected the story's narrative, and we did not need to use additional information to understand this story and artwork. This is reflected in artworks 1, 2, and 3. The image of the scar in artwork 1 aptly reflected the description in story 1, "A story of adventure. It is a story of perseverance. A story of overcoming an obstacle and taking risks." In artwork 3, two hands held together illustrated a call for people to work together to preserve tradition.

 A≠S	In this symbol, different colours indicate that we cannot wholly associate the artwork with its story. This is reflected in artwork 4 and 5. For example, artwork 4 is minimal and abstract, making it challenging to fully grasp the meaning of the image in the artwork alone. Upon reading the description, we can feel and interpret the green lines as representing upward movement. However, we still found connecting the visual imagery with the onigiri in story 4 difficult. *Onigiri* is a Japanese food made from rice formed into triangular or oval shapes and often wrapped in seaweed. As a result, while we could understand artwork 4 and story 4 individually, it was challenging to perceive a link between them.
S>A	This symbol suggests that the story had a more substantial impact than the artwork. When looking at artwork 6, we find it hard to comprehend its meaning. However, after reading the story, strong emotions arose, although expressing these feelings directly into words was difficult. After setting our emotions aside momentarily, we used drawing to explore the meaning and connection between artwork 6 and story 6. One picture depicted older trees' leaves turning into nutrition for young trees, revealing the connection and loss between old and young generations, which is also related to story 6. As outsiders to the specific culture referred to in story 6, it is challenging for us to empathise with it. Resonating with this artwork and the narrative of story 6 and exploring its meaning through imaging and drawing led us to understand that the meaning of story 6 is more profound than the artwork 6 itself.
A x S> A or S	This symbol means the outcome of the interaction between the artwork and the story surpasses either of them individually, as in artwork 7. The meaning of story 7 and artwork 7 support and complement one another. Although they take on different forms, they are profoundly complementary. The relationship between artwork 7 and story 7 is closely connected, and one allows us to understand and feel the other better.
 A for S for A	This symbol shows a complex process of understanding as represented in artwork 8. Initially, the narrative of story 8 was difficult to understand. Unlike Storymaker 8's definition of loneliness as 'blessing' and 'quiet time', loneliness is often experienced as unfavourable. However, upon feeling the artwork again, a sense of the narrative of harmony and peace was experienced through the regular circles, representing ripples on a peaceful lake. This perception helped to gain an understanding of story 8 as a cyclical process. Although we cannot combine artwork 8 with story 8 at first, the visual expression plays a crucial role in reading story 8.

Five different relationships between the artwork's visual expression and the story's narrative are presented in a limited form in Table 1, which can be expanded upon. Different patterns regarding the relationship between the visual expression and the narrative in the story-making are presented here as examples to illustrate the generative ability of art thinking in the ABR and analysis and how they can collectively serve as an approach to creating diverse understanding and insights into participants' inner worlds.

4 FINDINGS

The narrative extractions deriving from the collaborative analysis conducted by both authors (Author-participant 1 and 2) reflect the diversity and ambiguity of meanings generated from story-making. While they are complementarity, the meanings can be both implicit and explicit. Hence, the application of methodological complexity can be supportive ('a circle that helps me', Author-participant 1, 2024) in the analytical processes of ABR. However, simultaneously, it can elucidate differences, disjuncts, and uncertainties and bring forth the unsayable [30].

> *The artwork shows something bigger, or it shows something or explains something more than the story. But they're both related to each other; without the word's help, I can't understand the artwork, but after viewing the artwork, I also need help with the words. They are a circle that helps me understand what expression is. Some works are very direct, like the hands. (Author-participant 1, 2024)*

How does thinking relate to this process? For example, our thinking is very exploratory. It is abductive. It seeks to understand what is there. It seeks to find, to discover. But it is opening our possibilities. Illuminates the resources. (Author-participant 2, 2024)

If I use some artistic tools, I have to reflect and go back to my archive to explore, not just the process. And this archive is not something passive. Some actions can trigger the potentialities to come from your archives. Your way to explore more of the resources or knowledge in their life. It's a kind of emergence; to discover. (Author-participant 1, 2024)

ABR enables mental, performative and emotional spaces for story-making (and story-finding) as generative and analytical processes in ABR. In reflection on the narrative extractions from the analysis, story-making and grasping of stories to generate understanding of one another's worldviews, complexities and sensitivities are emphasised for developing more robust analytical processes for ABR. The chance to 'visualise and emotionally connect' (Author-participant 1, 2024) refers to ABR's potential to one another's inner worlds through collaborative, multisensory, and explorative story-making. In addition, through ABR, the artworks can serve as an impetus for creating intersubjective mental overlaps and spaces for reaching out into one another's inner worlds. Author-participant 1 (2024) explained, 'I turned to the artwork and tried to feel it directly,' which resonates with Frantz Fanon's [31] notion of feeling one another as a form of proactive, compassionate empathy [32].

If we want to know another person's thoughts, initially, we all share differences. If we're going to understand another person's story, we must learn their knowledge. That knowledge only exists in that person's background. I relate to this knowledge by reading the story first and then visually analysing it as a chance to emotionally connect with the person's knowledge through the artworks that my understanding changes. That changed my perception of the meaning. (Author-participant 1, 2024)

The excerpt above illustrates the role and importance of narrative revisionism, explained in Section 2.2. Narrative revisionism enables stories to be (re)interpreted, corrected, and (re)told to represent better meaning-making, emotions, and thus the depth of understanding. The complex methods selected for the study enabled narrative revisionism as to how what occurred could be questioned. New knowledge could emerge through careful and critical views of what was presented through the textile art and written reflections by the participants.

Story-making is a complex method based on data generation and analysis through a divergent and generative process. This process brings forth diverse meanings and interpretations while embracing complexities and an exploratory mindset, as illustrated by the narratives captured by the Author-participants in the analysis. Table I exemplified the subjective analysis used in artwork and story analysis by eight story-makers. In addition, it promotes 'openness of interpretation' [9] and illustrates the divergent and generative ability of ABR.

Table 1 is not instructive but aims to uncover how diverse understanding and sense-making can occur using various methods and methodological complexity in ABR. It illustrates how reasoning and emotions are influenced by the artwork's intricate visual cues and symbolisms and how or whether the written stories support them. However, they also support the indirect story-making and story-finding of those who read and interpret the ABR. The analysis also sheds light on the potentials, ambiguities, and complexities inherent in applying methodological plurality.

In storyline representations, three views can exist: a) the view of the audience or broader public on the artwork and its meaning to the viewers or arts audiences, and b) the view of the participants on their discoveries in their arts-based expressions, and c) the view of the participants on how the audiences receive their creative expressions or artefacts and whether understanding and empathy are generated around their needs. These findings shed light on the functioning and potential of ABR, specifically the story-making method, in social design practice and research regarding the needs and challenges communities face. Communities often remain unengaged in tackling their own challenges, which may be brought on by ill-defined social interventions and social designers who assume they best understand these needs and challenges [4]. A lack of empathy underpins ill-defined interventions. Not sufficient time and care are provided to delve deeper into aspects essential to community well-being and reform. ABR can effectively address this challenge in the early stages of community intervention design.

5 CONCLUSIONS

ABR does not seek to obtain a means to an end but to uncover and generate understanding through exploration and improvisation [10]. It is a divergent and generative approach to exploring challenges in research and practice. The improvisatory nature of story-making and its ability to stimulate re-learning and drive reform is evidenced by the excerpt *'it is opening our possibilities…illuminates the resources' (Author-participant 2, 2024).* In comparison, when pairing collaborative visual analysis with story-making, more complex, deep, and divergent findings can be generated by all researchers and participants of the ABR. Story-making can stimulate creative content generation and problem-finding while creating insights into the complexity of life experiences central to social design. It can facilitate diverse data generation, analytical approaches, and creative dissemination.

Social design can be better approached through open-ended cognitive, embodied, nonverbal, and reflexive processes to reveal participants' inner worlds, emotions, and experiences. Figure 1 presents the outcomes of the story-making, both the textile art and the written stories. In contrast, the data resulting from the authors' collaborative visual analysis is presented to illustrate the exploratory analytical approach to ABR. Table 1, the result of the collaborative visual analysis, presents an example for social design researchers and practitioners to explore people's life experiences using the analytic method developed in this study. This analytical method directly enhances empathy through the analysis of the visual information in comparison to the content of the story by creating deeper insights into the inner worlds of the participants. Integrating such methods in design contexts will set ABR's use in social design apart from socially engaged arts.

The study finds that the ABR approach story-making method can deepen insights into the participants' life experiences. This knowledge can facilitate effective social design processes to address the local change communities envision and the specific requirements they see as suitable to their contextual needs. In addition, this study illustrates that all research participants have an opportunity to participate in story-making through the creation of data and new insights, as well as knowledge production through analysis. Such methods enable the collaborative creation of knowledge, empowering participants to express their values and participate in joint data analysis through storytelling [33]. Research participants can co-analyse with researchers and collaboratively decide on the analytical methods and procedures to untangle the meanings of the data.

However, it is essential to understand ABR's limitations. While expressive, reflective, and transportive, ABR challenges social designers. This approach asks for more time, patience, creativity with communities, and a keen interest in uncovering their more obvious needs and journeys beyond the obvious [34]. Yet, some communities may resist creative approaches due to their unfamiliarity. Hence, arts-based methods must be carefully selected and integrated into social design practices, requiring additional resources in the social setting. In addition, the interpretive challenges ABR poses may create more undefined challenges than solutions. Social designers need skills in facilitation and choreography, with the first focusing on supporting dynamic group interactions [35]. The latter focuses on crafting precise, often predetermined, or pre-designed aesthetic actions brought to life through coordinated patterns and flows within environmental and spatial considerations [36].

This research is limited by being a single-setting, cross-cultural project executed as a single ABR activity. Future research should continue in different settings to validate and deliver robust results on how ABR and the story-telling method can be integrated into well-facilitated social design processes and community-choreographed social action. However, ABR's potential lies in its exploratory nature and in encouraging early research findings and theoretical explorations of the role of arts thinking as a generative approach in ABR.

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PROCEEDINGS OF ASIA DESIGN AND INNOVATION CONFERENCE
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INTRA-GROUP CONFLICT AND STUDENT TEAM'S PERFORMANCES IN DESIGN PROJECT

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ABSTRACT
In recent years, design projects have been held in various educational settings. Students take project-based learning (PBL) courses to learn design approaches and mindsets. Even though students act in the same settings, team performances vary, and researchers have been trying to reveal the differences. Although support for student teams is required, there is a lack of understanding of the team's level activities in a design project and a good way to grasp the student team's status. To bridge these gaps, this study proposes using a questionnaire for perceived intra-group conflict to monitor student teams. The objective is to understand the relationship between dynamic patterns of intra-group conflict and the student team's performance in a design project held as a PBL course at a Japanese university. Three types of conflict (task, relationship, process) were measured weekly with a questionnaire. The results revealed the difference between well-performed and not well-performed teams in task and relationship conflict. In the task conflict, not well-performed teams showed extremely high values at some points, while values of good teams moved moderately. In relationship conflict, not well-performed teams showed higher values than good teams. There were no significant differences in process conflict, possibly because of the fixed schedule of the course. In addition, dynamic conflict patterns extreme points and frequent changes throughout weekly data collection. This research is the first step in using dynamic conflict patterns to monitor the team's condition, and further data collection and analysis are required to make them more credible.

Keywords: Design Education, Intra-group Conflict, Student Team, PBL, Team Monitoring

1 INTRODUCTION

In recent years, there has been a growing emphasis on equipping non-design experts with design skills, leading to integrating design projects across various educational settings. In the design research field, various studies aim to understand novice team behaviour in the project (e.g., [1], [2], [3]). In an educational context, students take project-based learning (PBL) courses to learn design approaches or mindsets and work in teams over several weeks or months to develop new products or services using design thinking(e.g.,[4], [5], [6]).

However, novice designers often face various challenges in the design process, primarily due to the iterative nature of design. This iterative process, coupled with the complex, ill-structured problems it entails, can be particularly challenging for students [5], [7]. Even though students act in the same conditions, teams' performance varies depending on various internal factors. Researchers are interested in the distinction between successful and struggling teams to improve students' practice or learning experience. Some studies report the nature of teams under projects. For instance, Nizam (2022)[8] identified a pattern of behaviour typical to approximately 89 percent of failed projects. As another example, Suk and Lee (2021) [9] compared the problem framing activities carried out by student teams between high and low creative team, and revealed high-creativity teams tended to create a new frame by combining several frames, diving deep into a problem dimension, or framing problems collaboratively. Although some studies have revealed the difference, there are gaps in support development for novice designers or design teams.

One research gap is the limitation of the understanding of teams' behaviour. There is substantial research on individual cognitive processes and short-term team discussions in design [10], [11], [12], studies examining team dynamics on a larger, project-level scale are more prevalent in other fields, such as management. For instance, prior studies in management have explored long-term team activities and the static characteristics of teams. However, as noted by Cash et al. [13], a notable gap in research focused

on the intermediate, meso-scale level of team activities central to the design indicates a need for further investigation. This prevents us from developing support for the student team.
Another possible reason why we are unable to develop support is the difficulty in grasping student teams' status. Students' team activity occurs outside the lecture time, and the interim deliverables and feedback sessions are the few opportunities for instructors to gain insights into the teams' progress. Therefore, providing the teaching team with tools and data to evaluate and intervene in these team dynamics during the project is crucial.
As mentioned above, the enrichment of understanding of the meso-scale level of team activities and developing alternatives to monitor students' behaviour during the project should be achieved to realise a more effective learning experience. Thus, this study addressed these challenges by analysing data from classroom surveys completed weekly by student teams participating in design projects. This research aims to visualise conflict patterns and explore how differences in these patterns correlate with varying levels of team performance. Specifically, this paper addresses the following question: *How do the dynamic properties of conflict differ across teams with varying performance levels?* This study collected intra-group conflicts weekly during the design project and visualised them to compare the appearances between teams with different performances.
This paper is structured as follows: the prior art of design education and existing research on intra-group conflict are described in section 2. The method is explained in section 3, which includes the context of the study, and the way of data collection, evaluation of teams' performance, and data analysis. The dynamic patterns of conflict or comparison between teams are shown in section 4. Section 5 discusses the differences observed in the visualisation and its implications for future research and practice.

2 RELATED STUDIES

2.1 Students' practice in design education

Today, design is essential for dealing with a complex and ambiguous society. As the world's uncertainty increases, personnel with problem-solving skills are required. This is one reason design attracts lots of interest, and design education for non-specialists is becoming more widespread.
In design education, many projects are carried out so that students can acquire the skills or mindsets of design professionals through the experience. Those projects aim to develop new products, services, or systems using a human-centred approach, including design thinking frameworks. ME310 [14] is one of the most famous PBL courses in the world and uses the frameworks structured by five steps: "*empathy*", "*define*", "*ideate*", "*prototype*", and "*test*". The other framework often used is the Double Diamond Model, which Design Council suggests [15]. The model represents two divergence and convergence phases and consists of four stages: "*discover*", "*define*", "*develop*", and "*deliver*". The journey of the student teams in the design project is more complex than other PBLs because of the specific features of the design. Students need to manage an iterative process or tackle "wicked problems".
Challenges in design education are well known, and many researchers have tried to investigate them. For example, Rekonen & Hassi(2018)[5] identified four types of bottlenecks that novice design teams face in practice: resistance to iteration, overlooking the experimentation ideas of others' and oneself, losing sight of the initial problem to be solved, and a bias towards planning. Hölzle & Rhinow (2019)[7] clarified three different dilemmas are caused by teamwork with design thinking, which differs from other types of teamwork. In this sense, students struggle with tasks, relationships between members, or managing processes. Development of support for them is required to decrease the difficulties and improve the learning experience.

2.2 Intra-group conflict

Although design research has investigated intra-group factors affecting team performance, various things have remained to be revealed to deepen our understanding of design teams [16]. For example, intragroup conflict is considered a critical factor influencing team conditions, and it has been studied in management for a long time.
Conflict is defined as awareness on the part of the parties involved of discrepancies, incompatible wishes, or irreconcilable desires [17]. Jehn & Mannix (2001) [18] designed a questionnaire survey, measuring three types of conflict: task, relationship and process conflict.
Task conflict is defined as an awareness of differences in viewpoints and opinions about a group task [19]. It is categorised as cognitive conflict and occurs when ideas or opinions are different among

members [18], [20]. Relationship conflict is defined as an awareness of interpersonal incompatibilities [18]. Relationship conflict is categorised as affective conflict, including feeling tension and friction as well as personal issues such as dislike among group members or annoyance, frustration, or irritation [18], [20]. Process conflict is defined as an awareness of controversies about aspects of how task accomplishment will proceed [18], and represents how well groups are managing decisions about how to manage the logistical accomplishment of tasks and decisions about how to coordinate people in accomplishing the task [21].
The relationship between team performance and conflict has also attracted much attention in previous research. Jehn & Mannix (2001)[18] investigated the relationship between patterns of conflict in a project and performance and found that the dynamic nature of conflict depends on performance differences. The study reported that the low-performing group saw a sharp increase in the three types of conflict in the final week of the project. In contrast, the high-performing group saw a gentle increase in process and relationship conflict and a slight decrease in task conflict.
In the design research field, some studies analyse the conflict of the design team. For example, Paletz et al. (2017)[11] conducted a study focusing on temporal changes of micro-conflict and uncertainty. They analysed temporal relationships between expressed interpersonal disagreements and subsequent spoken individual uncertainty and figured out that successful design teams reduced uncertainty when micro-conflict occurred, whereas unsuccessful teams increased.
Although intra-group conflict is one of the critical factors affecting a team's performance, only a few studies have attempted to understand the conflict patterns of design teams. Panke (2019)[22] reviewed the literature and reported teamwork conflicts as one of the problems in education using design thinking. From a pedagogical point of view, it is essential to monitor student teams' condition during PBL to assess students' performance and interrupt or support students to improve their experience in the project. However, catching up on all activities outside lecture time is still challenging. Connecting the dynamic patterns of teams and their performance could give us some insightful hints for educators. Moreover, using a small number of questions is an effective means to understand the team's situation because it places a low burden on the design team. Therefore, the relationship between performance and the dynamic nature of conflict should be revealed.

3 METHOD

Since the objective was to compare dynamic patterns of intra-group conflict between different performance teams, evaluating teams' performance and collecting conflict data was conducted. We collected data during the design project at a Japanese university and compared those patterns between teams with different performances. The design educator with several years of experience evaluated the team's performance. Conflict data was collected by questionnaire survey at every lecture date. In the following section, the details are described.

3.1 Context

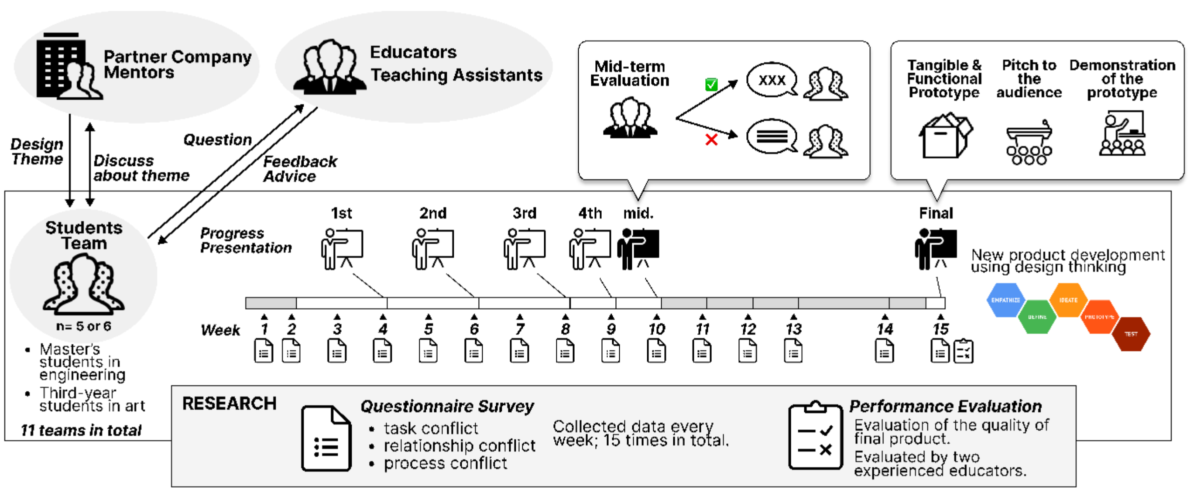

Figure 1. Details of the target project

The participants of this research were the students who joined the industry-academia collaborative project held at a Japanese university. This project is structured based on d.school's ME310 [14], which is held at Stanford University. Students learn the approach and mindset of user-centric design throughout this PBL lecture. This project took five months and aimed to create a new product. Figure 1 shows the details of this project.

Teams consisted of five or six students, including graduate students in engineering and third-year undergraduate students in art or other majors. Each team tackled the different open-ended design themes their partner company gave (e.g., "*In a future where disasters and everyday life are in close proximity, design a product experience that allows users 'NOT' to prepare for disasters*", "*Design playful outing experience for urban elderly people who feel their bodies deteriorating*", etc.). Teams were expected to follow design thinking steps and conduct design activities such as user interviewing, insight formation, ideation, prototyping, or user testing. Unlike projects with detailed requirements or aiming to improve existing products, this project requires students to try to define users, problems, or needs. In the first half of the project, they needed to present their progress once every two weeks; in total, they had five presentations. In the last half of the project, a progress presentation was not required, but a tangible and functional prototype was needed for the final presentation. In the final presentation, they presented their final product with the prototype. In the project, teams planned and conducted design activities independently. During lecture time, teams had a chance to ask advice from educators and teaching assistants or to discuss their perceptions of the design theme with the partner company mentors.

3.2 Performance evaluation

Outcomes in the final presentation were evaluated to classify teams as successful or not. The evaluator was involved in the lecture and had several years of experience in design education and design research. The team's performance was scored on a scale of 1-5, with one being not good and five being good.

3.3 Data collection

The questionnaire survey was conducted to understand each team's dynamic patterns of intra-group conflict throughout the project. The questions used in this study are shown in Table 1. Questions were cited from the works of Jehn & Mannix (2001)[18]. The questionnaire consisted of questions to measure three types of conflicts: task conflict, relationship conflict, and process conflict. Three questions were used for each conflict, and participants rated on seven-point Likert scales ranging from 1, "not at all", to 7, "a lot".

Table 1. Conflict Questionnaire cited from Jehn & Mannix (2001)[18]

Types of Conflict	No.	Question
Task Conflict	1	How frequently do you have disagreements within your work group about the task of the project you are working on?
	2	How often do people in your work group have conflicting opinions about the project you are working on?
	3	How much conflict of ideas is there in your work group?
Relationship Conflict	4	How much emotional conflict is there in your work group?
	5	How often do people get angry while working in your group?
	6	How much relationship tension is there in your work group?
Process Conflict	7	How often do you disagree about resource allocation in your work group?
	8	How much conflict is there in your group about how your group drives the project?
	9	How often are there disagreements about who should do what in your group?

All of the collected data was anonymised to protect individuals from identification. Data was collected at the end of the lecture day, so it was collected approximately once a week, fifteen times in total. There were 57 students in 11 teams, but the data analysed in this study was responses from 51 students in 10 teams who agreed to participate in this survey. The response rate to the questionnaire was 85.8%, which was sufficient data to provide an overview of the team's situation.

3.4 Data analysis

The conflict data collected was averaged to display the chronological changes for each team. Due to the limited sample sizes, statistical testing was not conducted. In a calculation procedure, data with no answers or missing data was excluded, and only data that could be handled was used. The calculated mean were used to visualise the chronological changes for each team.

4 RESULTS

The evaluation results are shown in Table 2. The evaluated performance is shown in the second column on a scale of 1-5, where one is not good and five is good. As a result, teams *B* and *F* were evaluated as good, and teams *E*, *I*, and *J* scored lower than others.

Table 2.Evaluation results

Team	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*
Evaluation (1-5)	4	*5*	4	4	*3*	*5*	4	4	*3*	*2*

The results of the conflicts collected during the project are shown below. The data was divided into teams, and the average were calculated for each type of conflict. The change in the time of conflicts for each team is shown in the following Figure 2.

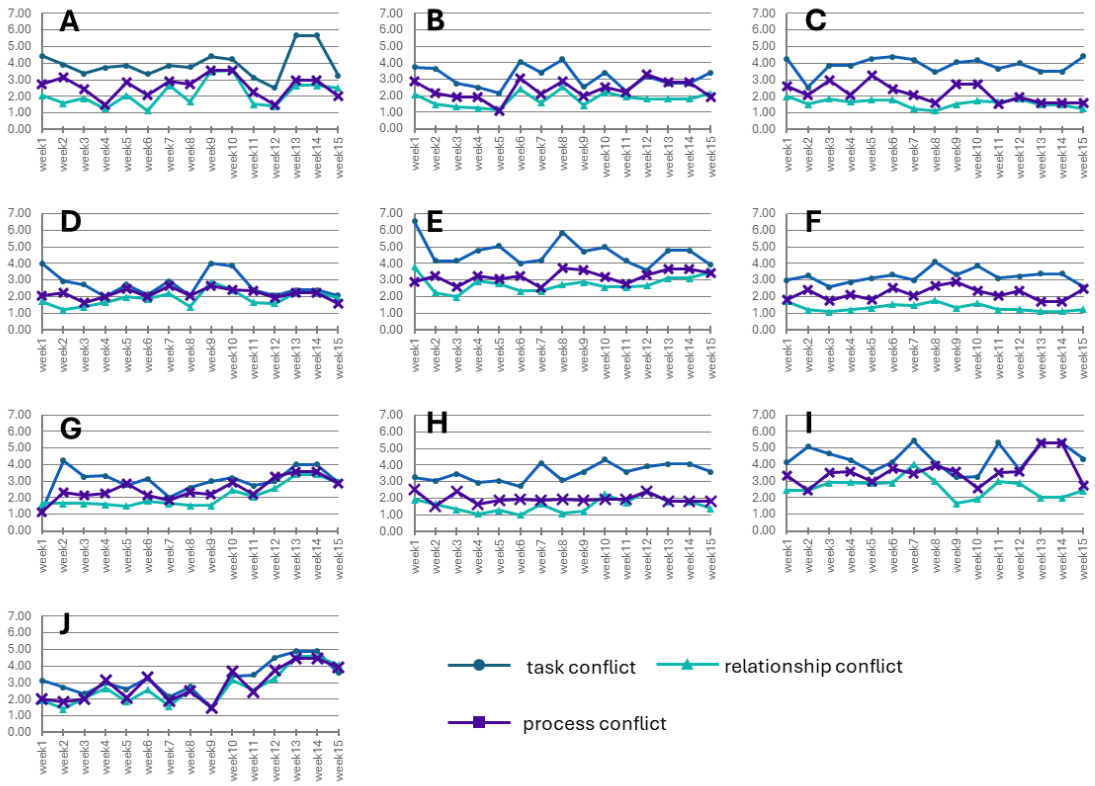

Figure 2. Visualisation results of dynamic conflict patterns for each team

All teams showed a general trend of highest values for task conflict, followed by process conflict and relationship conflict in descending order. The time series change of conflict shows the different natures depending on the teams. For example, *A*, *E*, *I*, and *J* continuously scored high task conflict; sometimes, they scored more than four or five points, significantly higher than other teams. Those teams also scored high in relationship conflict, around three points, while others scored low, around one or two. Some teams, such as *B* or *J*, show the corresponding between different types of conflict.

In addition, the conflict collected each week shows frequent changes every week. This means that intra-group conflict is not static but more dynamic than expected. The dramatic increase/decrease was significantly captured through the continuous data collection. For instance, *E*, *I*, and *J,* which were evaluated as not good, show frequent changes; *E* shows a significant decrease in task and relationship conflict between weeks 1 and 2, *I* shows that every conflict frequently moves up and down, and *J* shows continuous up and down move from week 3 to week 11 and increasing from week 11 to week 14. These changes are not observed through traditional two-point pre-post or three-point pre, interim and post data collection.

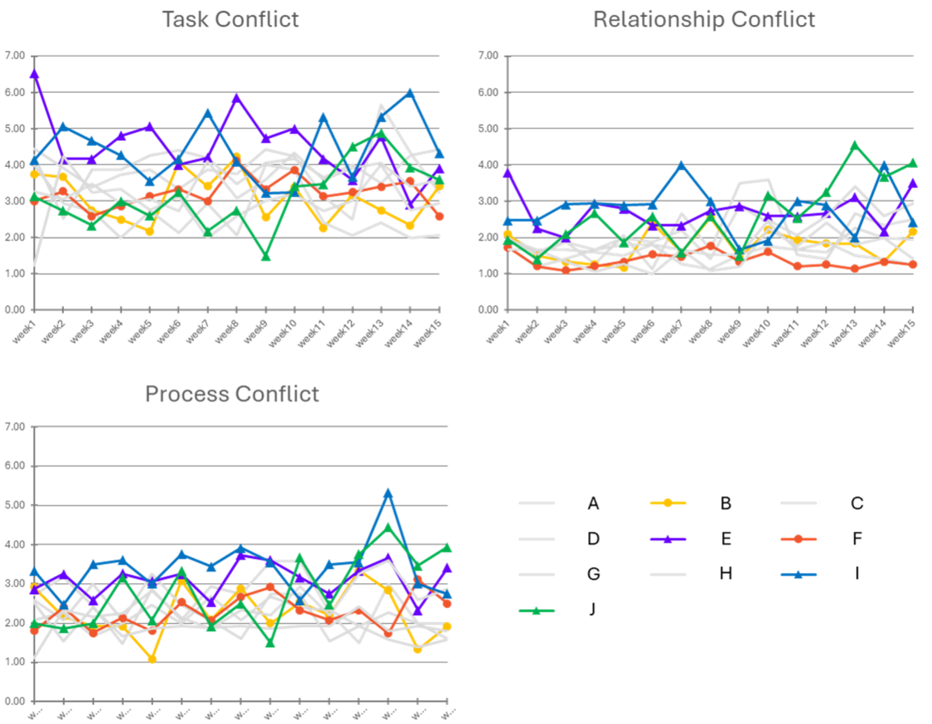

Figure 3. Comparison between teams by each conflict

Figure 3 shows the differences between teams based on three kinds of conflict. It reflects the evaluation results of the final presentation. Teams *B* and *F*, evaluated as a well-performed team, are shown with warm colours and circle markers, and teams *E*, *I*, and *J*, evaluated as not having good performance, are shown with cool colours and cross markers. The results show the difference between teams with different performances. Regarding task conflict, the well-performed team showed moderate value, slightly increased towards the project's midpoint and slightly decreased towards the end. However, teams evaluated as not good tended to remain high task conflict, more than four points. Team *E* and *I* maintained high values throughout the project, while Team *J* showed high values only at the end of the project. Regarding the relationship conflict, we can see a similar tendency. The well-performed team always shows less conflict, between one to two points, while not well-performed teams show higher conflict value and sometimes score more than three points. In relationship conflict, not well-performed teams have similar tendencies. Process conflict shows only a little difference among teams with different performances; however, teams evaluated as not good score higher conflict rather than a good team.

5 DISCUSSIONS

This research aims to visualise patterns of conflict measured weekly in a long-term design project and explore how differences in these patterns correlate with team performance. This is to enrich the understanding of the mesoscale team behaviour and develop a way to grasp student teams' status. In this section, the relationships between performance and dynamic patterns are discussed, and additionally, possibilities of the dynamic patterns of conflict are discussed from academic and practical points of view.

5.1 Relationship between performance and conflict pattern

Generally, dynamic conflict patterns differ among teams. Low-performance teams showed extreme peaks in each type of conflict. For example, in a relationship conflict, each team scored high at a different point; *E* scored at week 1 and 15, *I* scored at week 7, and *J* scored at week 13. In a process conflict, *I* and *J* showed high conflict in week 13. It was possible to observe this only through weekly data collection, unlike in the traditional way. These extreme points may reflect the team's problematic conditions, so further research is expected.

Regarding task conflict, the teams evaluated as not well-performed showed higher task conflict during the whole project than the well-performed team: in this survey, bad teams tend to have high task conflict, scoring more than 4 points. The value of a well-performing team seems to increase slightly from the start to mid-term and slightly decrease from mid-term to the end. This result is supported by the past study[18]. The project's midpoint is crucial for teams to promote progress or discussion. Not well-performed teams scored extremely high values at some points, and generally, values move around three to five points. Precisely, the values of teams *E* and *I* move in a higher range than those of other teams. Team J showed different results from existing research[18]. Due to the complexity or ambiguity of the design process, teams might need help managing the aggressive discussion. The relationship between process and conflict patterns is expected to be explored in future research.

Regarding relationship conflict, patterns showed differences between teams with different evaluation scores. The teams that were evaluated as not well-performed also showed higher values in relationship and task conflicts, so the aggressive discussion might cause tension or frustration. Controversy failure in team building might cause conflict in relationships and influence discussions. Relationship conflict could reflect the team's condition and help understand the team's tension or frustration.

Process conflict did not show a significant difference between teams. It might be because teams act under a structured process. They must present their progress once every two weeks until the project's midpoint, meaning they have to iterate five steps at least once every two weeks. During the last half of the project, they worked hard on creating the final prototype, which is required to be tangible and functional. Therefore, there were typical cycles naturally defined by the project's structure. They might not need to determine the due date by themselves, which could decrease process conflict compared to the condition without this structure. In PBL, process conflict may not indicate the team's performance, especially when there are exact requirements or structures.

5.2 Implications for studies

The results reveal that teams score significantly high in task conflict values and comparatively high in relationship conflict in the project. This was not clarified until continuous data collection was conducted. In other words, collecting dynamic patterns of conflict might give us insight into the team's behaviour. In many existing studies, conflict has been measured only after the project. Still, if we genuinely want to understand the team's condition, a few times measures may not be enough, especially in a design project with a complex and iterative process.

The other exciting trend was the correlation between different types of conflict. The correlation between process conflict and relationship conflict can be seen in teams *B* or *J*; this means that the conflict in how they manage the project and the conflict of emotions or intra-team tension interact. The existing research [21] pointed out that the construct validity of the process scale should be improved since it might have failed to separate construct concepts. On the other hand, the results of this study indicated that conflict from some teams did not correlate with different types of conflict. Past research relied on the theoretical construction by concept mapping and validation of the measurement by only one-time data collection after two months of group work. Therefore, the data collection settings differ, so further research is required to reveal the correlation between different conflict types.

Furthermore, the dynamic conflict patterns varied from team to team. The values fluctuated frequently as the project progressed and sometimes showed extremely high values. In the future, it is expected that analysis will be carried out in conjunction with changes in the internal situations to deepen our understanding of mesoscale team activities.

5.3 Implications for the practice

This research is the first step in developing a method for monitoring teams in design projects. As we discussed the limitations below, it is not currently possible to show statistical differences due to the limited sample sizes. However, the results of this survey show the qualitative differences between teams that perform differently. In a practical situation, real-time monitoring with qualitative use of conflict patterns might help determine the teams' conditions. For example, this study revealed different tendencies in task and relationship conflict. Thus, when teams show high values in task and relationship conflict, a teaching team may use them to signal the problematic situation in the student's team or supplement information to decide when to interrupt the team. To use a dynamic conflict pattern as such, further data sampling and analysis might make this system more credible.

Another implication of this research is the possibility of using it as a reflection material. Students have difficulties conducting appropriate reflection by themselves because they face various challenges and must manage complex tasks and processes. There are some gaps between the proposed frameworks and practices of students[23], so the frameworks must be improved. At this point, dynamic conflict patterns might help them objectively understand teams' conditions. In addition, since conflict can be measured with simple questions, there is no need to care about the risks or costs loaded on students. Again, further data sampling and analysis are required to use these practically.

5.4 Limitations

There are two limitations. The first is the limited sample sizes. A reasonable number of data and statistical treatment would be required to determine the team's situation based on the dynamic pattern of quantitative data from questionnaires. The second is the limited control within the research setting. While data was collected in the practical situation to capture teams' actual behaviours, some potential factors might influence the performance or the relationship between performance and conflict. This means the findings may confine generalizability. The relationship found in this research might be proven only in the exact context. The team's conditions and the qualities of their outcomes are affected by various factors, including the internal and external environment. Further research will be expected.

6 CONCLUSIONS

This research is the first step in identifying the difference between teams with different performances by analysing dynamic patterns of conflict. In this study, we collected approximately weekly conflict data, visualised time series changes, and compared teams. The results revealed the difference between well-performed and not well-performed teams in task and relationship conflict patterns. Poorly well-performed teams scored significantly high values in task conflict, around five points. Two of the three teams showed high values throughout the project. In the relationship conflict, teams evaluated as not good also showed higher values than good teams. In process conflict, teams show similar patterns, possibly because of the fixed schedule. Furthermore, the weekly conflict patterns show the extreme points in some teams; it was possible to observe only by this approach, unlike data collection at two or three points in the project. Teaching teams can use the data to infer the team's condition or as supplemental information to decide when to interrupt and support student teams. Students can use this to reflect and analyse themselves more objectively. To use the data in a practical situation such as the above, further data collection and statistical analysis are required to make them more credible.

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TOWARD A CONFIGURATION DESIGN METHOD FOR MECHANICAL METAMATERIALS

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ABSTRACT
Metamaterials are materials that exhibit behavior that is not observed commonly in nature, but that can be achieved by designing often complex geometric structures. Behaviors such as negative index of refraction, negative Poisson's ratio, or negative stiffness can be achieved with suitable lattice or other cellular structures at appropriate size scales. Such materials can be used in many applications to achieve functionalities that would otherwise be difficult to realize and can lead to innovative solutions. Assuming they exist, designers need a design method capable of identifying when metamaterials are suitable to use as a component in a developing system design. In this paper, we present a configuration design method to meet this need. From a selected function, designers should identify a suitable physical principle and model of desired behavior, then these can be matched to metamaterials and their behavior capabilities. Examples are presented using mechanical metamaterials including bistable mechanisms that exhibit negative stiffness and lattice structures that exhibit negative Poisson's ratio.

Keywords: Metamaterials, bistable mechanism, negative Poisson's ratio, configuration design

1 INTRODUCTION

Metamaterials are materials that exhibit some behavior that is not observed commonly in nature, such as negative index of refraction, negative Poisson's ratio, or negative stiffness [1]. Designers can take advantage of such behaviors by designing cloaks, for example, that can "hide" objects from detection by electromagnetic, vibration, acoustic, or other energy. Such cloaking devices act as band-gap filters, taking advantage of a negative index of refraction for light or negative Poisson's ratio for vibrations. Many other types of applications have exploited such metamaterials, some of which will be explored in this paper.

Metamaterials are not homogeneous, solid blocks of metal or polymer; rather they are typically geometric structures or compositions of multiple bulk materials. Their behaviors are the result of a combination of the properties of their constituent bulk materials as well as the designed structuring. For example, structures with negative Poisson's ratio behavior are typically specially shaped lattice structures [2] as shown in Figure 1. Structures for cloaking of light or sound have other, more complex geometric shapes, but their presentation is out of scope for this paper.

In the metamaterials literature, the design of devices with metamaterial is largely ad hoc and focused on the mathematical models governing the metamaterial behavior of interest. It is unclear if any attempt has been made to systematize design methods and develop a more general design method for any specific metamaterial type, much less the class of metamaterials. This paper is an attempt to offer insights into modeling and designing metamaterial devices that could lead to a comprehensive design method. That is, the purpose of this paper is to help designers identify when metamaterials should be used in the design of an engineering system, rather than the design of the metamaterial itself. We focus on mechanical metamaterials with negative Poisson's ratio and that exhibit intermittent motions, in the form of bistable mechanisms [3], since they correspond to our areas of interest and experience. Reasoning about their unique behaviors is central to the method; however, we demonstrate that this reasoning can be systematized and embedded into an iterative design method by focusing on the device's forces, displacements, and energy relationships.

By configuration design, we mean the identification of components and devices that are in the designed system, their arrangement spatially and logically, and their interactions with other parts of the system [4]. This topic is highly related to product architecture design [5] where the emphasis is on establishing

the relationship between functions and forms. In this work, we focus on establishing an initial solution structure by identifying an appropriate metamaterial, but do not go further in analyzing modules and refining modular architectures using design structure matrix techniques, as many other researchers do (e.g. [6]. We start with a function structure and develop a behavior model, then select appropriate structures, borrowing heavily from function-behavior-structure [7] literature. Furthermore, we include some qualitative reasoning of behavior, much like the structure-behavior-function method [8]. A fully developed design method for systems that utilize metamaterials will likely share characteristics with other computational design synthesis methods such as those proposed in [9, 10]. At this preliminary stage, however, the proposed design method is of narrow scope and is focused on identifying when metamaterials are suitable using simplified causal reasoning models.
In the next section, we provide an overview of mechanical metamaterials, explain their behavior, and develop mathematical expressions of their behavior that will be utilized in the design method. The proposed configuration design method is presented in Section 3, followed by two examples in Section 4. Conclusions are drawn and future work outlined in the final section.

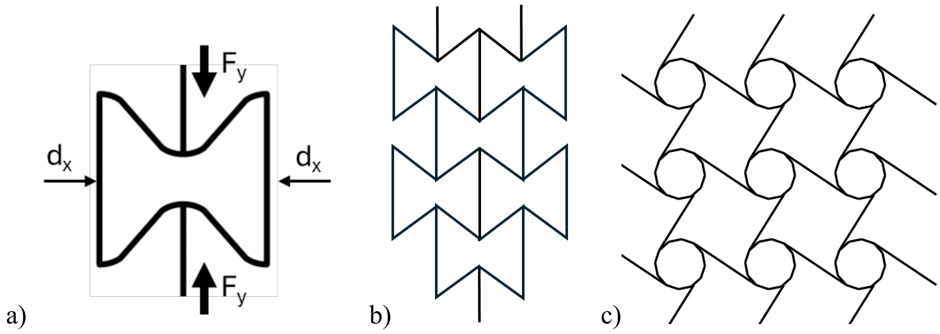


Figure 1: Auxetic materials, a) single unit cell, b) array of unit cells with simplified geometry, c) array of chiral cells. In all cases, applied compressive forces F_y cause contraction motions d_x.

2 MECHANICAL METAMATERIALS

Two types of mechanical metamaterials will be presented here, auxetic structures and bistable mechanisms.

2.1 Auxetic Structures

The term auxetic denotes negative Poisson's ratio. Typically, when a material is stretched, it contracts in lateral directions, consistent with the concept of conservation of mass. However, auxetic materials expand laterally when stretched; similarly they contract when compressed, as illustrated in Figure 1. Cork is an example of a material with approximately 0 Poisson's ratio; but as a general rule, materials have positive Poisson's ratios. Hence, auxetic behavior is achieved by constructing geometric shapes that have the desired behaviors. Two simple constructions are shown in Figure 1, but many more exist (good reviews are provided in [2, 11]).
Considering force-displacement relationships associated with behaviors governed by solid mechanics, a typical material exhibits a positive displacement in the direction of a given force. For the purposes of this presentation, displacements will be considered positive if they are in the same direction as forces that cause them. Hence, if a compressive force F_y in Figure 1a is considered negative, then it causes a negative displacement, $-d_y$. In the lateral direction X, a material with a positive Poisson's ratio will exhibit a positive displacement in the X direction, d_x. In contrast, an auxetic material, such as in Figure 1a, will exhibit a negative displacement. In 3 dimensions, a variety of similar reentrant lattice constructions are common as seen in Figure 2. For 3D, given the same compressive force, $-F_y$, the lateral X and Z displacements, d_x and d_z, respectively, will be negative for an auxetic material.
A behavior model can be derived for auxetic materials using these force and displacement terms. Such models will be given in the form of a rule with causality. The symbol ⇒ denotes "causes" in this work. In general 3D context, the behavior rule can be expressed as

$$F_x > 0 \Rightarrow d_x > 0 \Rightarrow d_y > 0, d_z > 0$$

This rule can be stated as: for a positive force F_x causes a positive displacement d_x which, in turn, causes positive lateral displacements d_y and d_z. Of course, the subscripts (directions) can be switched around to suit the geometric configuration being modeled.
In the case of 0 Poisson's ratio materials (0PR), the lateral displacements will be 0.

2.2 Bistable Mechanisms

A bistable mechanism has two stable equilibria corresponding to two different positions of the links in the mechanism. Transitions between states typically require little net power; input power and energy to cause the transition can be recovered in subsequent motion, which is helpful when the mechanism is used as an actuator. On the other hand, bistable mechanisms can be designed to absorb energy by transitioning between states with a loss of energy. Furthermore, when designed properly, the stable states of the mechanism can be robust to external disturbances which facilitates applications for locking mechanisms and energy traps. Figure 3 shows two types of bistable mechanisms. On the left, a simple mass is suspended by beam attached above and below it. The mass shuttles back and forth between the two positions indicated using solid and dashed graphics. In the left configuration, a force to the right that is above a certain threshold can cause the mass to snap to the dashed configuration. In contrast, forces below the threshold do not cause the transition, indicating stability. On the right, a 4-layer array of bistable mechanisms exhibits progressive contraction through beam buckling [12].
The metamaterial phenomenon exhibited by bistable mechanisms is negative stiffness. This type of behavior can be seen readily by investigating the force-displacement relationship (similarly the stress-strain relationship) of the mechanism as it undergoes loading. As is well known, the slope of a material's stress-strain curve is its stiffness, more formally called the elastic modulus. If the slope becomes downward, this indicates negative stiffness.

Figure 2: 3D auxetic unit cell.

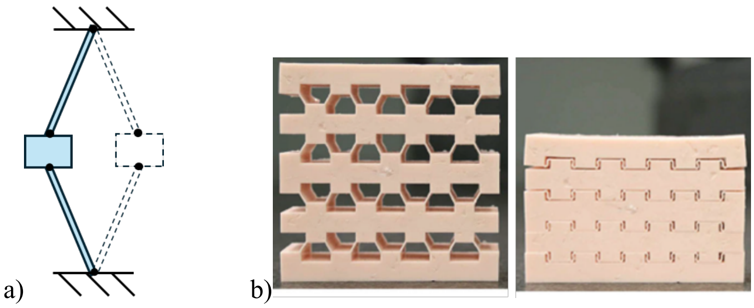


Figure 3: Two types of bistable mechanisms that rely on beam buckling to transition between equilibrium states. Mechanism b) [12] is considered to be multi-stable since it consists of 4 rows of collapsible beams.

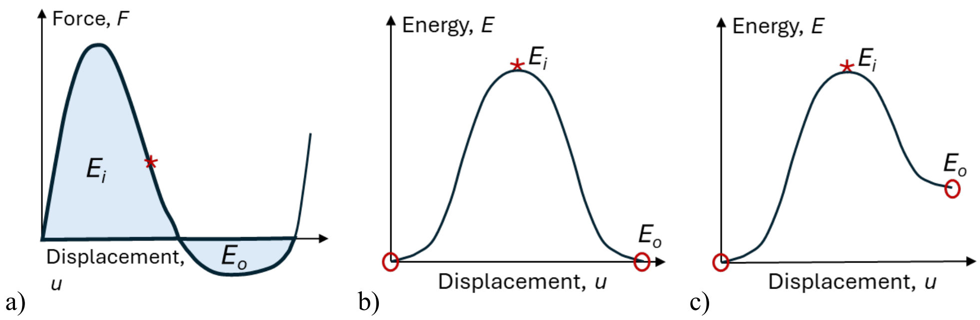


Figure 4: Notional force and strain energy relationships as a function of displacement for the mechanism in Fig. 3a (a, b) and energy for the mechanism in Fig. 3b (c). Red circles indicate stable equilibria. The red '' indicates an unstable equilibrium position.*

A typical force-displacement curve for a bistable mechanism is shown in Figure 4a. After reaching its peak, the curve turns downward, corresponding to the buckling of a beam(s) in the mechanism. If the curve goes into the negative force region, this indicates that the buckled beam is transferring energy to the structure; that is, it is exerting a force in the direction of mechanism motion. The area under the force-displacement curve indicates the strain energy associated with the material. The area labelled E_i

indicates the energy associated with deforming the mechanism until it reaches the snap-through point. Area E_o indicates the energy into the mechanism from the buckled beam. The difference $E_i - E_o$ corresponds to the energy that is "locked into" the mechanism after snap-through; much of this can be recovered upon returning it to its original configuration. Strain energy as a function of displacement is plotted in Figure 4b that shows energy troughs that correspond to the bistable mechanism's two stable states. The peak between them represents the energy barrier that needs to be applied to cause a state transition. This peak corresponds to the inflection point of the force-displacement curve in its down trajectory. These force-displacement and energy phenomena can be applied in many applications, three of which are described here.

Actuator

Qualitatively, if a bistable mechanism is pushed so that it deforms a bit, then it will snap-through, providing a jump in displacement. The ratio d_o / d_i indicates the motion amplification that results, where d_i is the displacement until snap-through and d_o is the displacement after snap-through. Stated mathematically, a force F_i resulting in a displacement d_i causes an increased displacement d_o. Stated as a rule, this relationship could be expressed as

$$F_i > 0 \Rightarrow u_i = d_i \Rightarrow u = d_o$$

where u is the displacement and is in the same direction as F_i.

Energy Absorber

Bistable mechanisms have been proposed for many types of energy absorber applications, including armor, helmets, and other sport equipment. Considering the energy-displacement curve in Figure 3b, energy absorption is indicated by the difference between the peak and the right-hand stable state, $E_i - E_o$. This energy difference is a function of both the snap-through behavior and any hysteresis in the mechanism itself, typically caused by viscoelastic behavior of its material. Stated as a rule, the relationship between these quantities can be expressed as

$$F_i > 0 \Rightarrow u = d_i,\ E = E_i \Rightarrow u = d_o > d_i,\ E_{abs} = E_i - E_o$$

where E indicates strain energy and E_{abs} denotes absorbed energy. Restated, input force F_i causes displacement d_i and strain energy E_i which then causes the jump to displacement d_o and energy absorption E_{abs}.

Contraction/Expansion with Intermittent Motion

This application could be considered as a special case of an actuator, but is intended to indicate that it is the change in length of a structure as being of interest. The behavior can be explained as an applied force F, less than or equal to some force threshold, F_{th}, causes a series of intermittent motions. Expressed as a rule, the behavior can be described by

$$F_{th} > F_i > 0 \Rightarrow u = n\ \delta$$

where n is the number of intermittent motions (indicating the number of bistable mechanisms linked serially) and δ is the magnitude of the displacement.

3 DESIGN LIBRARIES

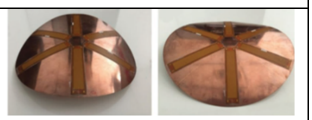
Since awareness is an important element in designing with metamaterials, the development of browsable design libraries is proposed to enable designers to explore different physical principles and metamaterial types and applications. The two design libraries described here include information that will be useful in support of system design. The first design library is for physical principles, as presented in Table 1, which has three representative principles, 1 or 2 levels of sub-principles, and qualitative behavior models similar to those presented in Section 2. The entries were chosen to for their relevance to designing with metamaterials and to the specific mechanical metamaterials of interest in this paper. The insight that led to this library was that simple qualitative behavior models were sufficient to distinguish common physical principles from the uncommon principles that govern the behavior of metamaterials. Regarding notation, most symbols were defined in Section 2. Others are: T is torque, φ is rotation angle, η is refractive index, and θ_x are angles of refraction.

Table 1. Physical principle design library

Solid mechanics	**Sub-topic**	**Qualitative behavior model**
Continuum mechanics	Positive Poisson's ratio	$F = \mathbf{E}d$, $F_i > 0 \Rightarrow d_i > 0 \Rightarrow d_j < 0, d_k < 0$ $i,j,k \in \{X, Y, Z\}$
	0 Poisson's ratio	$F_i > 0 \Rightarrow d_i > 0 \Rightarrow d_j \cong 0, d_k \cong 0$
	Negative Poisson's ratio	$F_i > 0 \Rightarrow d_i > 0 \Rightarrow d_j > 0, d_k > 0$
	Positive stiffness	$F_j > F_i > 0 \Rightarrow d_j > d_i > 0$
	Negative stiffness	$F_j < F_i > 0 \Rightarrow d_j > d_i > 0$
Kinematics		
Intermittent motion	Linear motion (linear ratchet)	$F_{th} > F_i > 0 \Rightarrow u = n\ \delta$
	Rotary motions (rotational ratchet)	$T_{th} > T_i > 0 \Rightarrow \varphi = n\ \varphi_\delta$
Nonlinear optics	Positive refractive index	$\eta = \theta_o / \theta_i$, $\theta_o > \theta_i$,
	0 refractive index	$\eta = \theta_o / \theta_i$, $\theta_o = \theta_i$,
	Negative refractive index	$\eta = \theta_o / \theta_i$, $\theta_o < \theta_i$,

The second design library has several example metamaterials, references to their governing physical principles, expressions relating dimensions to properties or motions, and references to typical geometric implementations. Only two metamaterial classes are provided, for brevity. In the parametric models, **E** denotes elasticity tensor, ν is Poisson's ratio, κ is curvature, l, d, t represent length, diameter, and thickness dimensions, and u is displacement. The buckling surface images show a buckling disk in its two stable shapes with the curvature axes rotated 90 degrees from each other [13].

Table 2. Metamaterial design library

Type	**Sub-type**	**Physical principle**	**Parametric model**	**Image**
Auxetic	Linkage	Negative or 0 Poisson's ratio	$\mathbf{E} = \mathbf{E}(l,d,\text{topology})$, $\nu = \nu(l,d,\text{topology})$	Figs 1b,2
	Chiral structure	Negative or 0 Poisson's ratio	$\mathbf{E} = \mathbf{E}(l,d,\text{topology})$, $\nu = \nu(l,d,\text{topology})$	Fig 1c
Bistable mechanism	Buckling beam	Negative stiffness, Linear motion	$u = n\ \delta = f(l,t,d)$	Fig 3
	Buckling surface	Negative stiffness, Surface buckling	$\kappa = \kappa(D,t)$	

4 CONFIGURATION DESIGN METHOD

As stated in Section 1, the purpose of this paper is to help designers identify when metamaterials should be used during the design of an engineering system, rather than to design the metamaterial itself. The metamaterial is envisioned to be a component in a larger system being designed. The scope of the proposed configuration design method is the search for solutions to the functions in the function structure. The designer should choose a function, or a set of related functions, then start developing a solution. For that, s/he should identify physical and solution principles, develop behavior models, and select specific components and devices to implement the solution. Further, the method assumes that the designer may not be well acquainted with metamaterials so will likely select conventional physical principles and solution concepts. An insight that distinguishes this work as focused on metamaterials is as follows. Metamaterials exhibit behaviors that may seem impossible, or at least unusual. They present an apparent contradiction between what is needed (e.g., auxetic behavior) and what is familiar (e.g., positive Poisson's ratio). From that viewpoint, this work shares an interest in the contradictions that are central to Triz-based design methods [14]. The method then guides the designer to a behavior model, or a different physical principle, that meets the design requirements.

The proposed design method is listed in Figure 5. From a selected function, or set of functions, the designer identifies a candidate physical principle and develops a solution using that principle. A behavior model for the solution should be developed and quantified so that it can be evaluated analytically. That is, parameters and dimensions should be identified and related using analytical expressions based on the physical principle. The model should also integrate with the behavior model for the rest of the developing system solution, as appropriate. Then, the solution's behavior should be evaluated and compared against the design requirements.

If requirements are not met, then the design needs to be modified. Assuming the designer utilizes the previously selected physical principle (Step 9.a), then they should try to identify a parameter in the underlying math model of the principle such that a value for that parameter can be computed that enables the design requirement to be achieved. For example, an auxetic material has a negative Poisson's ratio; Poisson's ratio is the parameter associated with continuum mechanics (selected physical principle) and any negative value will enable lateral expansion of a material when it is under tension. A conventional approach involving continuum mechanics would have assumed a positive Poisson's ratio, which could not achieve simultaneous expansion under tensile loads. If the incorrect physical principle was identified originally, a new one should be investigated. The designer has already identified a solution principle and behavior model and quantified parameters in the previous design iteration. With this additional knowledge, they should be able to identify a more promising physical principle and adjust the behavior model accordingly. This would be case when considering a bistable mechanism and using Hooke's law governing solid materials as the governing physical principle. By changing to an intermittent motion principle, a bistable mechanism could be identified as a suitable solution and its behavior model developed by modifying the previous model. This method and the examples will be investigated in more detail in the next section.

For implementation, a library of physical principles should be developed, as well as a library of metamaterials, along with their behavior models. This work is underway but will not be reported here. For the purposes of this paper, only the metamaterials and physical principles discussed in Section 2 will be considered. Desired behaviors will be expressed using relationships similar to those in Section 2 and will be matched to the presented metamaterial behavior models to identify suitable metamaterials.

1. Identify candidate physical principle to implement the selected function(s)
2. Propose a solution concept based on the physical principle
3. Develop a behavior model
4. Identify and quantify physical parameters associated with relationships in the model
5. Evaluate behavior
6. Does device's behavior meet requirements?
    7. If so, then done
    8. If not, then
        9.a Identify relationships governing the physical principle's behavior OR 8.b Identify different physical principle that is closer to the desired behavior
    10. Identify parameter value of physical principle model that satisfies the requirement
    11. Find solution with that parameter value that achieves the desired behavior
    12. Update solution concept and return to Step 2

Figure 5: Configuration design method for metamaterials

5. EXAMPLES

5.1 Extending Beam

Assume that it is desired to design a beam that can expand by 20% in length but maintain a constant cross-section. Zero Poisson's ratio (0PR) materials could be used to maintain the constant cross section. The problem and proposed solution elements are shown in Figure 6. A scissors mechanism will be chosen to fulfill the extension requirement. However, as it extends, the mechanism contracts in the lateral (Y) direction. Any structures connected to the scissors will be deformed accordingly.

To maintain a constant cross-section, accommodations must be made for these lateral displacements. These requirements can be stated more precisely as: beam extension d_x causes lateral displacement $-d_y$. At cross-section boundaries, $u_y = u_z \cong 0$. To be able to match to the metamaterials, the requirement will be specified as a rule:

$d_x > 0 \Rightarrow u_y = -d_y \Rightarrow u_z = 0$

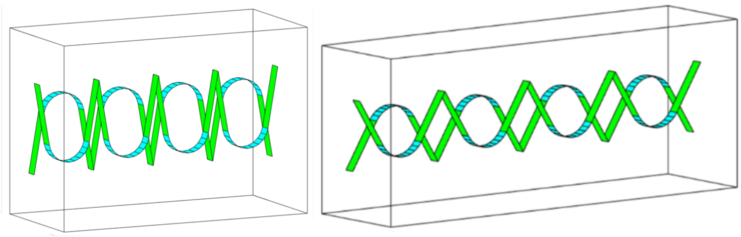


Figure 6. Extending beam example shown in beam's initial (left) and final (right) shapes

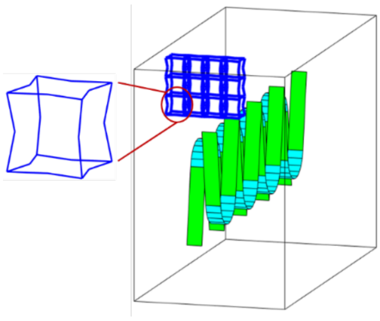


Figure 7. Extending beam example showing a partial row of 0PR unit cells

These requirements indicate that a 0PR material could be used to comprise the beam, since this requirement can be matched to the 0PR form of the auxetic behavior rule: u_y is not 0 and u_z is 0. That is, the scissors mechanism is the actuator that performs the extension, but the remaining volume within the beam is filled with 0PR lattice structure. Figure 7 shows an end-view of the beam with one row of 0PR lattice structures to illustrate the concept of connecting the scissors mechanism with the 0PR material to ensure the side and top walls maintain their positions.

5.2 Closure for Wearables

In the design of wearable devices, a requirement for good body fitting is often necessary. We are interested in developing a variety of assistive and rehabilitation devices for patients that augment or exercise joints, such as knees, elbows, and wrists. Such devices need to fit the patient's body parts well. Furthermore, for home usage, it must be easy for patients, who may have physical disabilities, to attach and remove the devices. Easy-to-use adjustments are needed.

We are developing a series of adjustable closures for these wearables. One type is meant to be adjustable by simply compressing the closure with a modest force to tighten it, then use body heat as the stimulus for a shape memory material to progressively release the closure. Stated more precisely, the requirement is that with a limited force, a series of discrete displacements is achieved. Mathematically, the tightening operation can be expressed as: $F_{th} > F_i > 0 \Rightarrow u = n\ \delta$. Since this is the same expression used to define the contraction/expansion with intermittent motion application of the bistable device, the progressive tightening operation can be performed by a series of bistable mechanisms connected in series. Note that the negative stiffness physical principle associated with bistable mechanisms is not needed for mechanism identification. A mock-up of a wearable on the calf with a 4-layer bistable mechanism to adjust tightness of fit is shown in Figure 8.

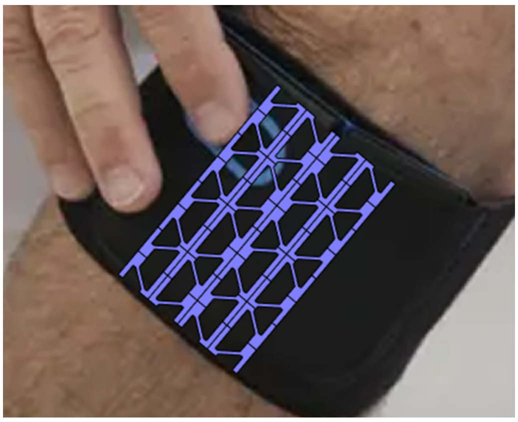


Figure 8. Bistable mechanism to adjust fit of wearable.

6. CONCLUSIONS

This paper introduced preliminary work towards a design method for identifying when metamaterials are suitable to use as a component in a developing system design. With their uncommon behaviors, metamaterials can be used to achieve functionalities that would otherwise be difficult to realize. Auxetic and bistable mechanisms were presented as example metamaterials and are related to their underlying physical principles. Snapshots of physical principle and metamaterial libraries were included to illustrate the type of information that should be available for designers to browse and use in the design method to configure solutions. Examples were presented to illustrate the usage of the design libraries.

Based on this work, simple qualitative physics models can be used to represent metamaterial behavior in a manner that facilitates identification of opportunities to utilize metamaterials in a developing design. If the behavior needed to achieve a function, or set of functions, is described using a similar qualitative model, physical principles and metamaterials can be identified. These qualitative models should represent forces, energy states, and resulting motions that describe essential metamaterial behaviors. Future work should explore additional metamaterials and governing physical principles to ensure broad applicability. More extensive design libraries should be developed, and a formal grammar developed to represent the qualitative physics models. The proposed configuration design method should be updated and tested to verify its correctness and usefulness.

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UNIVERSITY EMBLEM SYMBOL CONSTITUTION AND CONNOTATION ON THE BASE OF IDENTITY CONSTRUCTION -- TAKE 985 UNIVERSITY AS AN EXAMPLE

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ABSTRACT
The emblems of universities, as symbols of their identity, incorporate the unique characteristics and development goals of each institution. Based on Identity Construction Theory, this paper uses Saussure's two-axis analysis method to examine the symbolic composition of the emblems of 39 domestic 985 universities at the levels of personal, social, role, linguistic, and interactive identities, while exploring their underlying design thinking and connotations. According to these five levels, the design form is divided into five categories: history and culture, geographical indications, education features, school mottos, and dynamic development. It is concluded that the symbols in the university emblem have multi-dimensional connotations and promote the identity construction of universities to varying degrees. This study aims to provide new ideas from a design perspective for the identity construction of universities and offers new perspectives on image shaping and identity recognizing.

Keywords: University Emblems, Identity Construction, Symbolic Composition, Design Thinking

1 INTRODUCTION

1.1 Research Background

As higher education is emphasizing by China, the development and construction of universities have become one of the cores of social progress. As cultural symbols, university emblems can reflect a university's history, characteristics, and cultural philosophy. They are crucial for both internal and external promotion and help enhance the university's reputation and influence[1]. Despite the diversity in the design of university emblems in China, there are common design patterns that allow people to intuitively perceive the similarities and differences between different university emblems, reflecting each institution's construction concepts and methods of identity building.

1.2 Research Ideas

Based on this social context, this study utilizes Identity Construction Theory to conduct an in-depth analysis of the emblem designs of 39 Chinese 985 universities, exploring their identity construction in terms of personal identity, social affiliation, role positioning, linguistic expression, and interactive relationships, refer to Figure 1. This research aims to deconstruct emblem designs using Saussure's two-axis analysis method, extracting semantic keywords and analyzing the symbolic elements to reveal the thinking patterns and connotation embedded in the emblem designs. Furthermore, it seeks to provide innovative perspectives for universities and other organizations in shaping their image and constructing their identity through design.

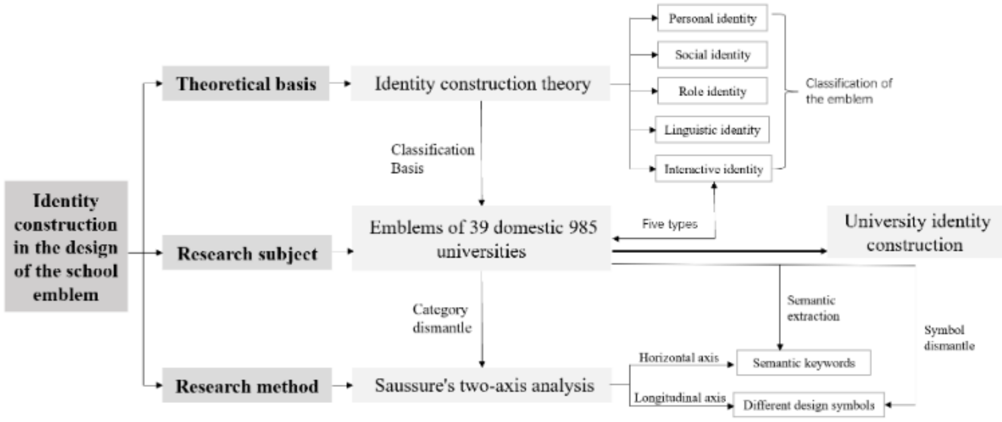

Figure 1. Framework diagram of research ideas

1.3 Review of University Emblem Design Research

The design of university emblems has been analyzed in terms of design cognition by scholars at home and abroad from different aspects. Ahn (2013) put forward the connection between university emblems and dentities, and through user research on the preference analysis of South Korean university emblem designs, it was concluded that emblems with the types of vision, ideas and directions are more influential[2]. SJ Go (2021) further compared the emblems of South Korean universities with Chinese universities and pointed out the problems existing in the design of Chinese university emblems[3]. ČÁBYOVÁ et al. (2020) took the emblems of several universities in Slovakia as examples, pointed out the importance of visual identity in university communication, divided them into categories such as figure marks and abbreviations of names, and gave corresponding design strategies[4]. Bayirli (2022) took the emblems of 200 universities in Turkey as examples and analyzed their design trends in terms of form, color and background[5]. At present, foreign research on university emblems is relatively sufficient, and corresponding research has been carried out with the emblems of different countries as representatives. However, in China, there is relatively less research on the design of university emblems, and there is a lack of research on its internal identity construction.

2 CLASSIFICATION OF IDENTITY CONSTRUCTION IN EMBLEM DESIGN

Identity is a sociological concept that refers to the social attributes of individuals or groups, presenting as their positions or statuses in certain social relationships, or the roles they play in society, reflecting the division of social roles in a specific society[6]. Identity Construction Theory is a multidimensional social psychology theory that explores how individuals or collectives form and develop identity through social interaction[7]. Stryker (1980) proposed Identity Theory, suggesting that the roles individuals play in society are internalized as identities, and the integration of these identities constitutes the self[9]. From the perspective of social psychology, Tajfel and Turner (1986) proposed Social Identity Theory[8], which forms social identity through processes of social categorization, social comparison, and positive distinctiveness[10]. Simon (2004) proposed the Identity Self-Orientation Model, where the self includes personal attributes and characteristics, and identity possesses both cognitive and social aspects[11]. As research gets deeper, scholars have gradually recognized that identity construction is a dynamic, multi-level, and strategic process[12], influenced by various factors such as social structure, cultural background, and individual psychology[13]. By organizing these theories, it can be found that the core of identity construction theory mainly involves five levels: personal, social, role, language, and interactive identities.

In emblem design, Identity Construction Theory can help understand how emblems reflect and shape a school's identity. The diverse symbolic language in emblem design also exhibits certain regularities and can form generalized classifications. Emblems usually contain symbols such as the school's history and culture, educational philosophy, and social status, and convey the university's collective identity through visual symbols[14]. This paper chooses to extract and classify the most typical features reflected in the emblems of 39 domestic 985 universities according to the five levels in Identity Construction Theory. These correspond respectively to History and Culture representing the university's personal identity, Geographical Indications representing social identity, Educational Features representing role identity, School Mottos representing linguistic identity, and Dynamic Development representing interactive identity. The universities included in each category are listed in Table 1.

Table 1. Classification of school emblem design symbols

No.	Identity Construction	Classification	University
1	Personal Identity	History and Culture	Peking University
			Fudan University
			Renmin University of China Nanjing University
			Nankai University
			Beijing Normal University
			Tianjin University
			East China Normal University
			Sichuan University
2	Social Identity	Geographical Indications	Wuhan University
			Sun Yat-sen University
			Southeast University
			South China University of Technology
			Hunan University
			Shandong University
			Northeastern University
			Lanzhou University
3	Role Identity	Educational Features	Shanghai Jiao Tong University
			Beihang University
			Xi'an Jiaotong University
			Harbin Institute of Technology
			University of Electronic Science and Technology of China
			Chongqing University
			Ocean University of China
			Northwest Agriculture and Forestry University
			National University of Defense Technology
			China Agricultural University
			Northwestern Polytechnical University
4	Linguistic Identity	School Mottos	Tsinghua University
			Xiamen University
			Huazhong University of Science and Technology
5	Interactive Identity	Dynamic Development	Zhejiang University
			Tongji University
			Beijing Institute of Technology
			Central South University
			Dalian University of Technology
			Jilin University
			Minzu University of China
			University of Science and Technology of China

3 DECONSTRUCTION AND ANALYSIS OF SYMBOLIC COMPOSITION IN EMBLEM DESIGN

The design symbols within university emblems are the core elements of identity construction, capable of conveying information intuitively and effectively[15]. In different emblem designs, these symbols exhibit both commonalities and differences. By deconstructing them using Saussure's two-axis method, we can further determine the symbolic composition in each category of emblem design and the connotations they represent.

Saussure's two-axis analysis method is a concept he proposed in his linguistic theory, which includes two types of relations: "syntagmatic relations" and "paradigmatic relations"[16]. Syntagmatic relations refer to the meaningful ways in which linguistic symbols are combined in specific contexts; this relation is horizontal. Paradigmatic relations refer to the potential series formed in the human mind by linguistic symbols; this relation is vertical and involves relationships between symbols that can be mutually substituted[17]. By deconstructing each type of emblem design according to these horizontal semantic keywords and vertical symbolic representations, a clear understanding of their symbolic construction can be gained.

3.1 Personal Identity Symbols—History and Culture

The construction of personal identity in university emblems is mainly manifested through the institution's developmental history and the culture embodied in its evolution. Due to the characteristics of Chinese historical culture, most emblem designs can reflect developmental journey and features of Chinese culture, including calligraphy, patterns, and other elements. By deconstructing representative emblem designs in the history and culture category that reflect personal identity construction, four semantic keywords are extracted: Text, Humanistic Thinking, Implication, and Quality. By selecting and combining typical emblem of Peking University, Nanjing University, Tianjin University, and Sichuan University, the two-axis diagram of personal identity symbols is shown in Figure 2.

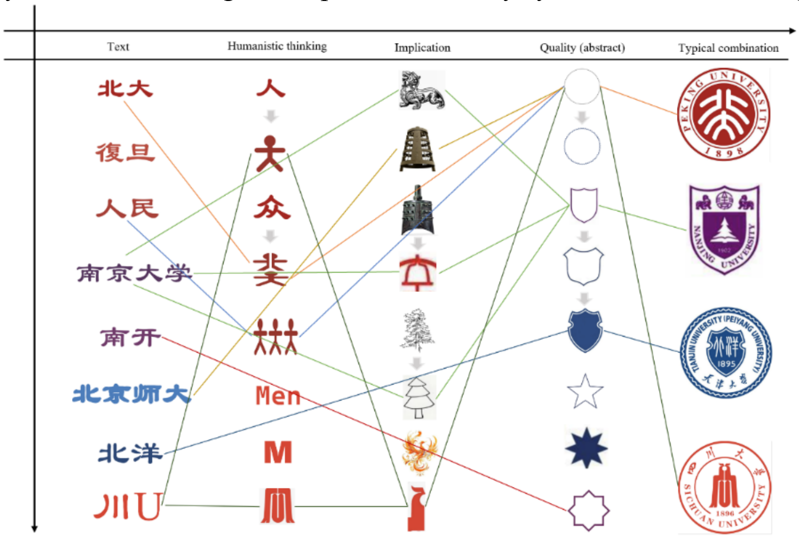

Figure 2. Two-axis diagram of personal identity symbols

By deconstructing these designs, it can be seen that university emblems that use history and culture as symbolic forms for constructing personal identity often deform and redesign the textual forms of their school names. They choose historical fonts, such as Small Seal Script, or select historical names like "Beiyang" to convey a sense of profound history. Besides, they utilize variations of the character "人" (meaning "person") to incorporate the traditional Chinese philosophical concept of "people-oriented" into the emblem design, thereby expressing the educational philosophy inherent in the university. Simultaneously, they convey cultural connotations through typical traditional Chinese symbols like the Pixiu (a mythical creature) and cedar trees, and they incorporate abstract geometric symbols that can represent qualities cultivated through education—such as circles expressing inclusiveness, shields symbolizing resilience, and polygons representing all-round development—into the emblem design. Through such symbolic construction that represent history and culture, universities can further construct a distinctive and meaningful personal identity.

3.2 Social Identity Symbols—Geographical Indications

In Identity Construction Theory, social identity construction is related to developmental backgrounds and distinctive social classifications[18]. In university emblems, social identity is connected to the school's geographical location and social status. Some of the emblem designs of the 985 universities use geographical indications or characteristic architectural forms as typical symbols. By deconstructing the emblems that reflect social identity construction through geographical indications, three semantic keywords are extracted: University Buildings, Regional Features, and Geographical Traits. We selected typical emblems of Sun Yat-sen University, Southeast University, Shandong University, Northeastern University, East China University of Science and Technology, and Hunan University to combine, resulting in Figure 3.

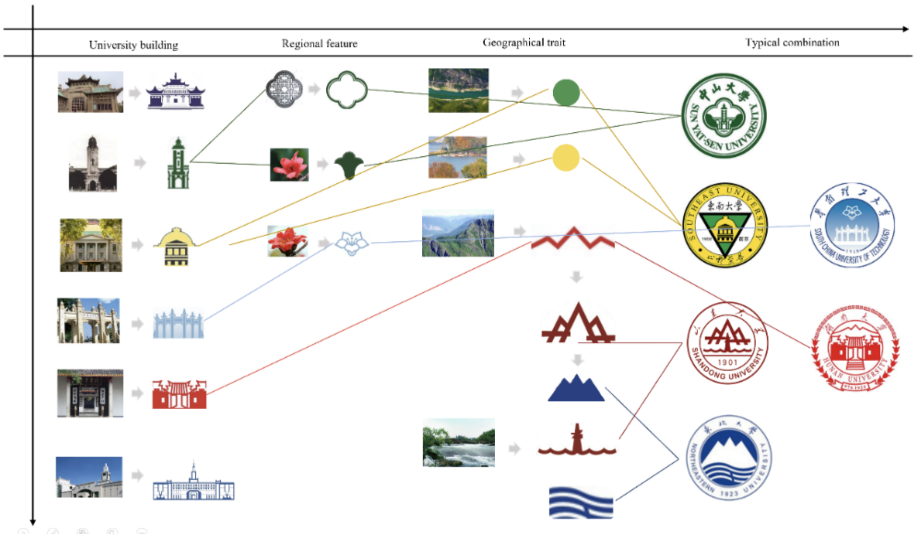

Figure 3. Two-axis diagram of social identity symbols

By deconstructing these designs, it can be seen that social status and geographical location are also important symbols in emblem design. In terms of architecture, emblem designs commonly choose buildings with historical and educational significance, such as libraries and monuments, simplifying and abstracting them to form symbols. For regional features, they often select local specialties or iconic vegetation to highlight the regional differences from other areas—for example, the kapok flower representing the Lingnan region. When choosing geographical traits, identity construction often relies on geographical locations and their representative landscapes, such as the "White Mountains and Black Waters" where Northeastern University is situated. Therefore, constructing social identity requires selecting representative symbols related to the local area while creating unique symbols based on their own identity. Combining the two allows universities to effectively construct their social identity.

3.3 Role Identity Symbols—Educational Features

Role identity construction is a multidimensional concept that involves how individuals or groups form and develop identity in different social and cultural contexts and interactions[19]. An important aspect of identity construction research is how role identity dynamically evolves in social communication interactions to meet specific communicative needs. By deconstructing the emblem designs of educational features that reflect role identity construction according to social positioning, two semantic keywords are extracted: Academic Features and Educational Identity. Academic Features can be further divided into six categories: Engineering, Aviation, Ocean, Electronic, Defense, and Agriculture. Representative universities are selected according to these six categories—namely, Shanghai Jiao Tong University, Beihang University, Ocean University of China, University of Electronic Science and Technology of China, National University of Defense Technology, and China Agricultural University—to combine, resulting in Figure 4.

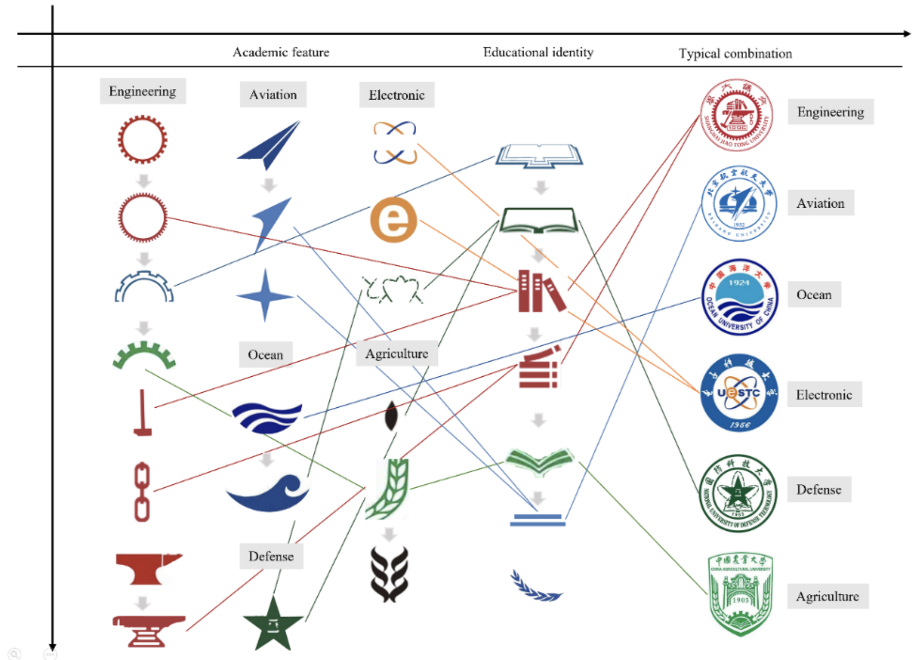

Figure 4. Two-axis diagram of role identity symbols

By deconstructing these designs, it is found that universities with a focus or strong disciplines often use symbols representing their academic features in their emblem designs to construct their role identity. For example, universities primarily centered on engineering often adopt symbols like gears and chains; universities specializing in electronic information tend to use symbols such as particle trajectories and electromagnetic waves. In emblem designs, the educational attributes of universities are usually symbolized by books. The use of these two types of symbols enables universities to establish clear characteristics and advantages, forming a representative role identity, thereby positively promoting their identity construction.

3.4 Linguistic Identity Symbols—School Mottos

Linguistic identity construction focuses on how identity is dynamically constructed, negotiated, managed, and disseminated in discourse interactions. Specific identities are built through discourse, emphasizing the contextual attributes when particular social identities connect with the immediate context[20]. In the design of university emblems, linguistic identity is manifested through variations in the font of school name and the inclusion of school mottos. Statistical analysis shows that among the 985 universities, Tsinghua University primarily constructs its identity through linguistic symbols, namely its school motto. Additionally, Huazhong University of Science and Technology and Xiamen University have incorporated their school mottos into their emblem designs. Their emblem designs are shown in Figure 5.

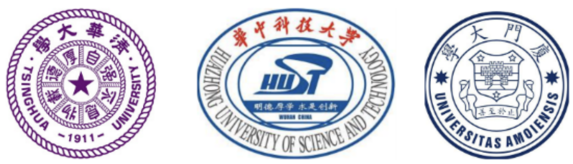

Figure 5. Design of the 3 emblems constructing linguistic identity

These three universities all use their school mottos as core design symbols, conveying the spirit of the mottos through a combination of text and images. The school mottos themselves, as language, can more intuitively convey the core philosophy compared to abstract symbols or images, and simultaneously serve to state identity. Using text as a symbol for graphical expression can make the meaning of the image explicit and clear. This method of directly constructing identity using the language of the school motto mainly involves the layout and transformation of the text, and uses the specific content of the language to perform the most direct linguistic identity construction.

3.5 Interactive Identity Symbols—Dynamic Development

Interactive identity construction is an important concept in identity construction theory. It emphasizes that identity is dynamically constructed in social interactions. The core idea is that it views identity as a dynamic phenomenon generated through the interaction within specific contexts. In interactive identity construction, identity is no longer a static concept but is continuously redefined and reshaped through ongoing social interactions[21]. Therefore, in the design of university emblems, symbols corresponding to interactive identity construction are defined as the dynamic development category. The same semantic elements can produce different expressions and symbols and convey dynamic effects. In this category, the selected semantic keywords are Forge Ahead and Relationship. Relationship can be divided into Union, Peace, and Responsibility. The representative emblems selected are Dalian University of Technology, Beijing Institute of Technology and University of Science and Technology of China, as shown in Figure 6.

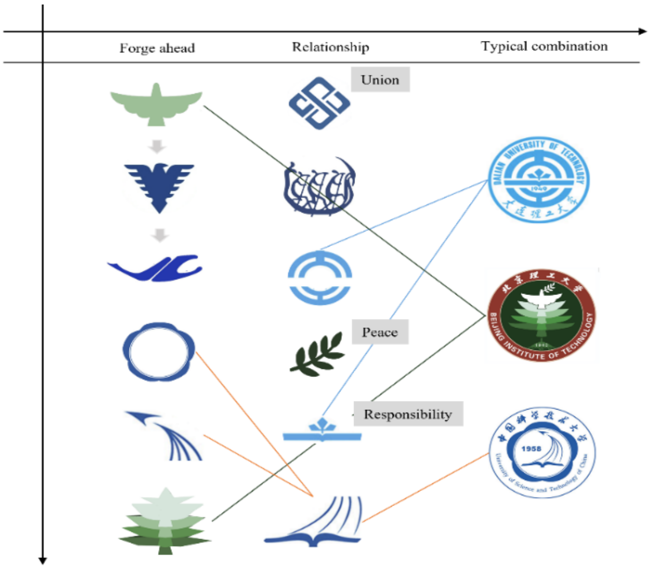

Figure 6. Two-axis diagram of interactive identity symbols

By deconstructing these designs, it becomes apparent that the symbols used to construct interactive identity often possess dynamic characteristics, such as an eagle with spread wings or a figure rowing a boat. These dynamic symbols can convey a spirit of striving and progress, aligning with the developmental philosophy of universities. Additionally, through the combination and arrangement of symbols, connections and relationships between different elements are established, showcasing interactivity through the construction of these relationships. In emblem design, the use of symbols with dynamic and interactive qualities can represent a dynamic development direction and continually evolving inner spirit of the university. Such dynamic symbols are conducive to making the identity construction more dynamic, creating interactive effects, and thereby promoting the advancement of university in keeping with the times.

4 RESULTS AND DISCUSSION

Conclusion

Based on Identity Construction Theory and employing Saussure's two-axis analysis method, this study conducted an in-depth analysis of the emblems of 39 domestic 985 universities. The research findings indicate that university emblems contain rich connotations through the use of symbols and facilitate the construction of university identities. Through analysis, this paper discovers that the design symbols in university emblems primarily exhibit the following characteristics in identity construction:

1. Personal Identity Construction

Emblem designs show the historical and cultural heritage of universities and their people-oriented educational philosophies through methods such as text deformation, the use of traditional symbols, and expressions of traditional qualities. The combination and transformation of these symbols further construct a distinctive and meaningful personal identity for the universities.

2. Social Identity Construction

Symbols representing social identity—such as buildings with historical and educational significance, regional characteristics, and geographical features—not only reflect the geographical location and social status of the universities but also enhance the recognition and sense of belonging associated with the emblems, which greatly construct social identity.

3. Role Identity Construction

Universities display their advantageous research fields and educational functions through academic features and educational identity symbols in emblem designs. This composition of symbols helps universities establish representative images and promotes the positive development of their identity construction.

4. Linguistic Identity Construction

As important carriers of linguistic identity, school mottos occupy a significant position in emblem design. Through specific font choices and linguistic expressions, school mottos directly convey the core philosophy of the university's development, facilitating the construction of the university's unique linguistic identity.

5. Interactive Identity Construction

The use of dynamic development symbols in emblem designs demonstrates the universities' dynamic development direction and their continuously evolving inner spirit. This enhances the interactivity and recognizability of the emblems and contributes to constructing the dynamic identity of universities.

Discussion

Through an in-depth analysis of the emblems of 985 universities, this study reveals the significant role of emblem design in identity construction. However, there are still some issues and future research directions worth further exploration.

1. Diverse Choice of Symbols

While this study has identified the commonalities and differences in the use of symbols in emblem designs, there is limited analysis on the reasons behind the selection and usage of symbols among different universities. Future research could delve deeper into the underlying reasons for these differences and their impact on university identity construction.

2. Other Elements in Emblem Design

This study focuses on the internal symbol composition, but lacks the research on the aesthetic characteristics of the school emblem such as form and color, which needs to be discussed at a deeper level based on relevant literature in the future.

3. Historical Evolution of Emblem Design

With the progression of time and societal changes, university emblem designs are continually evolving. Future studies can focus on the historical evolution of emblem designs, exploring the characteristics and changes of emblem designs in different historical periods, and how these changes contribute to shaping university identity recognition.

4. Cross-Cultural Comparison

This study primarily focuses on the emblem designs of domestic universities. Future research could expand to an international scope, conducting cross-cultural comparisons to explore the similarities and differences in university emblem designs across different countries and regions, and how they construct identity under different cultural backgrounds.

5. Innovation and Development of Emblem Design

With continuous advancements in design concepts and technologies, university emblem designs are also constantly innovating and developing. Future research can pay attention to the innovative trends and development directions in emblem design, exploring how to utilize new technologies and concepts to promote the innovation and development of emblem designs and their identity construction.

In conclusion, university emblem design plays a crucial role in identity construction. By deeply researching and discussing the symbolic composition and connotations of emblem designs, the process of constructing university identity is better understood. Future research can further broaden perspectives and methods to deeply explore the relationship between symbolic expressions in different designs and identity construction.

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DEVELOPING A SUSTAINABILITY ASSESSMENT INDICATOR FRAMEWORK FOR TEMPORARY USES BASED ON THE CASE OF THE FLOATING LAB

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ABSTRACT
In the surge of urbanization, cities face growing challenges in achieving resilience, equity, and sustainability. The temporary use of leftover spaces offers a potential solution, presenting new opportunities for sustainable development. However, the absence of comprehensive, measurable sustainability assessment (SA) tools for temporary use limits the optimization of these strategies. This paper addresses this gap by developing SA indicators tailored to the "Stand-in" strategy, a specific type of temporary use defined by the Urban Catalyst research group, within the Chinese context. Using the 2023 "Floating Lab" case in Shanghai's Knowledge and Innovation Community as a basis for scope definition and discussion, this research develops an SA tool for these temporary use cases.
The study is structured into three parts. In the first part, the initial framework is introduced, with indicators pre-selected from literature reviews. Feedback from 16 expert groups across four disciplines—academia, government and developers, content providers, and construction engineers—is synthesized to guide framework revisions. In the second part, key insights from these interviews are presented, followed by the detailed introduction of the revised framework, which incorporates a three-tier structure of 23 indicators across four sustainability categories. At the end of this paper, two potential application scenarios are proposed. This study provides a reference for developing generalizable SA tools for temporary use and offers an applicable tool for assessing the sustainable impact of similar temporary use cases.

Keywords: Temporary Use, Sustainable Assessment (SA) Indicator Framework, Urban Sustainable development, Expert Interview.

1 INTRODUCTION

In rapidly evolving world, the need for resilient, equitable, and sustainable urban development is increasingly urgent. Many developing countries are undergoing rapid urbanization, with spatial constraints in central areas presenting significant challenges in meeting the diverse societal and developmental needs of cities [6]. Despite this growth, many "leftover space" remain across cities globally. These spaces are often overlooked by large-scale developers due to their fragmented nature, short-term availability, and unclear boundaries, leading to wasted resources and reduced urban vitality [10]. This usustainability also results in economic and cultural losses. For instance, low-vitality spaces might lead to illegal activities, increase social security risks, and raise management costs. Thus, innovative solutions are vital for sustainably repurpose leftover spaces and enhance urban futures.
Temporary use strategies offer a promising approach to revitalizing leftover spaces. Unlike traditional developments, temporary use maximizes the utility of built-up spaces for a limited period without aiming for permanent occupation [8]. Temporary use provides flexibility in activating these spaces and is increasingly being applied worldwide. For example, the first Chinese leftover space planning guideline highlights "short-term mobility" as a key intervention [17].
However, despite its potential, there is a lack of integrated and measurable tools for assessing the sustainability impacts of temporary use. Triple Bottom Line (TBL) theory advocates for a comprehensive assessment of sustainability, covering environmental, social, and economic aspects [1]. In the context of temporary use, however, the absence of measurable environmental and social indicators has prevented decision-makers from taking a holistic approach to sustainability [18]. Tools like CASBEE-TC, developed for short-term buildings, focus primarily on “environmental quality and load

reduction” [11]. Similarly, Chinese national standard for Sustainability Evaluation Guidelines for Large Events (GB/T 44160) target temporary facilities but remain a traditional construction perspective[13]. Thus, sustainability assessment (SA) of temporary use remains a challenge.

In contrast, SA tools for traditional permanent development are well-established and widely applied. For instance, BREEAM and LEED are recognized and applied globally[9][15]. In China, the National Standard for Assessing the Sustainability Potential of Cities and Communities (GB/T 40757) also provides a SA tool for traditional space uses [12]. However, the differing goals and value between temporary and permanent uses make these tools unsuitable for evaluating temporary use. The lack of integrated and measurable SA tools hinders the optimization of temporary use strategies. In response, this study aims to develop a comprehensive, measurable SA framework for temporary use.

However, temporary use covers a wide spectrum. The European research group, Urban Catalyst identifies 8 models of temporary use, each with distinct goals, time constraints, and interactions with urban activities [16] [19]. Regarding the diversity, applying a universal SA framework to all temporary use models is impractical. Therefore, this paper does not seek to create a general SA tool. Instead, it focuses on the "Stand-in" strategy, one of the eight models, to develop a tailored framework and offer expert insights into the relevant indicators. While this paper provides an applicable SA tool for similar cases, it also aims to inspire further research on general SA tools for temporary use.

2 METHODS

This study employs a case study approach to define the scope and provide a practical context for expert discussion. The Floating Lab serves as a typical "Stand-in" in the Chinese context [16]. Conducted by the research team in 2023 in Knowledge and Innovation Community (KIC), Shanghai, the Floating Lab occupies a temporarily vacant street-side store. This vacancy arises from a 30-day gap between tenants. During this period, the Floating Lab hosted exhibitions and workshops, attracting 2,052 visitors. This effort revitalized the space that would otherwise left vacant, activating it before returning to its original state. Meanwhile, KIC, is known for its active temporary uses, e.g. weekend pedestrian streets, providing a rich context for SA tool development.

Table 1. Expert List

Area	Code	Position	Area	Code	Position
Academia	A1	PhD researcher in the field of social innovation design	Content Providers（e.g. start-ups, artists and NGO)	C1	Start-up founder
	A2	Associate Professor (Italian) in the field of temporary use		C2	Grassroots organizer team
	A3	Associate Professor (Chinese) in the field of sustainable design		C3	Grassroots organizer
	A4	Dean of research institution in the field of sustainable design and social innovation design		C4	NGO social worker and local resident
Government & Developers	B1	Real Estate Developer from State-Owned company	Construction Engineers	D1	Architect
	B2	Real Estate Developer from State-Owned company		D2	Design Consultant
	B3	Real Estate Developer from foreign-funded company		D3	Architect
	B4	Dean of Homeowners' Association		D4	Architect team

With the scope defined, the study employs a two-phase process to develop this SA framework. Firstly, potential indicators are identified through literature and producing a preliminary framework. The research team refines this list by removing redundancies, resulting in an initial framework. Afterwards, invitations are sent to over 30 individuals and working groups, yielding 16 valid interviews. These experts are drawn from 4 sectors: academia, government and developers, content providers, and construction engineers (Table 1). Noticeably, half of these experts (A4, B4, C2, C3, C4, D1, D2, and D3) are local participants currently or have participated in temporary use activities in KIC. Their interviews are recorded, transcribed, and coded, with the feedback synthesized. Based on their feedback, the initial framework is revised and sent back for confirmation, leading to the final SA indicator framework presented in this paper.

3 PRELIMINARY FRAMEWORK

The preliminary framework is developed through literature reviews, drawing from 3 primary sources: (1) existing SA tools, (2) research on the sustainability of temporary use, and (3) Chinese national standard and regulations. This process initially produces 63 indicators, which are subsequently refined to 20 for the initial framework (Figure 1). This initial framework was sent to experts before the interviews, and during the discussions, the focus is on refining the framework.

This framework employs a multidimensional, mixed-methods approach to assess the sustainability of temporary use, incorporating "narrative evaluation approaches for cases" [18]. A three-tiered SA framework was constructed to meet sustainability impact assessment goals, consisting of the criteria level, sub-criteria level, and indicator level. The next section summarizes key insights from the interviews, while Section 5 presents the revised framework in detail, with the expert comments.

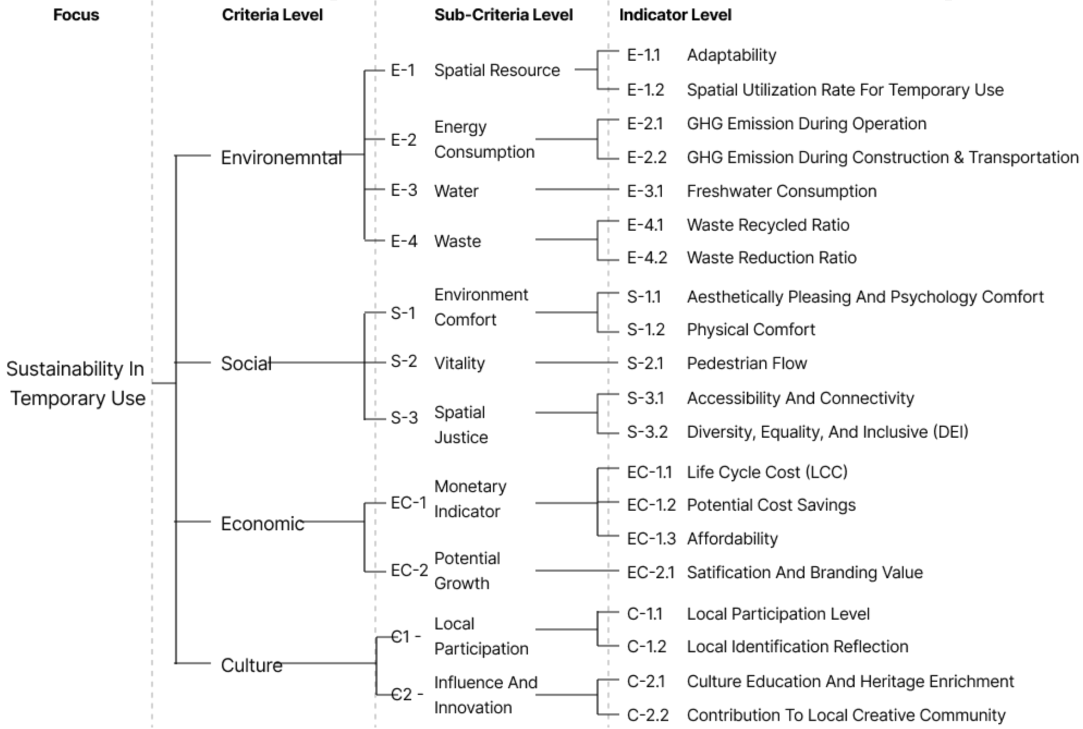

Figure 1. Preliminary SA Indicator Framework

4 EXPERT INSIGHTS

This four-criteria framework is developed based on TBL theory. While the traditional TBL model has limitations, recent research increasingly emphasizes the inclusion of cultural sustainability as a fourth dimension, recognizing its importance in sustainable development [7]. In temporary use projects, cultural sustainability also plays a significant role, especially for engaging local communities and marginalized groups [18][19]. Accordingly, this framework incorporates cultural sustainability as addition, with a focus on locality.

From the interviews, experts reached consensus on environmental and economic indicators, while the discussion focused on social and cultural sustainability. The insights are synthesized as follows.

- **Framework Comparisons:**Three experts compare the proposed framework with other SA frameworks. Expert B3 notes, "The cultural criteria remind me of the governance indicators in the ESG (Environmental, Social, Governance) framework." Similarly, Expert D1 suggests aligning this framework with the United Nations Sustainable Development Goals (SDGs).
- **Overlap Between Cultural and Social Sustainability vs. Emphasis on Locality.** Six experts perceive overlap between cultural and social sustainability. Expert A4 states, "Culture is the bond of society... local participation, for example, is a typical social sustainable indicator." However, most experts emphasize the importance of local culture in SA. Five experts strongly support

focusing on locality as a means to prevent the instrumentalization of temporary use for gentrification. Expert D1 concludes that while cultural criteria remains, all indicators should prioritize local identity and cultural capacity building.

- **Lack of Partnership-Related Indicators in Social Sustainability Criteria.** Two experts identified a absence of indicators for strengthening and renewing “partnerships” in the preliminary SA framework. D1 highlighted the importance of such indicators by referencing the Floating Lab project, where the temporary users collaborated with various stakeholders, including artists and community gardening groups, to co-create value.

Suggestions primarily focus on refining indicator names for clarity and avoiding redundancy, rather than changing the content. Moreover, Since there is no existing SA framework for temporary use to refer to, some experts express concerns about collecting quantitative data:

- **"Invisible Value Creation" as an essential Economic Indicator.** The sub-criterion of "potential growth" attracts considerable attention. The keywords of "barter trade among partners," the "ripple effect of Points of Interest (POI)," "branding value," and the "invisible economic value of charity" are frequently mentioned. Expert B3 cites the Floating Lab as an example: "The Floating Lab attracts 2,000 people, some of whom might dine nearby, boosting the local economy. However, quantifying that impact is challenging." Expert A2 suggests renaming the categories to "monetary flow" and "value flow" to better capture this indicator.
- **"Local Social Learning and Cultural Capacity" for Chinese-Speaking Contexts.** In the initial framework, the indicator “Culture Education And Heritage Enrichment” is developed from the international tool, BREEAM. However, during the interview, five experts raise concerns about the term "education," finding it too broad, and "heritage" as too closely tied to material or traditional aspects in Chinese contexts. Thus, Expert D4 proposes "community culture capacity" as a more suitable term, referencing the anime culture in the KIC neighbourhood also is an example of cultural capacity.
- **Challenges in Collecting Participant Data. S**ignificantly, all expert groups highlight challenges in gathering participant data for temporary use projects. Relevant data includes age, gender, occupation, intent, length of stay, visit frequency, satisfaction, and place of residence. Expert C2 notes, "Visitors may just want to explore and enjoy themselves, and might reject to provide personal information." Expert B3 proposes sampling research as a solution, while C2 suggests using co-creation whiteboards to encourage participants to record data collaboratively.

5 REVISED FRAMEWORK

Based on expert feedback, the initial framework is revised (Figure 2). The following sections dive into each sub-criterion and indicator,providing clarification on content and the measurement factors:

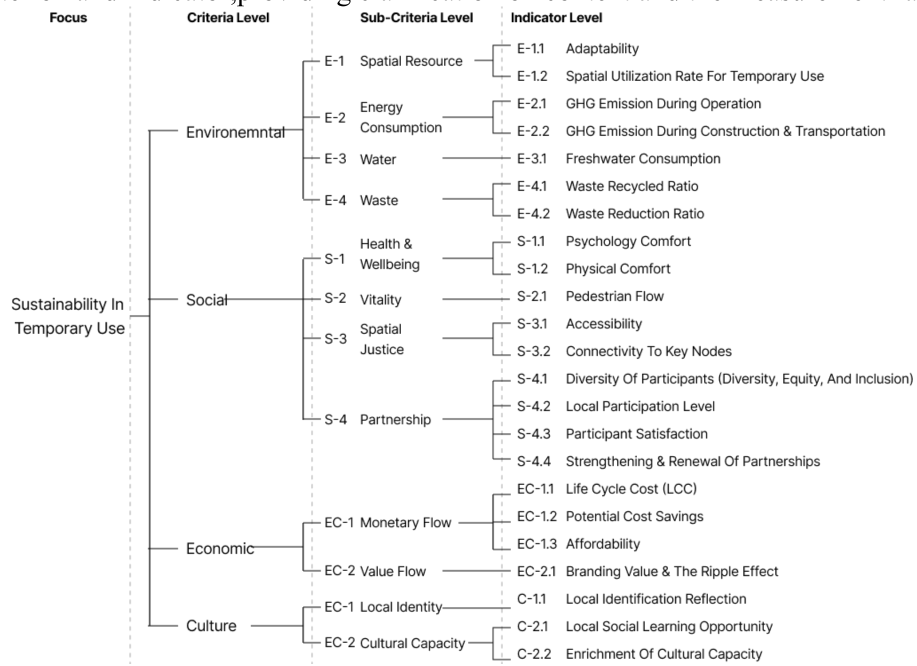

Figure 2. Revised SA Indicator Framework

5.1 Sub-criteria and Indicators for Environmental Sustainability

While the unsustainable impact of vacant leftover space has been noted, activating these spaces inevitably involves the consumption of environmental resources. This framework evaluates how efficiently and responsibly these resources are used, regarding the short life cycle of the "stand-in" strategy. The environmental criterion is subdivided into four categories: E-1 Spatial Resource, E-2 Energy, E-3 Water Resources, and E-4 Waste.

E-1 Spatial Resource

This sub-criterion assesses the efficiency and quality of temporary use in utilizing urban spatial resources across both temporal and spatial dimensions. Rating systems like LEED emphasize the importance of smart space selection and community planning to promote sustainable urban development [15]. The sub-criterion includes two indicators:

- **E-1.1 Adaptability:** This indicator evaluates how effectively temporary uses repurpose and adapt leftover spaces in a temporal perspective. As Expert A2 noted, "whether you can play with what you have", maximizing the use of existing infrastructure, is critical. Factors such as the condition of the leftover space and the ease of negotiations with property owners also affect this indicator.
- **E-1.2 Spatial Utilization Rate for Temporary Use:**This indicator measures the efficiency of temporary use by calculating the ratio of leftover space activated to the total leftover space available in the neighborhood. It draws from the "percentage of renovated buildings" in research by Rall and Haase [5] and space utilization metrics from GB/T 44160 [13].

E-2 Energy

In temporary use projects, energy consumption is significant, particularly during construction and transportation, which often exceed operational energy consumption [2]. Referring to LEED and the GB/T 40757 standard, greenhouse gas (GHG) emissions are a core indicator [12][15]. This framework divides energy consumption into two quantitative indicators:

- **E-2.1 GHG Emission During Operation** and **E-2.2 GHG Emission During Construction & Transportation.** Both indicators are measured in tCO2 eq/㎡/day, providing a precise reflection of environmental impact. All 16 expert groups agreed with this division, with some even noting the differing weightings of these two indicators in terms of overall sustainability impact.

E-3 Water

The Stand-in strategy commonly leverages the existing infrastructure of leftover spaces through short-term reoccupation. Thus, water consumption depends largely on the original design and facilities.

- **E-3.1 Freshwater Consumption:** Following the GB/T 40757, this indicator evaluates water efficiency [12]. It is assessed by comparing actual freshwater consumption with the theoretical consumption for the same space when vacant, measured in m^3/㎡/day.

E-4 Waste

The short life cycle of temporary use, particularly Stand-In types, poses challenges for waste management. Drawing from the GB/T 40757 standard and relevant studies [3][4][12], this criteria are divided into 2 quantitative indicators:

- **E-4.1 Waste Recycled Ratio:** This indicator measures the proportion of reusable, recyclable, and energy-recoverable materials to the total construction material used. This indicator emphasis what happen before and after the temporary use, e.g. the recycling pathways.
- **E-4.2 Waste Reduction Ratio:** This indicator assesses the reduction in waste relative to the total construction materials used, focusing on minimizing waste from the design stage, such as repurposing existing facilities in leftover spaces.

5.2 Sub-criteria and Indicators for Social Sustainability

By utilizing leftover space, temporary use strategies address diverse social needs and contribute to social sustainability. This framework structures the social criterion into three sub-criteria:

S-1 Health and Well-being
Although the stand-in strategy involves temporary use of leftover spaces, it still significantly affects the health and well-being of users. The Chengdu Guideline stresses the importance of comfortable furnishings, etc., to meet health needs [17]. This sub-criterion is further divided into 2 indicators:

- **S-1.1 Physical Comfort:**This indicator is standard across SA tools for traditional developments, e.g. China's Green Building Evaluation Standard (GB/T 50378) and LEED [14]. It uses systemic and quantitative metrics to evaluate air quality, thermal comfort, lighting, acoustics, and humidity throughout the temporary use life cycle.
- **S-1.2 Psychology Comfort:** This indicator addresses the mental health of users, incorporating elements like color psychology, spatial perception, connection to nature and aesthetic appeal.

S-2 Vitality
Temporary use strategies activate otherwise vacant spaces, introducing events, creating POIs, and enhancing neighborhood vibrancy,while reducing social risks. **S-2.1 Pedestrian Flow** is a common indicator in both research and existing SA tools. This indicator measures the vitality of spaces by comparing the average daily number of visitors during temporary use with that of the vacant period.

S-3 Spatial Justice
Temporary use strategies offer unique opportunities to promote spatial justice, particularly benefiting marginalized groups by creating accessible "incubators" for all community members [19]. The revised framework reflects significant changes compared to the initial version:

- **S-3.1 Accessibility:** This indicator assesses whether temporary uses are accessible to all social groups through both quantitative and qualitative measurements. Factors such as proximity to road systems, preferred neighborhood pathways, and transportation nodes are nominated in interviews.
- **S-3.2 Connectivity to Key Nodes:** This indicator evaluates whether temporary use establishes meaningful links with other spatial nodes in the surroundings. It assesses both strategic intentions and practical performance. As Expert C4, who is also a local resident, noted, “I like the idea of connection, but in practice, the community garden (one node the Floating Lab aimed to connect with) was too far, requiring a 10-minute walk... To achieving the intended connection, on-site staff need to persuade visitors to go there."

S-4 Partnership
This sub-criterion was not included in the initial framework but was proposed by experts during the review process. It builds on the Partnerships goal from the UN SDGs, which cross-sector collaboration can help achieve sustainability. This sub-criterion comprises four qualitative indicators::

- **S-4.1 Diversity of Participants (Diversity, Equity, and Inclusion, DEI):** This indicator evaluates the inclusiveness of the temporary use by considering the diversity of participants in terms of gender, age, disability, occupation, etc.
- **S-4.2 Local Participation Level:** This indicator measures the level of participation and the number of local community members, particularly marginalized groups, involved in the temporary use. As Expert B1 noted, “In KIC, local merchants and residents often have conflicting interests, with merchants usually having a louder voice. I hope that events like the Floating Lab can facilitate more seamless collaboration between these two groups.”
- **S-4.3 Participant Satisfaction:** Drawing from BREEAM and CASBEE, this indicator evaluates participant satisfaction based on factors such as length of stay and frequency of revisit. Sampling and questionnaires are employed to gather data from participants [9][11].
- **S-4.4 Strengthening & Renewal of Partnerships:** The keyword “ecosphere of participants” emerged during the interviews. This indicator evaluates whether original partnerships can be strengthened and new ones established by temporary use. Expert C2 stated, “The lack of information flow between partnerships is the biggest obstacle preventing cases like Floating Lab from occurring. For example, start-ups want to participate but do not know who to talk.”

5.3 Sub-criteria and Indicators for Economic Sustainability
Economic indicators are critical for evaluating the sustainability of temporary use strategies, particularly concerning financial returns and economic impact, which are top priorities for space users [18]. Based on expert feedback, the original two sub-criteria is renamed for clarity:

EC-1 Monetary Flow

This sub-criterion covers tangible, quantitative indicators derived from precise financial data, attracting the greatest interest among experts, with some claiming they are the most weighted factors:

- **ECO-1.1 Life Cycle Cost:** This indicator assesses the total cost of a project over its life cycle, including materials, labor, transportation, and related expenses. Based on research by Janjua et al., it involves a threshold comparison of the average daily cost per square meter for temporary use projects with similar developments in the same city [3].
- **ECO-1.2 Potential Cost Savings:** This indicator evaluates potential cost savings through temporary use, such as bargaining with landowner or adopting barter trade. As Expert B3 noted, “Through strategic negotiation with partners, Floating Lab saved cost significantly on rent and maintenance, which are considerable expenses in a costly city like Shanghai.”
- **ECO-1.3 Affordability:** As discussed, **t**emporary use aim to be accessible for low-incomers for experimental social innovation [19]. Drawing from Janjua et al., this indicator assesses the economic impact on users by comparing event costs to average local incomes [3].

EC-2 Value Flow

This sub-criterion addresses the potential economic value created by temporary use, a topic that initially sparked divergent opinions among experts. However, consensus was reached in the revised framework. **ECO-2.1 Branding Value & the Ripple Effect** evaluates the indirect economic growth resulting from temporary use, including the ripple effect and neighborhood brand enhancement.

5.4 Sub-criteria and Indicators for Culture Sustainability

Although some experts noted an overlap between cultural and social criteria, the final framework retains a distinct cultural category with a stronger focus on locality. Many existing tools emphasize the significance of locality in SA process, as CASBEE includes "Continuation of unique local character" [11], while BREEAM prioritizes local identity [9]. The final framework includes three indicators:

C-1 Local Identity

This sub-criterion emphasizes the significance of fostering a sense of identity and belonging within local communities, particularly among marginalized groups, in the context of temporary use. **C-1.1 Local Identity Reflection** evaluates the extent to which temporary use can express the uniqueness of local culture. As Expert D2 noted, “When a sense of belonging is established, marginalized groups are likely not driven away, and the unsustainable effects of gentrification can be somehow reduced.”

C-2 Cultural Capacity

This sub-criterion is emphasized in many existing SA tools. For instance, CASBEE encourages the enhancement of cultural activities in the community by providing spaces and facilities [11]. However, the use of term "cultural heritage," which carries different implications in Chinese-speaking contexts. Therefore, suggested by experts, these indicators have been renamed:

- **C-2.1 Local Social Learning Opportunity:** This indicator assesses the ability of temporary use to support local cultural capacity by providing learning opportunities and enhancing knowledge transfer. Expert A2 highlighted that, "The Floating Lab offers four artist workshops where local families can engage in activities like painting and jewelry making while learning about sustainability. It's a form of social learning to me, or you can say public education."
- **C-2.2 Other Enrichment of Cultural Capacity:** This indicator evaluates the indirect enrichment of local culture generated by temporary use. As Expert D4 noted, "The influence of the community management team and the Floating Lab has led to an increase in temporary uses within the KIC, creating a vibrant atmosphere and contributing to new community capacity."

6 CONCLUSION AND DISCUSSION

This study addresses the lack of a sustainability assessment (SA) tool for temporary urban use by developing an indicator-based framework, centered around a case study of the Floating Lab in China. The framework is initially structured from a set of indicators identified in the literature and refined through 16 expert interviews. At the end of this paper, resulting framework is presented, aiming to assess the sustainability impacts of future temporary uses.

Throughout the expert interviews, potential applications of this tool are widely discussed, leading to two primary application scenarios: (1) as a negotiation tool for initiators of temporary use projects and (2) as a project review tool for stakeholders.

In the first application scenario, this framework can systematically predict the potential sustainability impacts and value of upcoming temporary use events. Temporary use initiators, such as property owners of vacant leftover spaces or local residents aiming to activate such spaces, can leverage these evidences provided by the framework to persuade or coordinate with other stakeholders concerned with urban sustainability. Experts reveal the absence and importance of this tool when it comes to negotiation of temporary uses. In the second scenario, the framework serves as a feedback tool, allowing stakeholders of temporary use, especially investors and designers, to evaluate the sustainability performance and impacts of completed temporary use. This feedback loop not only informs more sustainable investment choices but also guides designers in refining strategies to enhance sustainability in future projects. Both are beneficial for the urban sustainable development.

To realize these scenarios, several study limitations should be addressed in future research. First, despite the refinement process of this framework, some ambiguity remains within certain indicators. For instance, indirect causal relationships among indicators may affect performance assessments, potentially amplifying or diminishing particular outcomes. However, these interactions may also reveal strategies that improve multiple indicators simultaneously, highlighting their unique sustainability value. Second, for efficiency, we reduced the granularity of certain well-established indicators in the expert interviews. For instance, we discussed physical comfort as a single concept (S-1.1 Physical Comfort) rather than dissecting it into specific aspects like acoustic and thermal comfort, which are already well-covered in other tools. While this approach streamlined discussions, future framework iterations should further detail each indicator to enhance practical value.

This study also uncovers research opportunities for future research. During the interviews, experts expressed varying degrees of importance and practical feasibility for each indicator, generating valuable raw data that can inform weighting and threshold calculations in future framework revisions. Methods like the AHP method and Delphi technique could refine this framework further, expanding its applicability across the cityscape and enhancing its contributions to sustainable development.

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HOW TO INCREASE CUSTOMER LOYALTY: KEY INSIGHTS INTO NPS SHIFTS IN PURE INTERNET BANKING EXPERIENCE

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ABSTRACT
The COVID-19 pandemic has accelerated the growth of FinTech in financial institutions. This study explores customer experience in Pure Internet Banking by analyzing the relationship between Perceived Value, Experience Domains, and Customer Loyalty through both qualitative and quantitative methods. Four experience domains—product, service, communication, and environment—are examined across Net Promoter Score segments to uncover key drivers that convert passive customers into loyal promoters. Results show that Customer Loyalty is strongly influenced by Perceived Values, with Functional Value playing the most crucial role. Service impacts all Perceived Value dimensions, while Communication significantly affects Emotional and Spiritual Values. This research provides insights for fostering innovation in Pure Internet Banking, driving targeted improvements to enhance customer loyalty.

Keywords: Customer Experience, Experience Domains, Perceived Value, Customer Loyalty, Pure Internet Banking

1 INTRODUCTION

With continuous advancements in technology and the increasing integration of digital systems, the global financial technology (FinTech) industry is experiencing a profound transformation, spurring the digitalization of the traditional banking sector. A 2017 survey conducted by PwC [1] revealed a significant rise in consumer reliance on internet banking, with usage growing from 27% in 2012 to 46% in 2017. Reinforcing this shift, McKinsey [2] reported that internet banking penetration in Asia expanded by 1.5 to 3 times between 2015 and 2018. The COVID-19 pandemic further accelerated this trend. For instance, Deloitte [3] observed that the number of first-time online banking users in Sweden doubled from 2020 to 2021. In Asia, digital banking has evolved rapidly, with Japan pioneering the trend by establishing Japan Net Bank in 2000, followed by the swift growth of institutions like Rakuten Bank. Between 2020 and 2022, Taiwan issued licenses for three fully digital, non-physical banks, marking a significant milestone in the region's transition to digital banking. As information and internet technologies continue to advance, the methods by which services are provided have fundamentally shifted. This wave of innovation has made a significant impact on the financial sector, evidenced by the rapid rise of FinTech companies in recent years. Pure internet banks, which operate entirely through digital channels, are particularly adept at leveraging technological advancements to quickly adapt and expand their service offerings. As of the second quarter of 2024, the market share gap between traditional and purely digital banks remains notable, with the former holding 88.82% and the latter accounting for just 11.18%. Taiwan's three digital banks collectively manage 2,492,721 accounts, with LINE Bank—launched on April 22, 2021—amassing 1,891,071 of these. In just two years, LINE Bank has secured an 8.48% market share and dominates approximately 75.86% of the pure internet banking sector in Taiwan [4]. These innovative service models are reshaping consumer expectations of digital banking and influencing their attitudes toward traditional banking services [5].

LINE Corporation's business portfolio extends well beyond banking, dominating Taiwan's social media sector. As reported in Digital 2024: Taiwan [6], by early 2024, 90.9% of internet users between the ages of 16 and 64 were using LINE, and 48.1% identified it as their top social media platform. This underscores the substantial growth opportunities for LINE Bank in the realm of pure Internet banking.

However, while the financial industry has seen significant technological progress, the predominant reliance on price competition among banks appears to be unsustainable. This strategy suffers from low service differentiation, negligible switching costs for customers, and weak brand loyalty. Moreover, a rush to leverage technology often leads to innovation focused solely on technical capabilities, rather than addressing the actual behaviors and needs of users. This disconnect complicates the potential for technology to build brand value and foster a sustainable loyalty loop. The Net Promoter Score (NPS), introduced by Frederick Reichheld in 2003 [7], remains a vital tool for measuring customer loyalty and driving improvements in business strategies, with long-term growth implications. For pure Internet banks like LINE Bank, which enjoy broad social network integration, shifting passive customers into loyal promoters is essential. Enhancing NPS is not merely about improving brand image, but also about building a stable customer base, leveraging positive word-of-mouth to reinforce favorable customer perceptions. Thus, the aim of this research is to explore customer experience in Pure Internet Banking, specifically investigating the relationship between experience differences among medium to high NPS segment customers and their mobility in terms of loyalty, in order to provide recommendations for business optimization. To achieve this, several key objectives are set:

1. To apply the Stimulus-Organism-Response (S-O-R) theory to construct a theoretical model, enhancing the understanding of customers' intrinsic needs throughout the process from service reception to loyalty formation, and identifying critical brand experiences.
2. To use NPS to assess the needs of Passives and Promotors, helping companies develop specific strategies for loyalty conversion under limited resources, and adjusting their experience design accordingly.
3. To examine the interaction between Experience Domains, Perceived Value, and Customer Loyalty through Structural Equation Modeling (SEM). We hypothesize that Spiritual Value, Emotional Value, and Functional Value positively influence Customer Loyalty, while Experience Domains (such as Product, Service, Environment, and Communication) significantly impact these values.

2 LITERATURE REVIEW

2.1 Pure Internet Banking

Pure Internet Banking operates entirely through digital channels, without physical branches or in-person services. Definitions may vary by country. Internationally, Internet-only banks are categorized by their operational models. In Europe and the U.S., these banks differentiate themselves from traditional models through technological innovation and enhanced customer experiences [8]. In Asia, however, the focus is often on a diversified shareholder structure, incorporating industries such as e-commerce, telecommunications, and retail to create a comprehensive ecosystem [9]. Based on shareholder composition, Internet-only banks are classified into four types: "technology creation," "bank/financial holding company investment," "group enterprise investment," and "group-bank joint ventures." European and American banks primarily fall into the first two categories, while the latter two are more common in Asia. In Taiwan, the Financial Supervisory Commission [10] defines pure internet banking as delivering financial services primarily via the Internet or electronic channels. These banks function like commercial banks but are limited to a head office and customer service centers, with no additional physical sales locations. This model, distinct from traditional banking, significantly reduces costs associated with physical infrastructure [11].

2.2 Customer Loyalty

Customer loyalty is a complex concept shaped by factors like experience domains and pricing. It reflects an attitudinal preference for a company, leading to repeat purchases and offering a competitive advantage [12][13]. Various indicators have been used to measure customer loyalty in research, each with distinct implications. Gronholdt et al. [14] identified four key indicators: willingness to repurchase, tolerance for price variation, likelihood to recommend, and cross-purchasing. Of these, repurchase intention and recommendation likelihood are considered the strongest measures of loyalty.

The Net Promoter Score (NPS), introduced by Reichheld [7] and expanded by Reichheld and Markey [15], is a widely used metric. It segments customers into three groups and provides both broad industry insights and customer-specific perspectives. Its simplicity and comparability make it ideal for resource-constrained companies to quickly evaluate customer relationships and prioritize strategies. This study utilizes the NPS to offer a holistic view of the brand's industry standing and customer perceptions.

Overall, customer loyalty can be divided into 'attitudinal' and 'behavioral' loyalty. Attitudinal loyalty focuses on maintaining a relationship with the service provider [16], while behavioral loyalty emphasizes the frequency and nature of purchases among available choices [17]. Thus, this study will explore both behavioral and attitudinal aspects of customer loyalty.

2.3 Perceived values and Experience domains

Perceived value is the customer's evaluation of a product or service [18], crucial in determining if needs and expectations are met [19]. It forms the basis of attitude, predicting behavioral intentions [20]. Understanding these intentions is essential for predicting customer loyalty. This study uses the perceived value measure by Sweeney & Soutar [21], refined with Maslow's Hierarchy of Needs [22]. The components are categorized as "spiritual," "emotional," and "functional" value. Spiritual value relates to self-worth and belonging; emotional value to positive feelings and safety; functional value to meeting basic needs.

Experience domains arise from interactions between service providers and customers during service delivery, representing the gap between expectations and actual perceptions [23]. High-experience domains are key for fostering customer loyalty [24]. According to Lai & Tang [25], customer experience comprises four dimensions: product, service, environment, and communication. Each uniquely shapes the overall experience. 'Products' include tangible and intangible offerings. 'Services' encompass behaviors of provision and receipt via personnel and digital channels. The 'environment' refers to the interaction space, both physical and digital. 'Communication' involves how enterprises engage with customers, directly and indirectly [26]. When these dimensions align, they enhance perceived value [27], improving the overall experience.

In summary, the study emphasizes a shift to service-dominant logic in the experience economy, highlighting the need for a holistic understanding of experience domains where products, services, environment, and communication shape customer experience. Based on the S-O-R theory (see Figure 1), the framework identifies "Stimulus" as the enterprise's experience domains, "Organism" as perceived value, and "Response" as customer loyalty. Using NPS to categorize customers, the study explores how different loyalty groups prioritize service and perceived value, aiming to identify factors influencing loyalty and propose strategies to convert neutral customers into promoters—particularly in the financial industry.

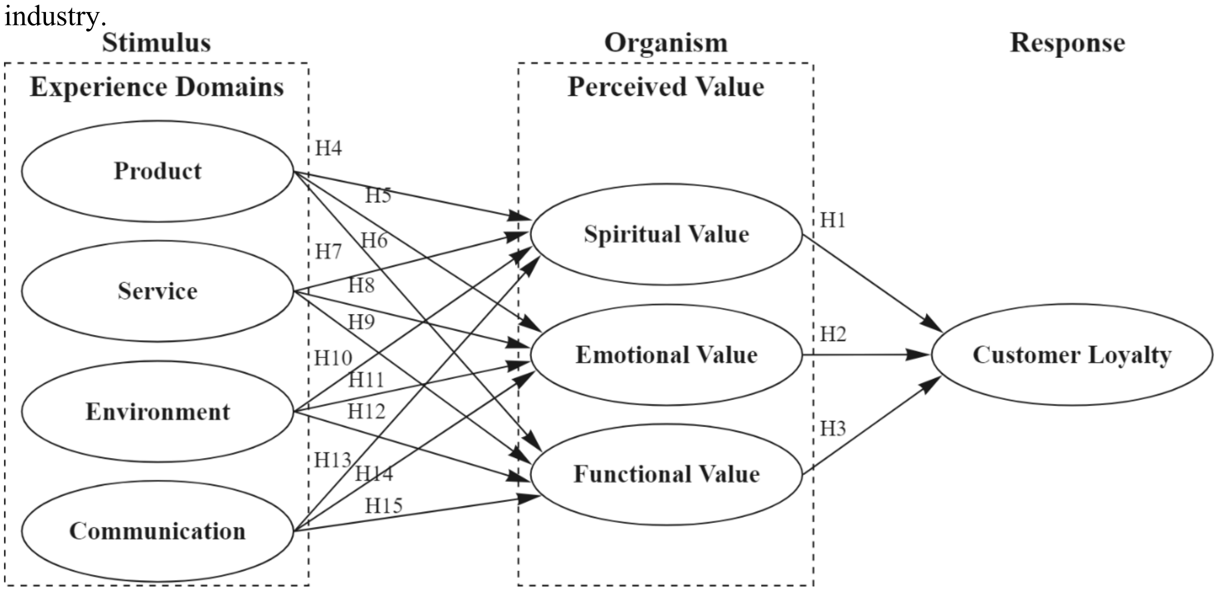

Figure 1. Theoretical Framework

3 METHODOLOGY

This study uses a case-based mixed-method analysis, employing the Pure Internet Banking app "LINE Bank" to explore how Experience Domains and Perceived Value influence Customer Loyalty and the shift in NPS from medium to high. The research consists of two phases: Phase 1 “Questionnaire Survey” and Phase 2 “Model Construction and Hypothesis Testing.

3.1 Data collection and sampling

This study collected online data from January 26 to February 14, 2022, in Taiwan, targeting users who had used LINE Bank. The questionnaire included filtering criteria to ensure response quality. Before designing it, six online semi-structured interviews and a preliminary survey were conducted to understand user backgrounds, motivations, and experiences, identifying key factors. Based on these interviews, the questionnaire was refined and pre-tested, with feedback from 40 customers confirming key factors related to service and experience.

The final questionnaire covered four main sections: "Experience Domains," "Perceived Value," "Customer Loyalty," and "Demographics," using a seven-point Likert scale for evaluation. The questionnaire content was constructed based on a literature review and pilot study, with KMO and Bartlett's test of sphericity used to verify sampling adequacy. Results showed KMO values of 0.886 for Experience Domains and 0.904 for Perceived Value, both exceeding the adequacy threshold of > 0.8, and Bartlett's test showed a p-value < 0.001, indicating suitability for factor analysis. Additionally, the Cronbach's α coefficients for Product, Service, Environment, Communication, Spiritual Value, Emotional Value, Functional Value, and Customer Loyalty between Passives and Promotors were 0.824, 0.824, 0.824, 0.797, 0.802, 0.824, 0.884, and 0.824, respectively, with an overall questionnaire reliability of 0.968.

3.2 Model Construction and Hypothesis Testing

To analyze the data, this study used Structural Equation Modeling (SEM) with the Partial Least Squares (PLS) method via SmartPLS 4.0 software. SEM is a well-established method in social science for evaluating causal relationships between latent variables. The analysis proceeded in two stages: first, validating the measurement model to ensure selected indicators effectively represented latent variables; second, assessing the structural model to explore predictive and causal connections between variables. Tests for collinearity, reliability, and validity were performed to ensure model soundness, with R-Square values evaluating the model's explanatory power. Bootstrap analysis with 5,000 resamples was employed to test the hypotheses.

Reliability was assessed using Composite Reliability (CR) and Cronbach's α to evaluate the internal consistency of the scales. A CR value greater than 0.7 is ideal, with values above 0.6 being acceptable [28], and Cronbach's α should exceed 0.7, with values above 0.8 indicating good reliability [29]. High reliability signifies that the questionnaire demonstrates strong consistency and stability in measurement, minimizing variation across multiple measurements of the same items.

To evaluate validity, both convergent and discriminant validity were tested. Convergent validity ensures that indicators measuring the same construct correlate well with each other. Factor loadings greater than 0.5 and an Average Variance Extracted (AVE) score above 0.5 are deemed adequate [28]. Discriminant validity checks whether constructs are distinct from each other. The Fornell & Larcker criterion requires that inter-variable correlations remain below 0.85, while the square root of each variable's AVE should exceed its correlation with other variables. Lastly, the explanatory power of the model was evaluated using the coefficient of determination (R^2). R^2 values around 0.50 indicate moderate explanatory power, while values near 0.75 suggest high explanatory power.

4 RESULTS

4.1 Descriptive statistics

Data were collected through an online questionnaire, yielding 437 responses. After removing invalid entries, 370 valid responses remained, resulting in an 84.67% validity rate. The sample was primarily female, with 263 women (71.1%) and 107 men (28.9%). Most participants were young adults: 260 respondents (70.3%) aged 21-30, and 56 respondents (15.1%) aged 31-40. Students constituted the largest demographic group, accounting for 122 participants (32.7%). Regarding disposable income, the largest category was NT$10,001 - 30,000, reported by 113 individuals (30.5%), followed closely by NT$30,001 - 150,000 from 111 respondents (30%).

4.2 Measurement model assessment

Tables 2 and 3 provide a summary of the model's evaluation during the measurement phase. The findings confirm that the questionnaire satisfies all required test criteria, shows no signs of collinearity, and exhibits strong reliability. Additionally, both convergent and discriminant validity are upheld according to established benchmarks.

Table 2. The result of measurement model assessment

Construct scales	Code	VIF	Outer loadings	Cronbach's α	CR	AVE
Product	PR1	1.803	0.828	0.824	0.883	0.657
	PR2	1.380	0.674			
	PR3	2.014	0.832			
	PR4	2.452	0.891			
Service	SE1	1.607	0.788	0.824	0.883	0.657
	SE2	1.624	0.720			
	SE3	2.251	0.870			
	SE4	1.492	0.771			
Environment	EN1	1.558	0.730	0.824	0.883	0.657
	EN2	1.818	0.776			
	EN3	1.722	0.751			
	EN4	1.942	0.821			
	EN5	2.096	0.850			
Communication	CO1	1.462	0.842	0.797	0.868	0.623
	CO2	2.087	0.863			
	CO3	1.883	0.811			
Spiritual Value	SV1	1.934	0.886	0.802	0.883	0.716
	SV1	1.934	0.886			
	SV2	1.690	0.844			
	SV3	1.652	0.807			
Emotional Value	EV1	1.985	0.860	0.824	0.919	0.850
	EV2	2.758	0.919			
	EV3	2.267	0.878			
Functional Value	FV1	2.764	0.907	0.884	0.928	0.812
	FV2	2.159	0.880			
	FV3	2.906	0.917			
Loyalty	LO1	1.963	0.924	0.824	0.919	0.850
	LO2	1.963	0.920			

Table 3. Results of discriminant validity using Fornell-Larcker criterion

	PR	SE	EN	CO	SV	EV	FV	LO
PR	**0.810**							
SE	0.649	**0.789**						
EN	0.639	0.598	**0.787**					
CO	0.611	0.546	0.632	**0.839**				
SV	0.555	0.611	0.578	0.649	**0.846**			
EV	0.626	0.680	0.600	0.636	0.791	**0.886**		
FV	0.664	0.684	0.660	0.626	0.638	0.759	**0.901**	
LO	0.640	0.672	0.573	0.557	0.674	0.746	0.745	**0.922**

4.3 Structural model assessment

Following the assessment of the measurement model, a structural model evaluation was performed to validate the proposed hypotheses. Figure 2 displays the results of the structural equation modeling, including R^2 values, path significance, and path coefficients for each variable. The smallest R^2 value is 0.527, which exceeds the threshold of 0.5, demonstrating that the structural model possesses moderate explanatory power. Table 4 outlines the results of the hypothesis testing carried out in this study. As shown in Table 4, except for H4, H5, H10, and H11, all relationships are statistically significant ($p <$

0.05). Customer Loyalty is positively linked with Spiritual Value (SV), Emotional Value (EV), and Functional Value (FV), with FV having the strongest association (ρ < 0.001). Product is significantly related only to FV, while Service is positively associated with all three values. Environment is linked only to FV, and Communication positively influences SV, EV, and FV.

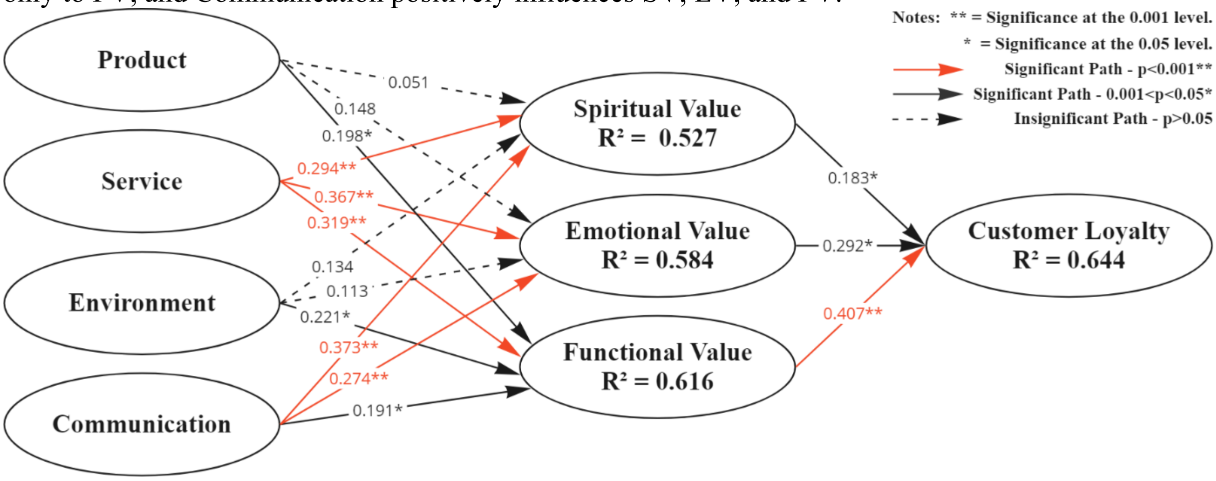

Figure 2. Results of structural equation modeling

Table 4. Hypothesis testing results

Hypothesis/path	Standard deviation	T-statistics	P-values	Results
H1. SV→LO	0.071	2.582	0.010*	Supported
H2. EV→LO	0.094	3.118	0.002*	Supported
H3. FV→LO	0.075	5.417	0.000**	Supported
H4. PR→SV	0.074	0.683	0.494	Not Supported
H5. PR→EV	0.078	1.899	0.058	Not Supported
H6. PR→FV	0.074	2.675	0.007*	Supported
H7. SE→SV	0.076	3.860	0.000**	Supported
H8. SE→EV	0.073	5.029	0.000**	Supported
H9. SE→FV	0.074	4.310	0.000**	Supported
H10. EN→SV	0.087	1.549	0.121	Not Supported
H11. EN→EV	0.100	1.132	0.258	Not Supported
H12. EN→FV	0.071	3.118	0.002*	Supported
H13. CO→SV	0.086	4.331	0.000**	Supported
H14. CO→EV	0.070	3.894	0.000**	Supported
H15. CO→FV	0.078	2.456	0.014*	Supported

5 DISCUSSION

This study, using the S-O-R theoretical framework, explores how Experience Domains and Perceived Value influence the shift of Passives into Promotors. The findings indicate that Customer Loyalty is significantly influenced by all three types of Perceived Value, with Functional Value (H3) having the greatest impact on Customer Loyalty, followed by Emotional Value (H2), and Spiritual Value (H1) having the least impact. This suggests that, for LINE Bank, the most critical factor in converting Passives into Promotors is Functional Value.

Functional Value is significantly influenced by all four Experience Domains, with Service having a relatively stronger impact on Functional Value. In other words, compared to Passives, Promotors place greater emphasis on the influence of Service. Therefore, to convert Passives into Promotors, it is essential to enhance the efficiency, personalization, and professionalism of services. For example, routine tasks should be handled promptly to meet users' needs, personalized services should be provided to help users regularly review and follow up on their financial situation, and relevant advice should be given.

The second factor influencing Customer Loyalty, Emotional Value, is primarily affected by Service and Communication, while Product and Environment do not influence Emotional Value among the medium-

to-high NPS group. This implies that high-quality customer service that makes users feel valued, coupled with tailored services that meet users' needs and minimize effort, and transparent, timely communication to enhance users' trust, are more effective in attracting Passives to become Promotors.
Spiritual Value is mainly influenced by Service and Communication, while Product and Environment do not affect Spiritual Value in the medium-to-high NPS group. This suggests that reinforcing security technology to ensure safe usage and creating sections in the app to showcase LINE Bank's corporate social responsibility initiatives and environmental campaigns can increase users' sense of brand mission, thus encouraging Passives to become Promotors.
In summary, to develop customer relationships, there should be a progression from fulfilling Functional and Emotional needs to satisfying Spiritual identity-based values. Product is no longer the core factor; instead, the focus should be on providing comprehensive experiences across Service, Environment, and Communication. Reviewing the questionnaire and interview data, Promotors and Passives share many similar evaluations and experiences. Compared to Passives, Promotors are more integrated into LINE Bank's current service offerings and better leverage its features to meet deeper life needs. When experiences strongly satisfy users' personal, stage-specific needs, it results in a heightened sense of satisfaction, elevating the perceived value to the level of Spiritual Value.

6 CONCLUSION

To explore the relationship between customer experience and loyalty, as well as strategies for loyalty transition, this study is based on the current industry development and existing literature. From both an industry and academic perspective, it seeks to gain an in-depth understanding of the brand experience of Pure Internet Banking and examines the service perspectives that can establish loyalty relationships in both directions. From a quantitative standpoint, the hypotheses of the research model are analyzed in two parts. First, how Experience Domains, as external stimuli, influence internal Perceived Value, and second, the extent to which the three types of Perceived Value affect Customer Loyalty. This study objectively evaluates the validity of the hypotheses, the path relationships between them, and their respective strengths. The implications of this study extend beyond Pure Internet Banking to other related digital financial services, pushing the boundaries of existing explorations into financial innovation service strategies.
To optimize users' Functional Value, LINE Bank can focus on enhancing existing Service offerings. For instance, introducing AI-driven functionalities to simplify repetitive tasks and improve the user experience can significantly enhance usability. Alternatively, developing AI-assisted financial services with intuitive and user-friendly interfaces can increase customer satisfaction. To improve users' Emotional and Spiritual Value, it is essential not only to allocate resources to enhance current services but also to focus on Communication with users. Leveraging AI to create personalized service assistants and delivering brand messages that resonate with customer values can strengthen customer engagement. Personalized in-app push notifications, tailored to individual preferences, can foster deeper connections between the bank and its users.
This study provides valuable insights for online banking companies, helping them understand customer perspectives across the four Experience Domains. This understanding aids in improving Product, optimizing customer experience, and reviewing service details across different levels of loyalty, thereby enabling effective management of the Experience Domains. Academically, it deepens the discourse on customer experience in Pure Internet Banking. By utilizing the S-O-R theoretical framework, the study establishes the relationship between digital service innovation in the banking sector and customer loyalty, offering a reference benchmark by integrating verifiable loyalty metrics into the "Person-Experience-Brand" holistic experience framework, enriching the competitive landscape of the financial ecosystem.
Finally, this study has some limitations. First, the sample predominantly consisted of young people and students, which may restrict the generalizability of the findings to the broader customer base of pure internet banking. Second, the data were collected two years ago. While they provided valuable insights at the time, the rapid evolution of the internet market may have impacted their relevance. Future research should aim to broaden the sample to encompass a more diverse range of age groups and socio-economic backgrounds. Additionally, updated data should be utilized to further validate the generalizability and applicability of the findings, thereby enhancing the study's comprehensiveness and practical value.

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TOWARDS HIGHER PERSONALIZATION: AN AI-DRIVEN CONTEXT-AWARE SMART PRODUCT-SERVICE SYSTEM DEVELOPMENT APPROACH COMBINED WITH MULTI-CRITERIA DECISION-MAKING

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ABSTRACT

Transformative technologies such as artificial intelligence, big data, and cloud computing are significantly influencing and reshaping daily life. In alignment with digital transformation principles, the objects of design have shifted from industrial and single-function products to digital service systems. Consequently, data-driven Smart Product-Service Systems (SPSS) have emerged. However, despite the widespread deployment and application of SCP and ICT products, current SPSS development methods are limited in their capacity to handle large volumes of structured and unstructured user-generated data, and an effective development paradigm has yet to be fully established. Meanwhile, artificial intelligence technologies—including large language models, image recognition models, and video generation models—have demonstrated advanced intelligence capability, leading users to expect SPSS to integrate these AI capabilities to achieve enhanced product and service functionalities. As a result, personalization and adaptability in service systems have become increasingly important objectives.

To address these challenges, this study presents a novel SPSS development approach that integrates context-aware artificial intelligence (AI) with multi-criteria decision-making (MCDM) methods, enhancing the system's capacity to process large amounts of user-generated data and configure personalized services. Specifically, a data-driven user state inference module is proposed, which collects multi-source contextual data and constructs AI models to infer users' physical and emotional states. Additionally, personalized service solutions are generated by applying MCDM techniques to represent, configure, and optimize service parameters based on users' states. To validate the proposed approach, two case studies were conducted to assess its effectiveness in real-world systems. The results indicate that SPSS integrated with AI technologies is highly effective, and that the automatic configuration of personalized services significantly enhances user satisfaction.

Keywords: Smart PSS, Context-aware system, Artificial intelligence, Multi-criteria decision-making

1 INTRODUCTION

The growing market for Smart Connected Products (SCPs) has led to increasing interest in concepts like Cyber-Physical Systems (CPS), and Smart Product-Service Systems (SPSS). SCPs, aided by digital servitization, allow companies to create innovative services and business models. This digital transformation enables value co-creation within dynamic digital ecosystems. The development of SPSS involves complex factors, including real-time responsiveness to changing user contexts. The development of SPSS follows the systematic approach, placing emphasis on "data-driven", "personalized services" and "value creation"[1, 2].

Integrating context-aware artificial intelligence(AI) into SPSS could enhance understanding of user needs, improve human-machine interaction, and generate tailored service solutions. In this regard, scholars have proposed diverse development methods for data-driven personalized services, leveraging various data sources such as context data[3], Internet of Things (IoT) sensor data[4], physiological data[5], and others. On the other hand, propelled by vast datasets and extensive computational resources, artificial intelligence technologies, exemplified by large language models[6], image recognition models[7], and video generation models, have exhibited higher- order intelligent capabilities. Therefore, it is worthwhile to explore in greater depth the mapping relationship between big data-driven artificial intelligence and intelligent service applications.

In addition, many scholars have delved into researching personalized services value. Demirkan et al. revealed the importance of collecting multi-source data and fostering co-created value between customers and businesses[8]. Chiu and Tsai introduced a multi-agent-based personalized product service system designed for swift adaptation to external changes and customer demands[9]. Some researchers have opted for method such as ontology-based knowledge reasoning[10], multi-objective optimization, and multi-criteria decision-making to orchestrate service value propositions across diverse entities within the system.
Given the abundance of both structured and unstructured data in the intelligent, interconnected cyber-physical space, data-driven paradigms are expected to integrate with multi-criteria decision-making methods to create an efficient and agile approach to personalized SPSS development. However, this area remains largely underexplored.
This study introduces a context-aware AI integrated with MCDM framework for developing Smart Personalized Service Systems (SPSS). The framework consists of three modules: multi-source context acquisition, user modality reasoning, and service recommendation. It collects data from sensors and wearable devices, processes it on a cloud platform, and analyzes user physical and emotional states for personalization. The service recommendation module employs MCDM methods like DEMATEL and TOPSIS to rank services based on user modalities, optimizing resource allocation. This approach enhances SPSS adaptability and effectiveness by aligning services with user needs through iterative decision-making processes.

2 RELATED WORKS

Significant advancements in internet deployment, computational intelligence, and network technologies have driven the rise of a new generation of SPSS[11]. Chang et al. introduced the concept of user-centric SPSS (UC-SPSS) and provided a development approach for UC-SPSS[12]. Zheng et al. stressed the need for a systematic method in Smart PSS development, concentrating on two key elements: the "data-driven" model and the "value co-creation" process[2].
The data-driven approach to SPSS development has become a major research focus. Wang et al. devised a context-aware concept assessment method for Smart PSS iterations that integrates natural language processing (NLP) tools and takes user experience into account[13]. Multi-agent systems[9] and knowledge graphs[14, 15] have been applied to construct SPSS. Yuan et al. utilized data from wearable sensors to assess users' physical states, using this data to personalize SPSS services[3].
In terms of service configuration, Song et al. proposed a systematic method that integrated a correlation matrix to identify configuration parameters, optimized multiple service objectives, and used the NSGA-II algorithm to achieve these objectives[16]. Chen et al. presented a framework to optimize SPSS configuration with two main goals: enhancing intelligent capability efficiency and value symbiosis efficiency, supported by corresponding optimization algorithms[1].
The SCPs in SPSS enable the acquisition of large volumes of heterogeneous, multi-source data. Given the advantages of context-aware artificial intelligence (AI) in self-adaptation and implicit requirement mining, it becomes possible to gather comprehensive user and contextual data, perceive user needs, and characterize service scenarios. In this context, a comprehensive personalized service generation method that integrates context-aware AI with multi-criteria decision-making processes warrants further exploration.

3 METHODOLOGY

This study proposes a context-aware artificial intelligence (AI) combined with multi-criteria decision-making(MCMD) Smart Product-Service Systems (SPSS) development approach. The proposed method is composed of three key modules: multi-source context acquisition, user modality reasoning, and service recommendation.

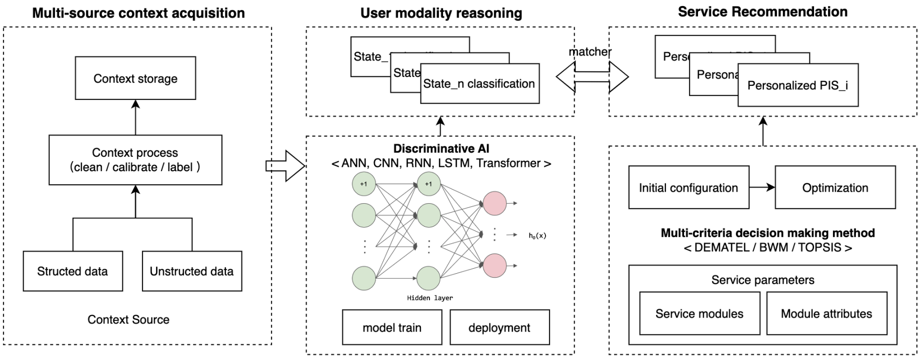

Figure 1. The overall framework of proposed approach

3.1 Multi-source context acquisition

Recent advancements in sensors, computer vision, and networking have led to the generation of extensive structured and unstructured data. For example, user identity data can be acquired through direct methods like surveys and indirect methods such as public datasets and mobile applications. Physical data is gathered from environmental sensors that monitor variables like location and temperature, while real-time sensed context is captured via wearable devices that track metrics like heart rate and blood oxygen levels. Additional data sources include IoT sensors, medical records, and biomedical images.

The data processing steps involve feature extraction, handling missing data, and validating datasets to remove anomalies. Data formats are standardized using various structures like key-value, tagged encoding, ontology-based, and hybrid formats. Data modeling, which aids in understanding data characteristics and relationships, is managed on a cloud platform. This enables the collection, storage, and analysis of large context datasets, ensuring safety, reliability, and flexibility. The process focuses on data source quality and context-specific feature extraction, with data being standardized and cleaned for better visualization and analysis capabilities.

In the data storage phase, a robust cloud-based database structure is established to accommodate concurrent access by multiple devices, particularly in healthcare settings. Cloud databases, favored for their accessibility and resource efficiency, support communication between various rehabilitation devices. The structure incorporates different types of databases, including relational (e.g., MySQL, Oracle, PostgreSQL), non-relational (e.g., MongoDB, Redis), and graph databases (e.g., Neo4J, InfoGrid), offering flexibility and scalability in managing multi-source data.

3.2 User modality reasoning

Modality reasoning is essential for extracting insights from data, especially in identifying user modalities, such as physical and emotional states, to enhance personalized experiences. By analyzing user contexts, SPSS can deduce these modalities, enabling the delivery of tailored product-service bundles. Context reasoning involves inferring high-level insights from general data through logical inference and probability calculations, addressing the challenge of associating and transforming raw data into meaningful context.

The reasoning process generates user modality, representing advanced attributes like exercise intensity, emotions, and service experiences. This concept draws from the term modality, meaning 'something exists, is experienced or expressed in a certain mode' [17]. User modality is linked to the entity's state (e.g., physical and mental), particularization (e.g., spatial perception and experience), and mobility (e.g., vehicle condition)[18]. With these understandings, SPSS can deliver enhanced environments, such as intelligent technology scenarios, value co-creation networks, and customized service packages.

The reasoning process is divided into three key modules: input, reasoning, and output. The input module gathers various context data—such as user identity, environmental context, and sensor data—through cloud-based middleware. In the reasoning module, supervised learning techniques, particularly neural networks, are used to predict new data from labeled datasets. The network processes multi-source data through an input, hidden, and output layer configuration, using backpropagation optimization to reduce errors and improve performance. The cost function incorporates regularization, and the model parameters are refined through continuous iterations. The output module generates user modalities, representing key characteristics like exercise intensity and emotional state.

Regarding model architectures, artificial neural networks (ANNs) are considered classic frameworks for machine learning inference[19]. Building on these foundations are deep learning architectures, including convolutional neural networks (CNNs)[20], recurrent neural networks (RNNs)[21], long short-term memory (LSTM) networks[22], and transformers[23]. CNNs are particularly well-suited for processing image data, while RNNs and LSTMs excel at handling sequential data. The transformer architecture, nowadays, is increasingly applied to multimodal data fusion and inference tasks.

3.3 Service recommendation

This section examines how context-aware AI systems can develop service strategies for identified user modalities through a multi-criteria decision-making (MCDM) process. The selection and ranking of service elements are based on established MCDM methods such as DEMATEL, TOPSIS, and BWM, which assign weights to service components like staff, equipment, and consumables. Each service element has associated weights and costs, forming a decision matrix that helps service providers optimize their allocation strategies. Service elements are ranked based on their influence, and optimal service combinations are identified through an iterative optimization process.

The process begins with identifying user modality, followed by the creation of a personalized service strategy. MCDM method is used to assign weights to service elements, generating a comprehensive relationship matrix to evaluate inter-element influence. Service elements are then allocated based on utility value, and the system iterates to optimize resource distribution. This matrix leads to optimized service configurations by balancing utility against costs. Providers can select service strategies tailored to specific user modalities, ensuring personalized service bundle (PSB) recommendations. After segmentation, users' personalized requirements are matched with tailored service strategies using a logic-based matcher. By using fuzzy numbers and an evolutionary algorithm to refine service configurations, improving the alignment between user needs and service modules. Additionally, evolutionary algorithms are employed to optimize weight matrices, ensuring service configurations remain objective despite expert biases.

4 CASE STUDY

4.1 A context-aware SPSS for supporting non-professional sports competitions

Non-professional sports events, such as marathons, pose higher risks for participants due to a lack of systematic training, leading to incidents like sudden cardiac death (SCD). The risk of cardiac arrest during vigorous exercise is significantly higher for individuals with low daily activity. Current preventive measures, including screenings and AED services, are inadequate for long-distance events. To address this, the Context-Aware Smart Product-Service System (CA-SPSS) framework[3] was implemented in the 2021 Shanghai Jiao Tong University long-distance race. Using wearable devices, the system monitors athletes' real-time physical states, offering personalized services and helping reduce on-field risks.

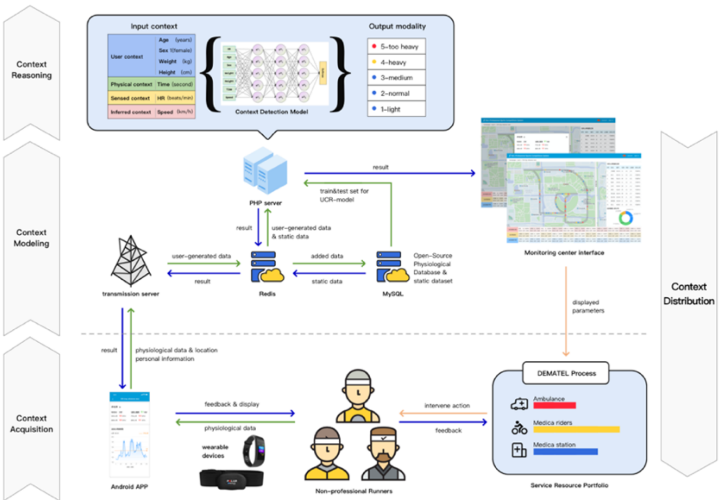

Figure 2. Overview of CA-SPSS for supporting Non-Professional Sports Competitions

The Context-Aware Smart Personalized Service System (CA-SPSS) for Non-Professional Sports Competitions (NPSC) gathers contextual data via a wireless sensor network that includes runners, wearable devices, and mobile phones. The system collects four types of context: user context (e.g., age, sex, height, weight) during registration, physical context (e.g., time and location) from mobile phone sensors, inferred context (e.g., speed), and sensed context (e.g., heart rate) through wearable devices. Heart rate data from devices like Polar H7 is collected via an Android app and transmitted through Bluetooth BLE, while location data is obtained using Baidu Maps SDK, all sent to the cloud for real-time analysis.On the cloud, the system models data using Redis for real-time context and MySQL for static user data. A PHP server processes data to detect exercise intensity, utilizing a modality-detection model that continuously updates with new data. The context reasoning process begins with clustering an open-source physiological dataset via K-means, followed by classifying exercise intensity based on the Metabolic Equivalent of Energy (MET) theory. A neural network model trained on 200 user profiles achieved 83.9% accuracy and an AUC of 0.94 in detecting five exercise intensity levels, forming the basis for personalized service recommendations in NPSC applications.

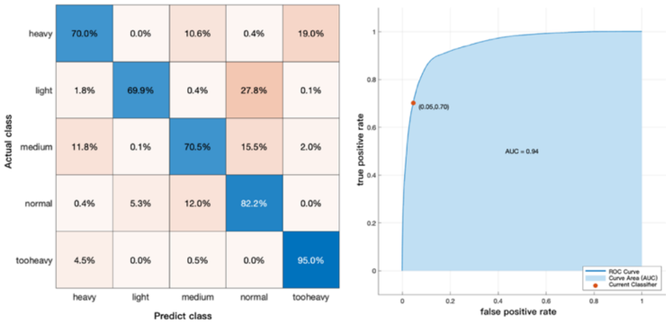

Figure 3 Exercise intensity modality-detection neural network model

In the model deployment phase, the exercise intensity modality-detection model was implemented using the PyTorch framework and integrated into a cloud platform with a PHP backend. The model processed real-time data from runners, including heart rate, speed, and time, formatted as JSON and linked to identity data stored in a MySQL database. It produced exercise intensity modality levels, which were sent to a context distribution layer for personalized service recommendations.
The user interface of the Context-Aware Smart Personalized Service System (CA-SPSS) for Non-Professional Sports Competitions (NPSC) displayed key information, categorizing runners into three exercise intensity levels: medium, heavy, and too heavy. This visual interface facilitated competition monitoring and risk detection. During a long-distance race, resource planning and allocation were optimized using the DEMATEL method, focusing on service staff and emergency equipment. Service strategies were tailored to runners' intensity levels, ensuring personalized care and enhancing safety and user satisfaction throughout the event.

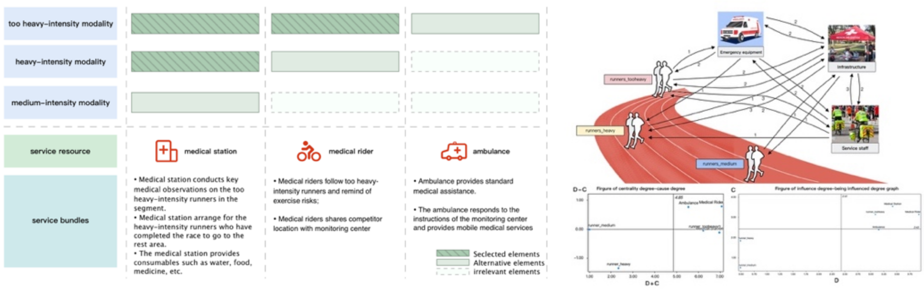

Figure 4. Blueprint with service strategies of CA-SPSS for NPSC

4.2 A context-aware SPSS based on fine-tuned large vision AI model and fuzzy-DEMATEL

Facial palsy, resulting from trauma, infections, or congenital issues, impairs facial muscle movement, affecting chewing, self-esteem, and overall health. Prompt treatment can facilitate recovery, while delays may lead to persistent symptoms. Current assessments, like the House-Brackmann Grading System, are prone to human error. This study suggests utilizing deep learning for automated evaluations.

Treatment varies based on severity; mild cases may improve with medication and exercises, while severe cases often require surgery. The Rehabilitation Management Smart Product-Service System (FPRM-SPSS) enhances patient compliance and exercise experience by integrating advanced human-computer interaction features, including exercise demonstrations and remote physician monitoring[24].

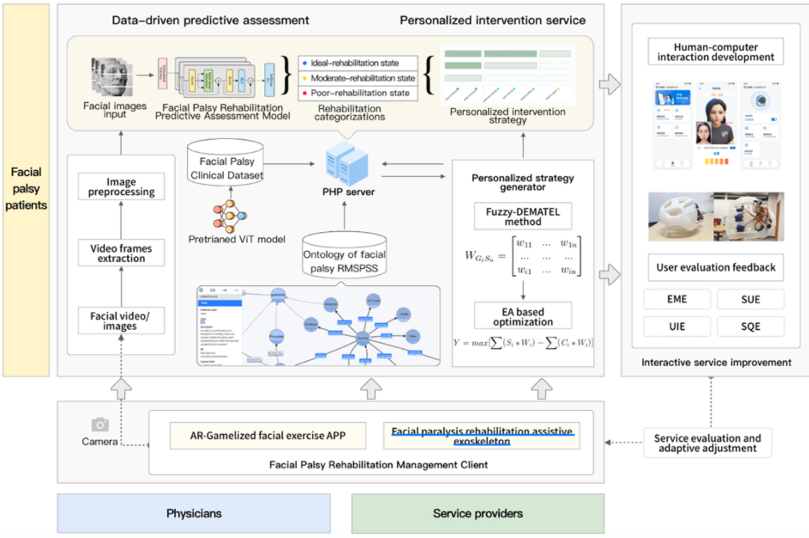

Figure 5. The overall framework of FPRM-SPSS

This study developed a Clinical Facial Palsy (CFP) dataset from clinical cases at a collaborating hospital, collecting 3,744 images of facial videos and images from 52 patients at various intervals (one week to twelve months post-intervention). Each image was preprocessed and annotated by facial nerve specialists, achieving a resolution of 500×500 pixels. The dataset was classified using three clinical grading scales: the House-Brackmann Facial Nerve Grading System (HBGS), Facial Nerve Grading System 2.0 (FNGS 2.0), and the Yanagihara Facial Nerve Grading System, categorizing patients into ideal, moderate, and poor rehabilitation states. Ethics approval and patient consent were obtained for the study. To enhance classification accuracy while reducing costs, the study utilized a pre-trained Vision Transformer (ViT) model for developing a facial palsy rehabilitation predictive assessment model. Training occurred on a cloud server equipped with an NVIDIA T4 GPU. The model demonstrated exceptional performance, achieving a training accuracy of 99.99%. Following pruning and compression, users can obtain predictive assessments by uploading facial images to the system.

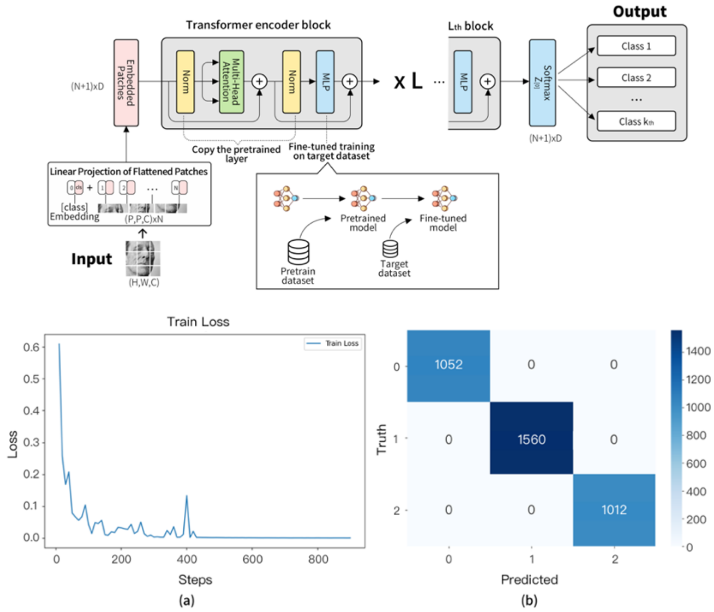

Figure 6. The fine-tuned predictive assessment model

This section outlines the development of a Smart Personalized Service System (SPSS) designed for facial palsy rehabilitation, structured into three layers: the service scope, service modules, and module

attributes. Personalized interventions focus on targeted exercises for specific facial muscles, developed in collaboration with hospitals. The system integrates clinical datasets, Vision Transformer (ViT) models for predictive assessment, and control algorithms for tailored interventions, while the attributes layer encompasses mobile devices and cloud resources. Rehabilitation exercises are categorized into five guidance modules and two exoskeleton-assisted modes, with personalization parameters based on severity levels of facial palsy (mild, moderate, severe). The study employs fuzzy linguistic evaluations and the DEMATEL method for decision-making, assessing rehabilitation scenarios through expert evaluations of service modules. The impact of various facial exercises is quantified and organized into a comprehensive influence matrix, enabling optimization via the NSGA-II evolutionary algorithm.
Furthermore, an interactive feedback system is developed, featuring an augmented reality (AR) gamified app and a rehabilitation exoskeleton. The app enhances engagement by allowing users to upload facial videos for assessment, receive exercise recommendations, and track progress, while the exoskeleton assists with targeted exercises. Together, these innovations significantly improve user experience and rehabilitation outcomes.

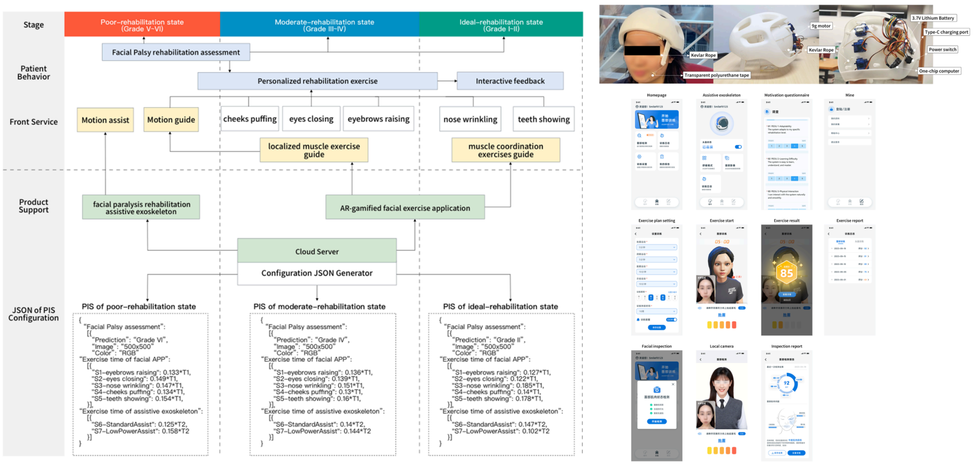

Figure 7. Facial Palsy rehabilitation management client and service strategies

5 DISCUSSION & CONCLUSION

This study explores a context-aware AI framework integrated with MCDM for developing SPSS. The framework aims to add value for stakeholders by improving service efficiency, reducing costs, and promoting sustainability through resource-efficient strategies. It includes three modules: multi-source context acquisition, user modality reasoning, and service recommendation. Multi-source context acquisition collects structured and unstructured data from sensors, processed through cloud-based feature extraction and standardization. Modality reasoning uses neural networks to predict user physical and emotional states, informing personalized service strategies. Service recommendation applies MCDM methods like DEMATEL to optimize resource allocation and tailoring services to user needs.
In comparison to existing research, the proposed approach incorporates context-aware AI to enhance recommendation quality[25].
This approach prioritizes users by focusing on deeply reasoning their needs and experiences. Unlike user-centric SPSS methods, which aim to address technical limitations and rely on qualitative user analysis[12], this study is more time- and cost-efficient in user research, providing a comprehensive data-driven approach. It can autonomously detect and identify user modality, showing promise in understanding implicit needs and offering more tailored PSB recommendations. Additionally, compared to knowledge-based personalized service configuration, this approach strengthens SPSS's ability to handle vast amounts of user data by incorporating advanced AI techniques.
This paper's contributions include: i) A novel conceptual framework for data-driven personalized SPSS, integrating context awareness to improve self-adaptation and implicit requirement mining, enhancing SPSS adaptability and effectiveness through AI and decision-making processes. ii) Two SPSS case studies demonstrating the application of the proposed approach, including a comprehensive evaluation of its effectiveness in real-world scenarios.
Although this study has several benefits, it also presents some limitations. For example, the user dataset used in the research exhibited similar geographic and ethnic traits, negatively impacting data quality.

Additionally, the approach does not fully address users' implicit needs. Integrating context-aware computing with qualitative methods like interviews, questionnaires, and focus groups could enhance future investigations.
Future research should take the following recommendations into account. First, as the convergence of digital and physical environments intensifies, the volume and diversity of user-generated data continue to expand. Therefore, it is crucial for researchers to employ advanced AI technologies, such as multimodal models, to better comprehend and define user needs and conditions. Additionally, the complexity of contemporary commercial ecosystems involves multiple stakeholders in SPSS. Thus, further research is needed to explore modeling techniques capable of addressing the intricacies of dynamic systems from diverse perspectives.

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EMBODIED INTELLIGENCE IN ASSISTIVE TECHNOLOGIES FOR THE VISUALLY IMPAIRED: ENHANCING INDEPENDENCE AND SOCIAL INCLUSION

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ABSTRACT
This paper investigates the application of Embodied Intelligence (EI) in assistive technologies for the Blind and Low Vision (BLV) community. The research identifies the specific needs and challenges faced by visually impaired individuals and introduces an EI framework that combines perception, decision-making, and action execution to improve their quality of life and social participation. The study emphasizes the potential of multimodal perception and intelligent decision-making in delivering personalized support and enhancing user experience. Moreover, it addresses the importance of social acceptance and ethical considerations for the successful deployment of these technologies. The findings underscore the need for ongoing research and development to ensure that EI can be practically and sustainably applied to increase the independence and confidence of the BLV population.

Keywords: Embodied Intelligence, Assistive Technologies, Visually Impaired, Human-Machine Interaction

1 INTRODUCTION

People who are blind or have low vision (BLV) face significant challenges in their daily lives, impacting mobility, access to information, and social interaction. Navigating unfamiliar environments, interpreting written and visual information, and engaging in meaningful social activities are daily struggles for this community. According to the World Health Organization, visual impairments are classified into four categories: complete blindness, severe low vision, moderate low vision, and normal vision, providing a framework for understanding their needs and designing tailored solutions [1][2]. These classifications are vital for ensuring assistive technologies meet diverse user requirements and accommodate varying degrees of impairment [3].

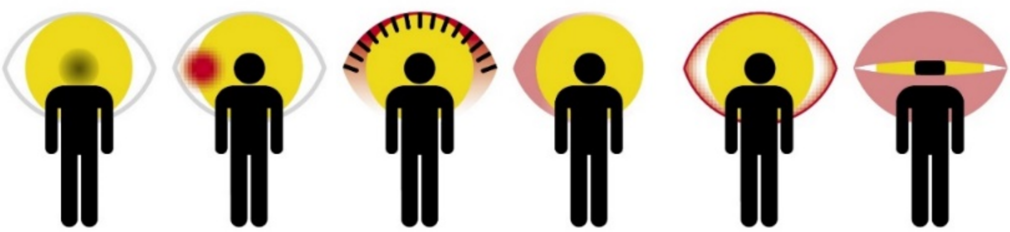

Figure 1. Different Types of Visually Impaired Populations

Figure 1 illustrates the spectrum of visual impairments, highlighting the distinct challenges faced by individuals in each category. For instance, those with complete blindness often depend on auditory or tactile feedback, while individuals with moderate low vision may benefit from tools that amplify remaining visual capacities [4]. Such distinctions emphasize the need for adaptive solutions that can address the wide-ranging demands of the BLV community [5][6][7].

In recent years, significant advancements have been made in assistive technologies, such as smart glasses, voice-controlled digital assistants, and intelligent canes, which have improved mobility and access to information [8][9]. However, despite these innovations, existing solutions frequently fall short in addressing the comprehensive needs of users, including personalized interactions, seamless integration into daily life, and adaptability to dynamic environments [10][11]. The growing prevalence of visual impairments, driven by aging populations and chronic conditions like diabetes, further amplifies the urgency for effective and scalable solutions [12]. Moreover, the significant investment in assistive technologies reflects their critical role in enhancing the quality of life for visually impaired individuals [13][14][15].

Embodied Intelligence (EI) has emerged as a promising paradigm for overcoming these limitations. EI integrates perception, cognition, and physical interaction, creating systems capable of dynamic adaptation and contextual understanding [16]. By leveraging advanced sensors, artificial intelligence (AI) algorithms, and real-time feedback mechanisms, EI-based solutions can address diverse and complex user needs [17][18]. Unlike conventional technologies, which often rely on singular modalities, EI employs multimodal inputs, such as auditory, tactile, and visual data, to offer a holistic and intuitive user experience [19][20][21].

This paper proposes a novel framework for applying EI in assistive technologies specifically designed for the BLV community. Key components of this framework include multimodal perception for processing environmental data, intelligent decision-making to prioritize actions, and real-time execution for adaptive interaction [22][23][24]. For example, multimodal systems can combine spatial audio cues with tactile feedback to guide users more effectively through unfamiliar environments [25]. Furthermore, intelligent algorithms ensure that assistive devices can respond appropriately to changes in context, such as detecting obstacles or navigating complex indoor spaces [26][27].

Addressing ethical and social considerations is equally crucial for the successful deployment of these technologies. Issues such as user privacy, the affordability of devices, and their societal acceptance must be taken into account to ensure widespread adoption [28][29]. Figure 1 reinforces the diversity of challenges and underscores the importance of targeted solutions that cater to the unique needs of visually impaired individuals [30].

Through a detailed exploration of embodied intelligence and its practical applications, this study aims to bridge the gaps in existing assistive technologies and contribute to a more inclusive society [31][32]. The proposed framework aligns the technical capabilities of EI systems with the specific challenges faced by the BLV community, ultimately enhancing their independence, mobility, and social engagement [33][34][35].

This paper is structured as follows: Section 2 reviews the literature on assistive technologies, identifying key limitations. Section 3 discusses the theoretical foundations of embodied intelligence. Section 4 introduces the EI-based framework, while Sections 5 and 6 evaluate its effectiveness through case studies and experimental results. Finally, Section 7 highlights future research directions and concludes with the broader implications of this work for the visually impaired population. By addressing these pressing challenges, this research aspires to empower individuals with visual impairments and promote innovative solutions that enhance their daily lives.

2 THE CURRENT SITUATION AND NEEDS OF THE VISUALLY IMPAIRED POPULATION

2.1 Blindness and Low Vision (BLV): Definition and Classification

Blindness and Low Vision (BLV) denote significantly reduced visual capabilities, encompassing both complete blindness and varying degrees of low vision. Total blindness is characterized by a complete absence of vision, while low vision refers to conditions where visual acuity falls below certain thresholds, such as 0.3 or 20/70. According to the World Health Organization (WHO), visual impairments are further categorized into complete blindness, severe low vision, mild low vision, and normal vision. These classifications provide insights into the diverse needs and challenges that individuals with various levels of visual impairment face, serving as a basis for developing assistive technologies.

2.2 Challenges Encountered by the BLV Population

People with visual impairments encounter numerous challenges in their daily activities, primarily in areas such as mobility, safety, information access, and social interaction. For example, without critical environmental information, navigating public spaces can be hazardous, increasing the risk of accidents. Additionally, these individuals face significant obstacles in accessing information and engaging in social interactions, which can negatively impact their quality of life and hinder their career opportunities and social involvement.

2.3 Analysis of the Need for Assistive Technologies

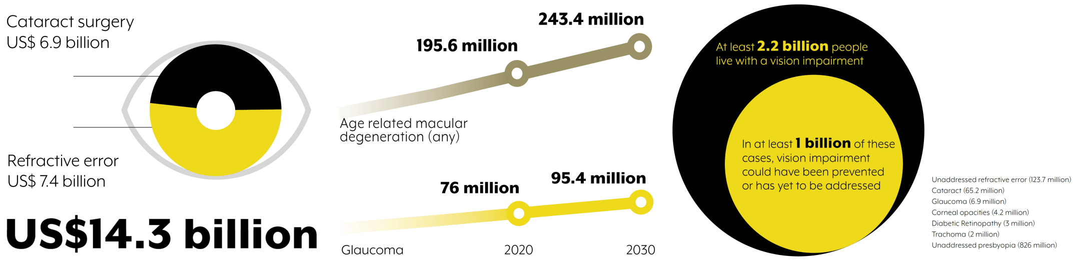

Figure 2. Need for Assistive Technologies. (left) Investment Required to Treat Existing Unaddressed Cases of Refractive Error and Cataracts Globally. (middle) Projected Number of People with Age-Related Macular Degeneration and Glaucoma from 2020 to 2030. (right) Proportion of Individuals with Visual Impairment and Those Whose Condition Could Have Been Prevented or Is Still Unaddressed.

With a vast number of individuals affected by unaddressed cases of refractive error and cataracts worldwide, the investment needed to address these issues is estimated at $14.3 billion, as shown in Figure 2(left). Additionally, Figure 2(middle)(right) depicts a consistent annual increase in the global population affected by visual impairments. While emerging technologies have shown promise in improving the lives of visually impaired individuals, current assistive devices still exhibit limitations, such as limited convenience, poor user experience, and insufficient personalization. Consequently, there is an urgent need for more intelligent, adaptive, and personalized assistive technologies to improve the quality of life, social inclusion, and self-confidence of the BLV community. Exploring the potential of embodied intelligence in this domain could help meet these unmet needs.

3 DEVELOPMENT AND CONCEPT OF EMBODIED INTELLIGENCE

3.1 Embodied Intelligence: Definition and Innovation

Embodied Intelligence (EI) is not merely an integration of perception, cognition, and physical actions; it represents a paradigm shift in how we conceive intelligent systems. Traditionally, intelligence has been viewed as an abstract cognitive process, detached from the physical world. EI challenges this view by asserting that true intelligence is inseparable from the body and its dynamic interaction with the environment. This framework introduces a novel approach where the physicality of the agent is central to its intelligence, enabling a more nuanced and context-aware decision-making process. By embedding the agent within a physical context, EI systems can adapt to changes in real-time, responding with actions that are not just reactive but also predictive, based on a deep understanding of the environment and the agent's goals. This synthesis of elements introduces new knowledge by bridging the gap between cognitive processes and physical actions, creating a more holistic and effective model for intelligent systems.

3.2 Theoretical Foundations of Embodied Intelligence

The theoretical foundation of EI combines insights from cognitive science and robotics, proposing that an agent's cognitive abilities are deeply intertwined with its body and environmental interactions. The "body-mind" model from cognitive science challenges traditional brain-centric views, highlighting the influence of bodily structure on cognitive processes. Through multimodal perception, EI systems can adapt dynamically to complex environments. Furthermore, by incorporating elements of robotics and artificial intelligence, EI enables robots to exhibit advanced adaptability, empowering them to make complex decisions in changing environments. This interdisciplinary research advances robotic intelligence, particularly in human-robot interactions, where EI systems offer more natural and intuitive experiences. In essence, EI supports the design of intelligent systems and paves the way for more effective human-machine interaction.

3.3 Domains of Application for Embodied Intelligence

Embodied Intelligence has a broad range of applications, including humanoid robots, autonomous vehicles, and assistive technologies. Within assistive technology, EI provides novel solutions for improving the lives of visually impaired individuals, enhancing their quality of life and promoting social inclusion. As research progresses, EI's application prospects are expected to expand, driving intelligent development across various fields. For example, OrCam glasses illustrate the application of artificial intelligence in assistive technology by enabling visually impaired individuals to read printed text, recognize supermarket items, identify currency, and even recognize faces, significantly enhancing convenience for these users (as depicted in Figure 3).

Figure 3. Application of OrCam Glasses for Visually Impaired Individuals

4 EMBODIED INTELLIGENCE APPLICATIONS IN ASSISTIVE TECHNOLOGIES

4.1 Current Assistive Technologies Overview

With rapid advancements, assistive technologies have introduced a variety of solutions designed to help visually impaired individuals overcome daily challenges. Currently available devices, such as smart glasses, voice assistants, and intelligent canes, assist with environmental perception, navigation, and information transfer. However, many existing technologies still face limitations regarding user experience and interaction, highlighting the need to explore embodied intelligence to develop more comprehensive assistive solutions.

4.2 Potential of Embodied Intelligence within Assistive Technologies

By integrating perception, decision-making, and physical action, embodied intelligence represents an innovative approach to advancing assistive technologies and improving the lives of visually impaired individuals.

4.2.1 User Experience and Interactivity

Embodied intelligence enhances assistive technologies' interactivity by offering two primary benefits. First, these systems respond in real-time to user needs and environmental changes, providing assistance through voice and tactile feedback to aid with mobility. Second, EI systems allow for natural interaction methods like voice commands and gesture control, simplifying operation and optimizing user experience. Research has shown that wearable low-vision devices, such as the OrCam MyEye 2.0, which translates visual information into audio feedback, can significantly enhance reading abilities for individuals with advanced hereditary retinal dystrophies and cone-rod dystrophies. Figure 4 illustrate this improvement, displaying the mean score enhancement on the Visual Functioning Subscale before and after using the OrCam device [36].

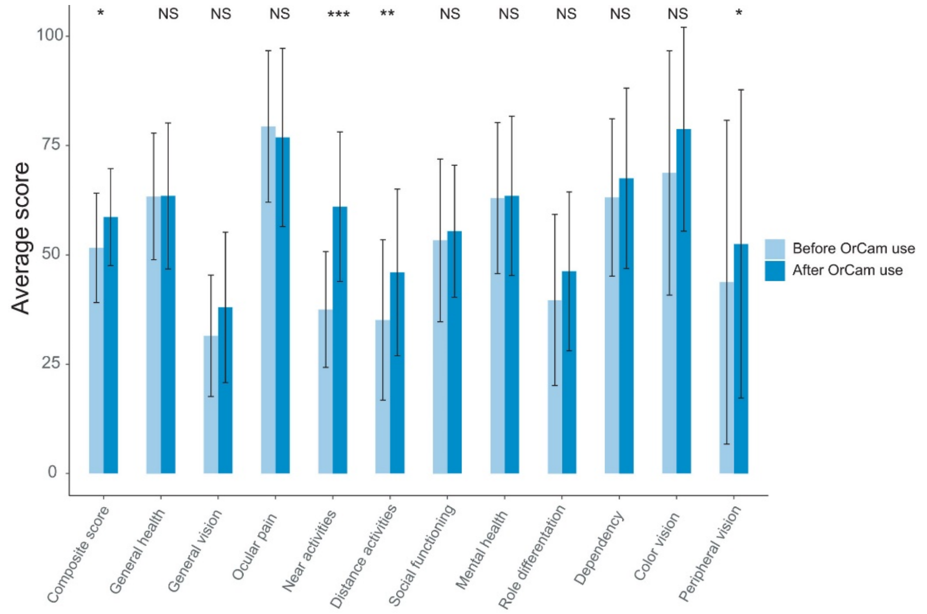

Figure 4. Average scores on the subscales of the National Eye Institute Visual Functioning pre- and post-rehabilitation with the OrCam [36].

4.2.2 Services Personalized and Adaptability

The adaptability of EI systems is essential for visually impaired users, enabling them to navigate dynamic environmental challenges effectively. By continuously collecting and analyzing environmental data, these systems can adjust strategies in real-time to maintain user safety and convenience. Additionally, EI provides personalized services by analyzing user data to deliver relevant information based on individual habits, thereby enhancing user engagement and independence. This personalized experience not only improves quality of life but also boosts users' social confidence.

5 FRAMEWORK CONSTRUCTION FOR THE THEORETICAL MODEL

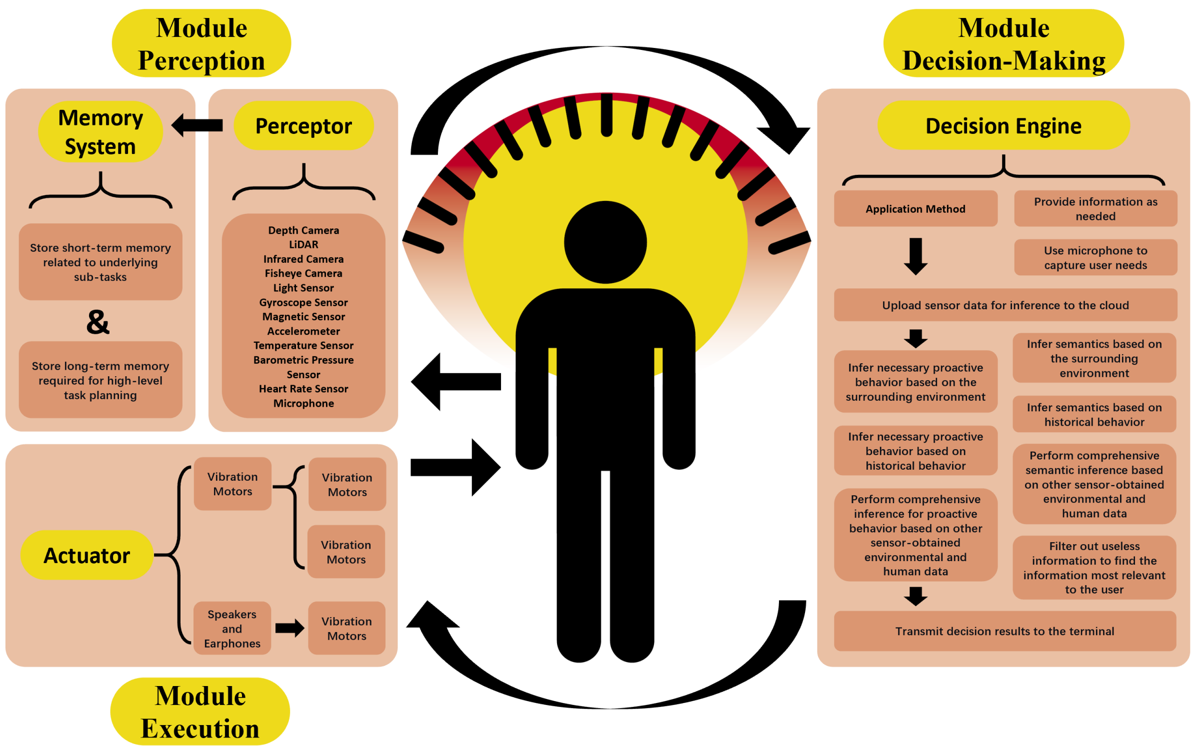

Figure 5. Framework of Embodied Intelligence and the Visually Impaired Population

5.1 Approach for Framework Development and Novelty

In constructing the framework for Embodied Intelligence in assistive technologies, the approach goes beyond traditional integration of perception, decision-making, and execution modules. Our framework innovates by introducing a dynamic feedback loop that allows for continuous learning and adaptation, a feature not commonly found in existing assistive technologies. This feedback loop enables the system to evolve with the user, becoming more attuned to their specific needs and environmental changes over time. The novelty lies in the system's ability to not just react to the immediate environment but to anticipate user needs and proactively adjust its support strategies. This proactive adaptation is a significant departure from static, one-size-fits-all solutions, offering a more personalized and effective assistive experience. To illustrate this framework, Figure 5 provides a schematic representation of the integrated modules and their interactions.

Furthermore, the framework should be scalable to accommodate future technological upgrades and additional functionalities. By adopting a systematic methodology, this framework can effectively realize the diverse applications of embodied intelligence, promoting social inclusion and independent living for visually impaired individuals.

Data collection for the study will involve both primary and secondary sources. Primary data will be gathered through interviews and surveys with visually impaired users to ensure reliability and validity. Secondary data will be sourced from relevant literature and technical reports to support the theoretical analysis.

5.2 Design Modular of the Framework

An efficient operation of complex systems relies heavily on a modular design. The embodied intelligence framework is structured into three primary components: the perception module, the decision-making module, and the execution module, each playing a crucial role in the overall system.

5.2.1 Module Perception

The perception module serves as the foundation of the framework, responsible for gathering and analyzing environmental information surrounding the user. This module integrates various sensors, including depth cameras, LiDAR, and infrared sensors, to capture comprehensive environmental data. By utilizing advanced image recognition and audio analysis technologies, this module can identify obstacles, pedestrians, and other critical elements in real-time, constructing a detailed environmental model. Additionally, the perception module must possess dynamic learning capabilities to optimize its performance based on user feedback and behavioral patterns, thereby enhancing the accuracy and efficiency of environmental understanding. The effective functioning of this module is vital for the decision-making module to generate intelligent decisions based on reliable data.

5.2.2 Module Decision-Making

As the core of the embodied intelligence framework, the decision-making module processes information received from the perception module and generates corresponding action plans. This module employs machine learning and deep learning algorithms to perform complex decision-making reasoning, taking into account both environmental information and the user's historical behavior. It must exhibit adaptability, allowing it to adjust strategies in real-time to respond to changing environments and user needs. Furthermore, this module should evaluate various possible actions, conducting risk assessments and outcome analyses to determine the optimal execution strategy, ensuring user safety and convenience in diverse settings.

5.2.3 Module Execution

The execution module translates decisions into specific actions, ensuring that the system effectively implements the intended plans. This module utilizes various execution devices, such as vibration motors, speakers, and mobile manipulators, to provide multiple forms of feedback and interaction. The execution module must have a high response speed and flexibility, enabling it to quickly adapt to user commands and environmental changes. Additionally, it should feature a user-friendly interface, allowing users to control the system easily through voice commands or other interaction methods, thereby enhancing the overall user experience.

5.3 Mechanisms of Interaction and Feedback for Users in the Framework

Effective user interaction and feedback mechanisms are crucial components of the embodied intelligence framework, aimed at ensuring efficient communication between the user and the system by providing information both proactively and on demand.

5.3.1 Provision of Information Proactively

Regarding proactive information provision, the framework utilizes historical behavioral data alongside real-time environmental information to intelligently anticipate user needs. By analyzing users' routine activity patterns, the system can proactively deliver relevant information about the surroundings, such as obstacle locations, navigable paths, and important landmarks. This learning-based mechanism for pushing information can significantly enhance users' decision-making efficiency in dynamic environments while minimizing potential risks. Furthermore, users can adjust the content and frequency of information updates through simple voice commands or touch operations, thereby enhancing personalized experiences.

5.3.2 Provision of Information on Demand

The on-demand information provision mechanism delivers information in response to users' immediate requests. The system can swiftly identify user needs and, based on historical behaviors and environmental recognition, provide relevant information promptly. For instance, when a user requests navigation details to a specific location, the system generates the optimal action plan by combining the user's historical preferences with current environmental data. This mechanism not only enhances user engagement and sense of control but also facilitates effective two-way interaction between the user and the system, making the entire framework more flexible and adaptable.

6 POTENTIAL APPLICATIONS AND FUTURE PROSPECTS

6.1 Trends in Development for Embodied Intelligence Technology

The evolution of embodied intelligence technology is fostering its extensive application within the realm of assistive technologies. With advancements in sensors, artificial intelligence algorithms, and computational power, EI systems are becoming increasingly precise in their environmental perception and decision-making capabilities, enabling natural interactions between humans and machines. The convergence of these technologies points to a promising future for embodied intelligence in assistive technologies, offering substantial support to enhance the quality of life for visually impaired individuals.

6.2 Long-Term Effects on the BLV Population

Technologies rooted in embodied intelligence significantly enhance the independence of visually impaired individuals, allowing them to engage more confidently in social situations. By providing real-time environmental feedback and navigation support, these technologies improve mobility and foster a more positive societal perception of the potential of visually impaired individuals. This, in turn, encourages the development of relevant policies and social support systems.

6.3 Considerations Ethical and Acceptance Social

The promotion of embodied intelligence technology requires a strong focus on privacy protection and social acceptance. Developers must ensure data privacy is maintained during the design of EI devices, while also emphasizing accessibility and inclusivity to prevent creating dependency on technology among users. By implementing transparent ethical reviews and encouraging user participation, a sustainable environment for the development of assistive technologies can be established.

7 CONCLUSION

7.1 Key Research Findings Summary

This study presents a framework for integrating embodied intelligence within assistive technologies, emphasizing its potential applications for the visually impaired population. The findings suggest that multimodal perception and intelligent decision-making can offer personalized support to visually impaired individuals, providing a theoretical basis for future advancements in assistive technologies.

7.2 Directions for Future Research Recommendations

Future research should focus on improving the perceptual and decision-making capabilities of embodied intelligence systems and explore their applications across other disability domains. Empirical studies assessing user experience and social acceptance are essential to ensure its practicality and sustainability.

7.3 Impact Positive on the BLV Population and Social Importance

Technologies based on embodied intelligence have the potential to significantly enhance the confidence and independence of visually impaired individuals, facilitating their better integration into social life. The widespread adoption of such technologies will also contribute to improvements in related policies, fostering greater understanding and inclusivity for the visually impaired community within society.

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INVESTIGATING HOW UX STRATEGIES FACILITATE DIGITALIZATION OF PUBLIC SERVICES：A CASE STUDY

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ABSTRACT
Developing digital systems is crucial to the digitalization of public services. However, the effort faces various strategic challenges, such as resource constraints and divergent stakeholder needs, making system development especially complex. User experience (UX) strategy is a user-centered approach to understanding user needs and aligning them with organizational objectives. This study explores Taiwan's Animal Exhibition Operators Management System as a case to investigate how this strategy can address these challenges and facilitate human-centered digitalization in public services. The findings reveal that the UX strategy effectively defines actionable pathways for achieving public sector goals, showcasing its tangible value. It enables strategic resource allocation, builds consensus among diverse stakeholders, and enhances collaboration between external teams and public agencies, thus advancing public service digitalization. This study introduces a strategy structure for designing public systems and demonstrates its practical impact from conception to implementation.

Keywords: UX strategy, digitalization, public service

1 INTRODUCTION

With the advent of the global digital era, Taiwan has proactively advanced the digital transformation of government, seeking digital solutions across various public services [1]. However, the digitalization of public services faces persistent challenges. When the government attempts data governance through digital platforms, inadequate planning can result in limited effectiveness. Since 2015, the Taiwanese government has sought to regulate animal exhibition enterprises through legal frameworks; however, public awareness of this issue remains limited [2]. Additionally, conflicting perspectives among stakeholders have hindered effective regulation, prompting the government to collaborate with external teams to develop the Animal Exhibition Operator Management System (AEOMS). This study examines this case to investigate how to plan a holistic user experience strategy for public service systems, thereby human-centered digitalization of public services.

User experience (UX) strategy is a comprehensive plan aimed at ensuring that products or services meet user requirements while providing an outstanding experience. It aligns business objectives, user needs, and technical feasibility, thereby offering organizations with a clear pathway to create meaningful and valuable user experiences. Integrating such a holistic strategy into the system development process of digital public services, not only ensures high-quality end-user experiences but also empowers designers to address potential challenges related to digitalization within the rigid frameworks of public institutions. Consequently, the research problem addressed in this study is the formulation and implementation of a UX strategy for system development in the public sector. Take the AEOMS as a case study. The study outlines three research objectives: (1) to identify the challenges encountered during the digitalization of public services in the context of case execution; (2) to propose a UX strategy structure and describe how the UX strategy can address these challenges; and (3) to evaluate the benefits and value of the UX strategy in promoting public services digitalization within the public sector.

2 LITERATURE REVIEW

2.1 Challenges of public services digitalization

Digitalizing public services involves using digital technology to enhance service efficiency, transparency, and accessibility, making it a crucial aspect of government digital transformation. However, implementation faces challenges beyond technology, necessitating a deep understanding of the public service domain [3]. The specific challenges vary across public service sectors [4]. This study examines obstacles in developing digital systems intended to replace paper-based processes.

A major issue is conflicting stakeholder perspectives, which often hinder digitalization. Differences in understanding digital systems lead stakeholders to have varying needs and expectations [5]. Civil servants, as central actors, may struggle to understand citizen needs, typically approaching digitalization with a top-down mindset [6]. Addressing these conflicts requires effective communication and balancing stakeholder demands. Additionally, existing legal frameworks can obstruct public service digitalization. Bureaucratic procedures, strict regulations, and multi-level decision-making processes complicate project execution [7]. Misalignment between regulations and current social needs further limits digital service implementation [8].

In summary, successful public service digitalization relies on a comprehensive understanding of stakeholders' needs and the challenges faced by public sector institutions to develop strategic plans that address the systemic constraints.

2.2 UX strategy in human-centered public service

In recent years, human-centered digitalization of public services has become a global governmental trend. The UN [9] emphasizes the principles of "leaving no one behind" and "promoting digital inclusion," advocating that digital governments should bridge the digital divide to ensure equitable access to digital public services. Likewise, the OECD [10] includes a "user-driven" approach as one of six core areas in its Digital Government Policy Framework, highlighting the importance of centering users in public service digitalization. However, research is currently lacking on how to concretely and strategically implement this user-centered concept in public digital service projects.

UX strategy offers a practical, user-centered methodology that could address this gap. Levy [11] describes UX strategy as a bridge between user needs and business strategy. It represents a process of integrating user-centric design with the strategic goals of digital products, ensuring alignment between business objectives and user expectations. According to NN/g [12], UX strategy prioritizes user experience quality and sets execution priorities, bridging UX design with business strategy to meet both user and organizational needs [11]. Applying such a strategy in public service system development shifts traditional commercial objectives toward public service goals, thereby aligning public sector projects more closely with user needs. This study investigates a public sector system development case that integrates UX strategy from planning to implementation stages, exploring its impact on advancing digitalization in public services.

3 METHODOLOGIES

This section describes the case and its execution process.

3.1 Case study

This study employs the 2023 project, *Development of an Animal Exhibition Operators Management System (AEOMS)*, as its case study. The project, part of the Ministry of Agriculture's initiative, *Diverse Pet Animal Welfare Assessment Mechanism*, seeks to enhance Taiwan's oversight of animal exhibition operators. An external team was commissioned to conduct the project from research to system design and full development. The external team's responsibilities were limited to system-related design, excluding tasks inherently tied to public sector duties, such as legal drafting and defining operational workflows, with recommendations provided only when necessary.

This study focuses on two critical experiences derived from the project's execution: the formulation of a UX strategy and the alignment and communication with the public sector. The researcher, who was actively involved as part of the project team, contributed to key activities, including stakeholder interviews, system function planning, and interface design. Data collection for this research consists of records from 17 stakeholder interviews, three progress reports presented to the public sector, 72 meeting minutes, and one system requirement workshop. The stakeholders interviewed in this study are shown in Table 1.

Table 1. Stakeholder Interview Participants

Stakeholder Type	Description	Number of Interviews	Duration (hours)
Central Government	Case owners and regulatory officials	4	6
Local Government	4 local governments nationwide, including department heads and staff	7	11
Licensed Operators	3 large facilities, including major aquariums and zoos	3	4
Unlicensed/Potential Operators	2 small businesses, including cafes and farms	2	2.5
Animal Exhibition Domain Experts	Expert in animal exhibition	1	1.5
Total		**17**	**25**

3.2 Case Execution Process

The project was executed in three phases over nine months. Table 2 outlines the objectives, the role of UX strategy, key steps, and the duration of each phase.

Table 2. Phases of Project Execution and the Role of UX Strategy

Phase	Objectives	Role of UX Strategy	Steps	Duration
1	Clarify the system goals	Construct User Experience Strategy	Conduct research → Build strategy → Prioritize tasks	4 months
2	Design the system	Implement User Experience Strategy	Develop system architecture → Execute high-priority tasks	3 months
3	Planning for next year	Review and implement User Experience Strategy	Review goals → Plan secondary tasks	2 months

Figure 1. Interviewing the public sector and the operators during the case execution

4 RESULTS

This section explores how UX strategies enable external teams to overcome the challenges of the digitalization of public services. The research results include the challenges faced within the case context, the UX strategy structure employed, and the contributions of the strategy in addressing these challenges.

4.1 Public services digitalization challenges in the case

While developing a UX strategy for digitalization, the external team struggled to set effective goals due to limited understanding and influence. Through case study, we identified two key challenges and offered specific recommendations to overcome them.

4.1.1 Stakeholder divergence leads to unclear system requirements

Stakeholder interviews revealed that the diverse and conflicting needs of stakeholders are a key barrier to digital transformation. Even when the public sector is willing to invest in digital system development, it struggles to clearly define system requirements due to the challenge of assessing the benefits of the new system for each stakeholder.

> *"Digitalization is the direction we want to move toward, but many businesses are already reluctant to cooperate with the government. If we force them to switch to a new digital system, it might just give them another reason to resist." - Service administrator*

> *"The goal of animal welfare groups is to end animal exhibitions, while our goal is to manage animal exhibition operators, which in some ways contradicts each other." - Service administrator*

In this context, mapping the stakeholders in public services can help external teams identify the root causes of conflicting demands. Based on figure 2, we identified the different roles of stakeholders in public services and assessed the challenges they face in their interactions.

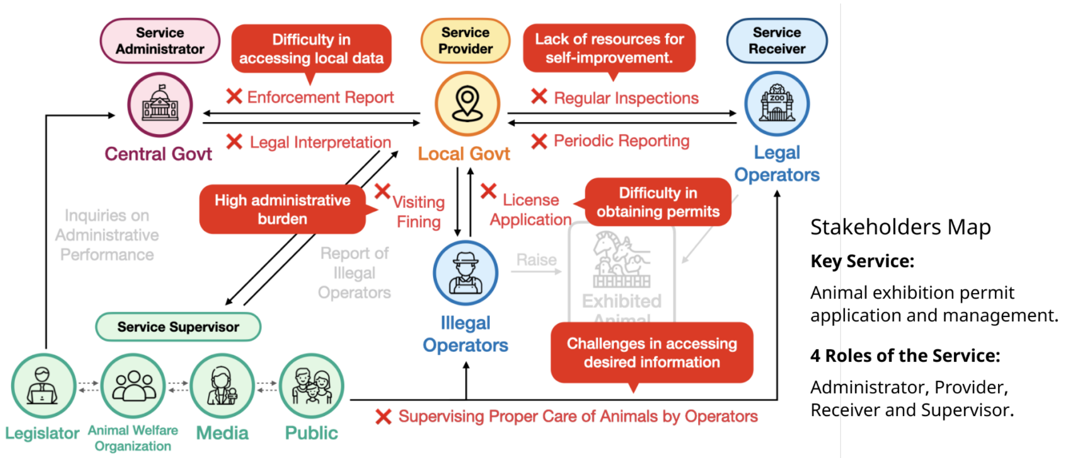

Figure 2. Stakeholders map in animal exhibition permit application and management

4.1.2 Incomplete administrative regulations lead to unrealistic expectations for the system

During the process of understanding business operations from both senior and frontline public sector staff, we found significant differences in workflows between local governments, stemming from the lack of comprehensive regulations from the central government. While this gives local governments room for flexibility, it also complicates maintaining data consistency during digital transformation. Simple digitization cannot compensate for legal gaps.

> *"I have to request local governments to provide a list of animal exhibition operators each quarter, but many counties are reluctant to cooperate." - Service administrator*

> *"The central government may not even know what data is needed to manage operators. We create our own forms to record operator status and visit frequency." - Service provider*

> *"We have posted a permit application process on our website, but I'm unaware of the processes in other counties." - Service provider*

In this context, public sector officers, lacking a full understanding of information systems, may assume that the mere introduction of a digital system will collect all necessary data. This overlooks the willingness of data providers to use the system and the need for consistent data validation standards. As a result, systems developed under inadequate planning risk creating further issues in the future.

4.2 Facilitating public service digitalization through UX Strategy

To clarify the overall goals of the system and identify actionable items, we developed a UX strategy structure. This subsection elaborates on how the UX strategy formulated through this structure addresses the challenges encountered in the case study.

4.2.1 UX Strategy Structure

As shown in figure 3, the structure consists of 6 levels according to the reasoning sequence:

- **Vision:** Defines the ultimate goal of the public service, serving as the guiding mission for the UX strategy.
- **Project Goal:** Explains how the project seeks to achieve the vision by designing and delivering an optimal user experience.
- **Stakeholders' Goals:** Identifies the specific objectives of each stakeholder involved, illustrating how the project addresses and aligns with their diverse needs.
- **Barriers and Plans:** Describes the process of deriving solutions from stakeholders' goals, with an emphasis on analyzing and formulating plans to overcome existing challenges.
- **Actionable Solutions:** Outlines practical and concrete solutions developed to achieve the project goals, focusing on identifying feasible actions under real-world conditions.
- **Tasks:** Categorizes solutions based on their relationships, providing a recommended sequence of execution tailored to the public sector's priorities.

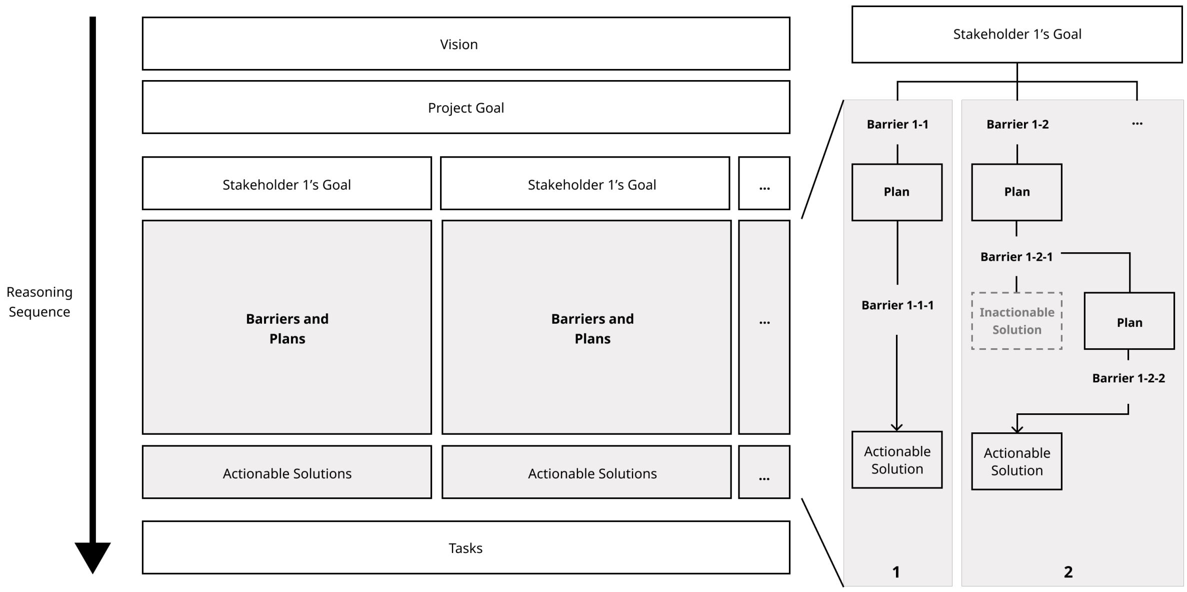

Figure 3. User Experience Strategy Structure

4.2.2 Setting Goals under an Inclusive Vision

To achieve transformational impact, design researchers need to co-create a vision with the organization to guide targeted actions for change [13]. Although the stakeholders in the case study held divergent perspectives, multiple interviews and alignment meetings revealed a shared vision: "The public can safely visit high-quality animal exhibitions under government oversight." This vision was defined as the guiding element in the UX strategy. A vision of this kind must be inclusive, practical, and research-based, providing a shared direction for both design researchers and the public sector while fostering mutual trust.

Under this vision, the project goal must explicitly connect how the public sector's existing resources and team expertise contribute to achieving the vision. In this case, the project goal was defined as " Creating a seamless user experience to enable effective central management of local governments and efficient oversight of operators." Equally important is defining the next level: stakeholders' goals. To demonstrate how the digital system addresses various stakeholder demands, we aligned the goals of all stakeholders involved as system users. This alignment became the foundation for categorizing key solutions. It also clearly shows how the actions proposed in the UX strategy respond to these stakeholders' needs and can serve as a reference for evaluating expected benefits and prioritizing tasks accordingly.

As shown in figure 4, these upper-level definitions were validated in meetings with the public sector, clarifying previously ambiguous system requirements and securing the public sector's support and trust.

> *"You (the external team) identified many details I wasn't initially aware of. I never thought of approaching system functionality this way." – Service administrator*

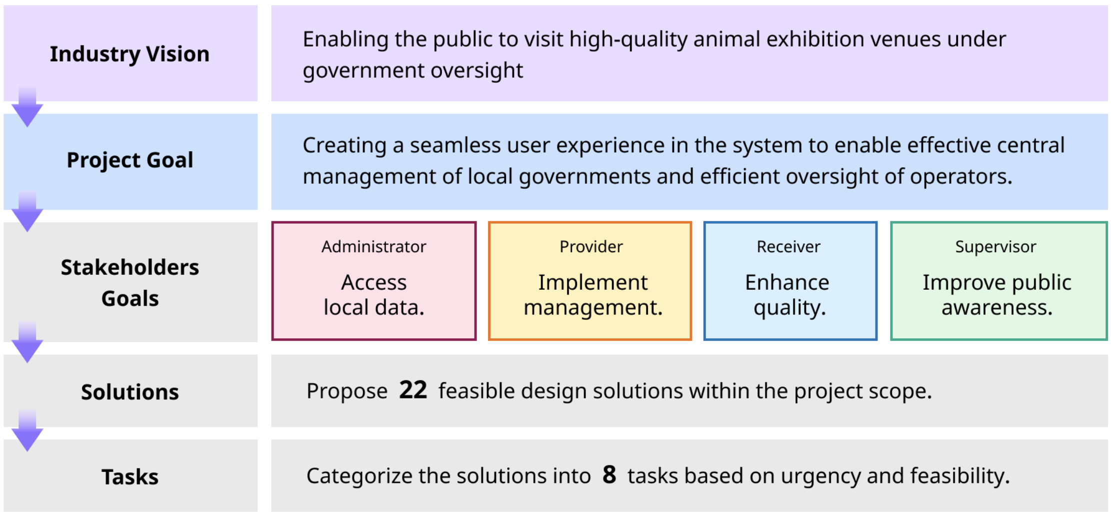

Figure 4. Alignment of Vision, Goals, and Solutions for Public Sector System Design

4.2.3 Planning under Rigid Constraints

To manage and align the public sector's expectations for the system, our interviews focused on two key areas: identifying immutable facts, such as established laws, and uncovering the current challenges faced by stakeholders. These insights played a pivotal role in the subsequent development of actionable solutions. Based on the diverse goals of stakeholders, the external team aimed to outline clear decision paths, justifying the prioritization of specific system functions. The "Barriers and Plans" phase further guided the team in identifying feasible paths to propose actionable solutions that align with higher-level goals, as illustrated in figure 5.

Through the UX strategy structure, the case study proposed 22 actionable solutions and 8 tasks. The tasks were grouped based on the interrelationships between the actionable solutions, focusing on three main aspects: whether a specific execution sequence must be followed, whether shared data requirements exist among solutions, and whether the solutions share the same level of urgency. The final categorization revealed that the UX strategy not only defined system functions but also identified areas requiring external resources, such as clearer regulatory definitions and additional training resources for operators.

This UX strategy transformed the traditional supervisory relationship between the public sector and external teams. By rationally distributing responsibilities and tasks according to each party's expertise, the public sector gained a clearer understanding that the success of the system requires their active participation.

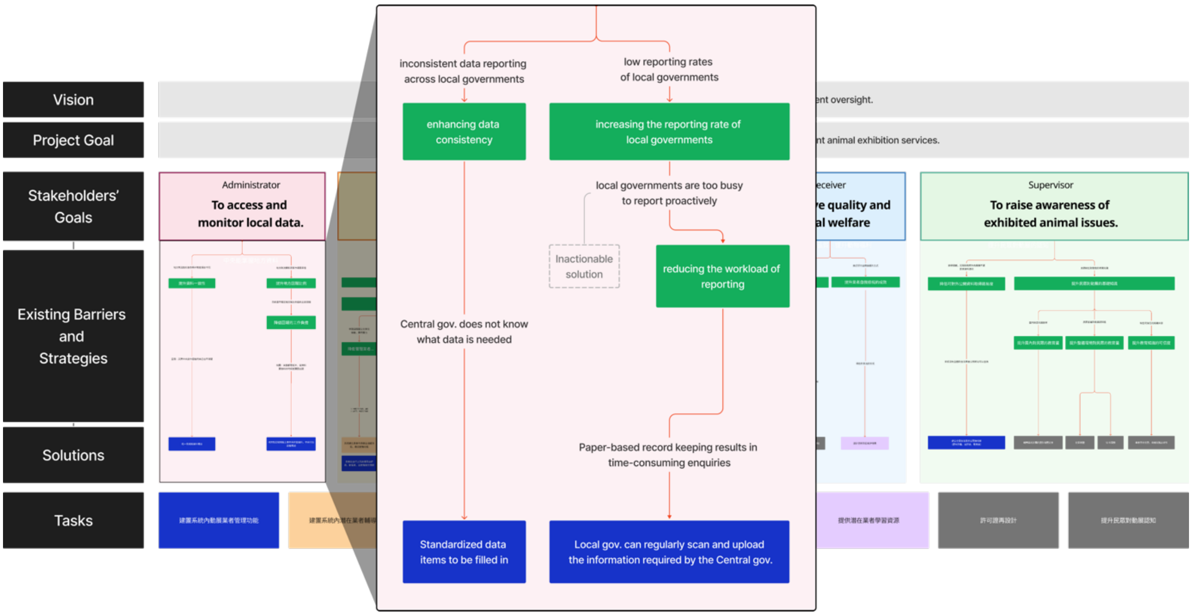

Figure 5. The UX strategy of AEOMS

5 DISCUSSIONS

5.1 Impacts of the UX strategy on Public Services digitalization

Public services digitalization is a long-term initiative, influenced by multiple factors, making it difficult to precisely assess what leads to success or failure. Drawing on the successful outcomes from this case study, this section focuses on exploring the specific ways in which the UX strategy effectively advanced digital transformation in the public sector.

5.1.1 Planning for Rational Resource Allocation

With limited budget and time constraints, public sector organizations often struggle to fully understand actual needs, resulting in digital system development that only addresses surface-level issues. However, by establishing a UX strategy in advance, the public sector can engage in long-term thinking about the desired vision and strategically allocate resources to achieve incremental progress toward that goal. It is essential to align the measures of digital transformation with the public value they can generate for society [14] This approach offers a clear problem-solving flow, showing how specific resources can address particular problems and meet stakeholder goals. It allows public sector officers to reassess whether resources are allocated effectively and enables external system design teams to focus on the most urgent and critical tasks, maximizing resource efficiency.

> *"We originally planned to have all operators use the system this year, but given the complexities of data management, we will focus on features related to licensed operators instead." – Service administrator*

5.1.2 Building consensus through human-centered approach for Public Service Alignment

In this case, both conflicting stakeholder views and imperfect legal frameworks significantly contributed to the public sector's lack of clarity on the next steps. As a user-centered strategy, UX strategy effectively visualizes research findings, serving as a crucial foundation for discussions between the external team and stakeholders. It not only highlights each stakeholder's needs within the service but also neutrally presents the perspectives of various stakeholders, helping them recognize the importance of building consensus at this stage. This positioned the external team as an influential third-party mediator, steering stakeholders toward compromises in their expectations to achieve the shared vision.

Furthermore, the UX strategy highlighted the value of user experience to the public sector, demonstrating how a well-designed user experience can align systems more effectively with governmental objectives and bridge the gap between user needs and public sector goals. Figure 6 demonstrates how we explained to the public sector the importance of system usability in gathering local data and how adhering to these design principles would help achieve their goals.

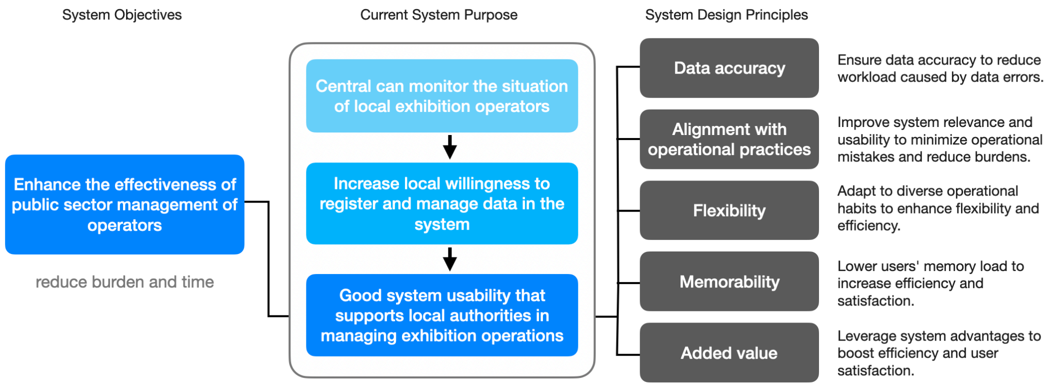

Figure 6. Illustration of UX Value for Public System: Objectives, Purpose, and Design Principles

5.2 Suggestions for Formulating a UX Strategy for Public Sector Systems

The design and development of public digital systems have long been regarded as a key tool for advancing public services digitalization. Planning a UX strategy tailored to address the challenges inherent in public sector structures can offer new opportunities for the many public systems that fail due to practical constraints. This section presents relevant suggestions.

5.2.1 Starting from the goals of multiple stakeholders

The digitization of a public service necessitates changes to established habits among all stakeholders, which may provoke resistance to change. A digital system that fails to gain acceptance holds little value. Therefore, this study recommends conducting a comprehensive investigation into stakeholders' attitudes toward digitization, identifying their challenges, and understanding their expectations before developing a UX strategy. It is also advised to align actionable solutions with these stakeholders' goals, providing the public sector with a way to evaluate the impact of different tasks. This approach offers flexibility in prioritizing stakeholder needs, helping to mitigate conflicts and challenges that often arise during digital transformation.

5.2.2 Identifying the gap between challenges and goals as the entry point

As an external team, a lack of understanding of public sector structures can lead to operational constraints or wasted effort managing frequent changes in requirements. This study recommends identifying ground rules beyond the external team's influence—such as legal requirements governing workflows or access limitations within existing databases—before formulating the UX strategy. These unchangeable constraints provide clear direction for system design and enhance the practicality of proposed solutions. Prioritizing these gaps ensures that every developed feature directly addresses specific needs and challenges, facilitating the effective implementation of digital transformation in real-world public sector contexts.

In summary, gaining the trust of the public sector through a comprehensive UX strategy is essential for advancing digital transformation. External teams must understand the reasons behind stakeholder disagreements and assess how these differences impact system design and development. Through the UX strategy structure, these insights can be synthesized into a coherent structure to allocate resources effectively and achieve project goals. This approach fosters better task distribution between the public sector and external teams, facilitating a more constructive and collaborative partnership.

6 CONCLUSIONS

This study, through a case study of AEOMS, explores how UX strategy facilitates digital transformation in the public sector by supporting external teams. We propose a UX strategy structure and analyze how the UX strategy formulated based on this structure addresses challenges arising from divergent stakeholder interests and incomplete regulations in the case. The study reveals that the implementation of UX strategy provides strong evidence of UX value within the domain of its designed products, enhancing rational resource allocation, fostering consensus, and expanding influence, ultimately promoting more positive collaboration between the public sector and external system design teams.

This provides a new approach for addressing structural and strategic challenges in e-government-based digital transformation, aiding in demand coordination, improving development efficiency, and achieving a human-centered public services digitalization.
This study is based on a single case, which may limit the generalizability of the findings, and it primarily focuses on short-term impacts. Future research could expand to a wider variety of projects and incorporate metrics that evaluate both public sector performance and user needs to assess the quantitative impact of this strategy. These metrics are particularly useful for measuring the Project Goals and Stakeholders Goals outlined in this strategy. Examples include metrics defined by the UK's Digital Government Services, such as cost per transaction, digital take-up, and user satisfaction [15].
In conclusion, this study provides new perspectives and tools for digital transformation in the public sector, highlighting the critical role of UX strategy in overcoming complex challenges and advancing human-centered digitalization in public services.

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PROCEEDINGS OF ASIA DESIGN AND INNOVATION CONFERENCE
5–6 DECEMBER, 2024, SHANGHAI, CHINA

LIMITED STORIES: SOCIAL DESIGN POTENTIALS WITHIN INDIGENOUS CONTEXTS

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ABSTRACT
In social design processes, designers seek to improve challenges by using design to solve problems and answer communities' needs. Aspects of change are central to social design, as transformative change usually forms the goal of the design action. This study will consider narrative practices, such as stories and creativity, to explore how they can—and cannot—reconstruct realities faced by marginalised communities. Social designers frequently encounter such settings to address particular needs using social design tools. The article is based on a focus group discussion conducted during a community arts-based intervention, thus prioritising a qualitative approach to comprehend the fundamental problems in this particular South Australian context. When dealing with sensitive matters and designing with marginalised communities, social designers need to understand narrative practices' power to be changed and transformed. People, processes and artefacts can contribute to the reinterpretation of stories, thereby changing the direction of dominant narratives. Social designers ought to gauge the power of stories with care to create better cohesion and carefully guide disruption.

Keywords: Social Design, Narratives, Stories, Arts-based Methods, Trust

1 INTRODUCTION

Enabling narrative practices in the early stages of the social design process can bring about rich narrations, which can create possibilities for storytelling but also outline its limitations. However, a critical view on the role of narratives should also consider the destructive or adverse consequences of storytelling and narrative practices. Such research contributes to breaking down stereotypes and fostering cross-cultural appreciation in social design.

The unique contribution of this article lies in demonstrating how arts-based storytelling fosters trust and community cohesion. The research provides a new lens for understanding social design in marginalised settings by employing techniques such as collaborative art-making and narrative sharing. This approach highlights the role of emotional and cultural sensitivity, emphasising the importance of context-specific engagement strategies that respect and amplify the voices of marginalised communities [1]. The study facilitates personal and cultural expression by utilising creative practices like felting and storytelling while encouraging the co-creation of narratives that can influence social change. These arts-based practices are essential for eliciting rich qualitative data and engaging participants meaningfully [2].

This study aims to illuminate the limitations of storytelling and embodied action as methodologies within social design contexts. To convey the significance of the intervention, it is vital to understand Ceduna’s challenges, including limited resources, cultural disconnection, and intergenerational trauma. This context highlights why creative engagement and storytelling through felting are crucial for cultural preservation and community well-being.

Furthermore, the research reflects on how narrative practices used in social design, specifically storytelling, can be central to understanding complexities within marginalised contexts. The research asks, ‘What are the possibilities and limitations to storytelling and embodied action for creating trust and context-specific understanding with vulnerable groups or environments in the early stages of social design processes and throughout?’ ‘How can stories create awareness to better design social processes and relationships that address challenges within sensitive contexts?’

An intervention will illustrate the use of stories and embodied action in the fuzzy front end of social design research. The fuzzy front end of design is often perceived as the initiating and empathy-building phase in design processes [3]. This intervention entails an arts-based felting workshop at Arts Ceduna, an Aboriginal art centre in the isolated and remote town of Ceduna on the west coast of South Australia's Eyre Peninsula. The initiative was carried out in collaboration with the Ceduna Aboriginal Corporation (CAC) and the University of Lapland. This study used arts-based research to engage with the artistic community of Ceduna due to their familiarity with arts-based practices. The arts-based methods (ABMs) used were based on textile making, painting and storytelling. During the intervention, a focus group consisting of the three authors discussed the role of creativity within the community and how the arts can elicit more active engagement. They shared their creative experiences, concerns, and beliefs about the purposes of art practice. By doing so, the results delivered insightful understandings that advance knowledge on using narrative practices to guide empathic engagement in early and ongoing social design and research processes within marginalised contexts.

2 NARRATIVE PRACTICES IN VULNERABLE CONTEXTS

Denzin [4] illuminates the role of narrative practices, with their benefits and limitations, within vulnerable groups or environments. Such practices can assist in the uncovering of hidden gaps, disconnects, conflicts, congestions, constraints, and power distortions in the early stages of design practice by creating – audibly, visually or performatively – a holistic understanding of the interactions between or within communities. The value of storytelling in exploratory design phases has been acknowledged in sensitive contexts. Stories are frequently used to amplify, divert from, or alter what is experienced, what is current reality, and what is yet to come when nurturing the potential of the possible. Narratives are transportive, illustrating the 'persuasive potential of stories' [5, p. 385; 6]. Transportation is understood as a 'loss of oneself' or to 'travel within the text' [6, p. 385]. Narrative persuasion results from the level of immersion into a story and its ability to influence the beliefs of the listener or reader of the story [5]. The limitations of storytelling amongst participants living in peripheral contexts include the often silenced and interrupted stories [1]. Within social design and cultural contexts, audiences play important roles as the recipients and interpreters of stories. Audiences are stories' protagonists as they 'progressively construct models of meaning that represent the people, places, and problems of a story' [7, p. 323]. Therefore, audience as a social construct is relevant to social design. When an audience experiences a story, they must place themselves inside the narrative's mental model and take on the character's viewpoint. However, they must also be conscious of their social position within the group [7]. They need to negotiate the positioning of the players, characters, and roles within a story. Thus, audience participation in stories is essential for revisiting and reinterpreting shared histories. This opens the possibilities for capturing and processing the unfolding of current events and to express ideas, needs and dreams about the future [1]. However, critical views on the power of audiences should not be overlooked, as audiences' participation in stories can also be unfavourable.

3 NARRATIVE FUNCTIONING, ARTS-BASED METHODS AND EMOTIONS

Narrative goes beyond merely telling stories; it becomes a powerful tool for sparking creative insights and initiating transformative actions. Narrative practices are cognitive, emotional and performative constructs. In addition, they are mental simulations; they can transport people into narrative worlds through vivid imagery that can feel like real experiences that shape attitudes and lead to adopting beliefs [5]. In addition, the narrative function itself can critically reflect on, question and also undo dominant narratives. By embracing narrative, individuals gain the ability to navigate the complexities of creativity with flexible and visionary insight, ultimately leading to the development of fresh and creative ideas [8]. The greatest social impact of the arts is encouraging critical reflection on personal and others' experiences [9]. Arts-based inquiry fosters new dialogues and participation, proving valuable for impactful research and visual dissemination [2]. Arts-based enquiry captures rich qualitative data through diverse strategies, addressing complex issues and offering innovative solutions to societal challenges by revealing underlying narratives [10]. When applied collaboratively and with care, ABMs stimulate engagement and storytelling through multimethod, open, and improvisatory processes.

Emotions and feelings elicited through narratives can contribute to the persuasiveness of a story through the transference of information, during which feelings can become vital moderators of social influences [11]. Such influences can emerge from stories [11]. Therefore, how individuals and groups feel about their circumstances influences their well-being and resilience in change processes. Emotions' role in well-being and coping with change is central to stories at both individual and community levels. Stories are essential to ensure the functioning of change mediation in marginal communities [12]. Although stories can drive emotional and other forms of resilience [13], they can have negative effects on communities when stories break down and voices are silenced. This leads to the exclusion and degradation of coping mechanisms, which impacts emotional well-being and cohesion within society from the individual to the community level [14]. The arts can transport, create new meanings and heighten our attention as they are a medium for evoking new interpretations and aesthetic experiences such as emotional responses [15]. This form of transportation is an immersion into narrative worlds and a form of mental engagement that can affect attitudes and beliefs [**7**]. Mental models must be 'constantly updated as the narrative moves forward' [**7**, p. 323]. Narratives are frequently used to amplify, divert from, or alter what is experienced, what is current reality, and what is yet to come when nurturing the potential of the possible. The power of narrative practices, or stories, should be used cautiously, as uncontrollable or runaway change [16], which can be detrimental, does not always result in long-term benefits. The abilities of stories within social design and with a specific focus on vulnerable contexts to connect and control are illuminated in this article. Uncovering the impact of narrative practices in marginalised contexts needs cross-checks and balanced views by everyone involved. Social designers should be sensitive to, and critically consider counteractions to ameliorate power dimensions at play in marginalised contexts that come about and are often perpetuated through narrative practices and other expressive processes.

4 METHODS

Researchers are advised to employ qualitative methods such as participatory research, autoethnographic research, narrative and biographical research, or traditional qualitative research based on interviews with representatives of marginalised groups that involve community members in the decision-making process, ensuring their voices and perspectives are integral to the research design and implementation [17, p. 8−11). In collaborative approaches to research, more democratic approaches to data collection and interpretation are promoted. In marginal contexts, often situated at the fringes of societies, specific care is needed in the delicate initial phases of the work and research. ABMs, specifically felt-making and painting, were used to engage with the Indigenous arts community at Arts Ceduna for these purposes. A focus group discussion was conducted while implementing the arts-based activities.

The choice of implementing a felting intervention is deeply rooted in the historical and cultural significance of textile arts within Indigenous practices [18]. Felting art is believed to have originated from nomadic peoples, such as the heritage of Turkic nations [19]. This art form provides a creative outlet and a communal space for storytelling, which is essential for reinforcing cultural ties and facilitating healing. This approach acknowledges the rich traditions and heritage of Indigenous communities, requiring researchers to be sensitive and respectful of cultural protocols and the non-linear and experiential nature of storytelling to ensure community members feel honoured and heard.

4.1 The research setting, participants and focus group

During the intervention in Ceduna, South Australia, in 2023, arts-based activities were implemented at the Aboriginal Cultural Centre and the Women's Centre of CAC. Ceduna has a small population of less than three thousand residents, including several Indigenous language groups such as Kokatha, Mirning, Wirangu and Pitjantjara. The management board of CAC authorised the intervention and invited the academic research team from the University of Lapland in Finland to collaborate with the Indigenous community. Two team members, who engaged in the arts-based activities and the focus group, were researchers from the University. Both were also practising artists. One of the researchers—the first author—had a long-term working relationship with Arts Ceduna through previous project work conducted in 2016-2017 and again in 2022-2023. During the latter period, she coordinated a felting project with the artists from Ceduna. She had twenty years of felting experience and used her knowledge to coordinate a two-month felting project with the artists of Ceduna, transferring two and three-dimensional felting skills to the artists. The third author, an Indigenous Aboriginal practising artist, also coordinated the CAC Women's Centre during the intervention. She initiated the focus group and is herself a felting artist.

The arts-based activities included felting with Australian lambswool, as shown in Figure 1. The eight participating Aboriginal artists coordinated and orchestrated their works. Two large, felted textiles of about 1.2 x 1.6 meters were laid out on long wooden tables in the Arts Ceduna studio. The artists grouped themselves into two groups, each creating their own textile design using their personal stories. One group created a textile design that reflected their individual stories and experiences about the sea and coastline of Ceduna. In contrast, the second group used personal stories about the land around Ceduna to create their textile. The groups discussed and developed the narratives they wanted to embed into the textiles.

Figure 1. Arts-based activities by the artists at Arts Ceduna. Photography, Amna Qureshi, 2023.

During the focus group, the artists were not asked any specific questions; instead, the author-researchers engaged in the process by participating alongside them, allowing the artists to take the lead. The researchers listened to the artists' stories, observed their choice of colours, and noted how they carefully placed the felt on the table. The artists brought their verbally discussed themes to life without preliminary sketches, as if the designs were already fully formed. They added pieces of wool, constructing design elements that beautifully illustrated their stories. This silent observation and active engagement method allowed the researchers to capture authentic expressions and understand the creative decision-making process in real-time, providing valuable insights into how art can be a pathway for cultural expression and heritage preservation. Observing the narratives begin to take shape within the first couple of hours was fascinating. There were unplanned breaks along the way, during which the artists engaged in light-hearted conversations, often adding and tweaking elements in their work. However, the author-researchers did not ask specific questions during the focus group; their involvement and observations served the purpose of the research. The researchers sought to understand how engaging in creative processes could facilitate a deeper exploration of cultural themes and community stories.

This approach aimed to reveal insights that might not surface through conventional interviews, emphasising the potential of ABMs to elicit rich, narrative-driven data.

Amidst creative felting practices, this unique exchange fostered a rich blend of perspectives, merging cultural insights with a collaborative exploration beyond conventional interview structures [17]. It created a space for genuine connection and a shared understanding of the role of creative practices in a community setting. This collaboration's significance lies in its role in preserving cultural heritage and empowering the artists by valuing their stories and skills [20]. By positioning the community members as leaders in the process, the research underscores the importance of working with, rather than on, marginalised communities. Additionally, this collaboration facilitated storytelling and emphasised the significance of art as a means for cultural preservation and intergenerational dialogue. By engaging in these shared activities, the artists could bridge generational gaps, passing down traditions and knowledge while simultaneously creating new cultural expressions that reflect the evolving identity of their community.

4.2 Data Collection and Analysis

The focus group was conducted amid creative art-making activities and was digitally recorded. It was a collaborative dialogue that moved beyond the conventional interview structure: a friendly and personal exchange without research questions or prompts. This approach enabled abducting [21] to ensure spontaneity and for new issues to emerge from the dialogue. The focus group was based on a friendly conversation between the three authors. The unstructured discussion focused on the creative practices of the specific intervention and within the community. The recording time of the focus group was 59 minutes and 7 seconds after the sensitive data had been deleted from the recordings. The transcribed data was collaboratively decoded remotely in a shared document, using an unstructured approach to enable the essence of the interview to emerge. The interview data was deidentified and lightly edited for readability purposes. The discussants are presented as 'Speaker 1, 2 and 3'. The coded themes were analysed using an interpretative approach.

Four narrative representations, or interview excerpts, were selected first quantitively according to the frequency of keywords, determined by word count using Microsoft Word's find function in the transcribed data set. The authors intersubjectively eliminated sections in the transcribed data according to the word count density in certain sections [22]. The transcribed data was organised by 'identifying similar themes or concepts from the data' [22, p. 498] and extracting parts representing a dense cluster of the keywords and related themes, as shown in Table 1. The data is represented as narrative fragments, which means that the integrity of the narratives was kept intact by illustrating the conversational flow between the discussants. Although unnecessary wording was eliminated, the flow of the interview and how themes followed one another remained unchanged.

Table 1. Keyword clusters and themes emerging from the interview data.

Keywords cluster	Themes
Connections, Trust, Listening	Building connections between individuals from varied backgrounds; Role of trust in interpersonal encounters
Creative Practices, Challenges, Community Connections	Role of creative practices in overcoming challenges and creating better connections within communities
Diversity	Extending connections between individuals through interactions with people from diverse cultural, social, and geographic contexts

4.3 Ethical Considerations

The ethics committee of the University of Lapland approved the research, which followed the ethical outlines of the Finnish National Board on Research Integrity (TENK). Given the personal nature of the focus group, the interview data has been de-identified. Informed consent, using a consent form in English, was sought from all participants in the research, not only the three authors. This entailed a community meeting at the Indigenous art centre in Ceduna, where participants were informed in English about the intention of the study, as this is the language all participants use in their daily practices. Participants had the opportunity to ask questions regarding the research and all researchers engaged in answering these questions. Participants were informed about their right to withdraw from the research at any stage. The researchers were careful not to coerce, elicit, record or otherwise learn about or capture any sensitive narrative information from the Indigenous artists. The artists were very aware, and themselves took care not to reveal sensitive narrative information that may not be shared with outsiders. In storytelling practices, sensitive stories may be present not only verbally transferred but also visually created. Significant care is needed to counteract the harm that may come to Indigenous peoples when their Indigenous knowledge and stories are appropriated and undervalued. The counteraction is possible through narrative functioning that can raise awareness of the protection of Indigenous Cultural and Intellectual Property (ICIP), which encompasses all elements of the traditional knowledge and cultural expressions of Aboriginal and Torres Strait Islander peoples.

5 FINDINGS

The narrative excerpts reveal respect, trust, building connections and relationships, and sharing with others through listening and giving time. Two clusters of key themes emerged from the qualitative content analysis. Firstly, the theme of generating trust, the role of narrative practices and learning that can emerge through creative and community engagement emerged. Secondly, the theme of art making, creative practices, and the narrative qualities of the arts for expression, storytelling, and dealing with aspects of change within a community setting emerged. The analysis following the four narrative fragments exemplifies how social designers can approach narratives in sensitive contexts during the fuzzy front end of the design process and for empathy building throughout a social design process.

In narrative fragment 1, the discussants' dialogue reveals themes of building connections between individuals from different cultural, social, and geographic contexts and the role of trust in such encounters. In narrative fragment 2, the discussants extended the role of connections between individuals and learning opportunities through meeting people from different contexts. The role of trust and creative practices in dealing with challenges shaping better connections within communities are themes that emerge in narrative fragments 3 and 4.

Narrative Fragment 1

Speaker 1: We tried to build a connection before physically meeting. Did it help to build any trust or connection?

Speaker 2: It's about respect, I think. But it's hard to say if you don't know a person. And that's why you try to build a relationship. You could go around it and find ways to trust.

Speaker 1: So, it's a lot of the sensing, what happens between people.

Speaker 3: I wanted to build trust, somehow, you know, kind of an affirmation; here I am, and I'm going to come and see you, meet you, talk to you, listen to your story and do something about it. When I came and met the community the first day, I felt enthusiasm in the entire group. Some artists grabbed my hand and told us: 'Sit and listen to my story'. One artist was attached to her storyline, which she painted. She kept on telling different parts of it.

Narrative Fragment 2

Speaker 2: It's learning because learning something different and what other people have to offer. And it's about being different, but we still have the same ideas in cultural things. But then when somebody else comes from a different place, we have to show them courtesy, respect and trust.

Speaker 1: Do you think that's important before you start the work, to have that time to meet each other and discuss expectations?

Speaker 2: Because you have to build that connection. Because if you don't build that connection, what do you have?

Speaker 1: But also, is it a question of what is left behind after they left?

Speaker 2: Well, for instance, when you came to this community you showed us a lot of things that we've learned, like felting. And building a connection with us, and for me that is returning to trust again—a better understanding of the outcomes of art projects and what they can do for this community. Art is a way of living. It's about being creative. What people get out of all these things is knowledge.

Narrative Fragment 3

Speaker 1: I want to know how to better work with communities. When you have an intervention in a community, it's a new activity. So, it's kind of intruding on your regular program. But interventions, I guess, also have benefits and how we hope to achieve what is best for the community.

Speaker 2: It was a good thing to bring women together showing them a different conception of how to get better from a lack of well-being, just being together and sharing each other's ideas. It's a time to be

here together, laughing and sharing ideas and how things can be better for our community and the next generation, because that's where everything starts, at home.
Speaker 3: To get out of that, you know, home-related, tough routine.
Speaker 2: I want to do things with plants or learn how to pot or do sewing, felting, painting, and just being still. Meditation. Some people have got a big wall up, and they don't want to talk, and they're screaming, and they're shouting and all kinds of stuff like being upset, grief, anger, all sorts of things. Whatever stays here in this place or, being said here, stays here. It's about having trust. They need that trust. If they don't have trust, they've got nowhere to go.

Narrative Fragment 4
Speaker 1: We hope to work better in the community. You know, how to draw people in, how to engage people better. Do you have an opinion about how to engage people better?
Speaker 2: But some of the artists are not up for change. They are so used to one direction, and sometimes you need to go there and stir it up and turn it in another direction. Some people just put up that wall and say, 'No, I'm not doing it.' Then, all of a sudden, they see the other artists doing it and then ask, 'Oh, okay, how come I'm not doing it?'
Speaker 3: Becoming too comfortable with the one thing that they have achieved, they just feel comfortable doing that. Trying to get people engaged in the programs, because this community needs to understand what art can do for the community.
Speaker 2: Being a little bird out in the community and saying, you need to get in here and prepare for the exhibition. Well, you need to go out there and get your story out there. You are an artist. So, listening to what other artists are doing in the community.

6 DISCUSSION

The themes of trust, community and creative engagement, well-being, dealing with change, and creative practice, emerged as central to the intervention's impact. The narrative practices used, including felting and storytelling, are embedded in the cultural fabric of the Ceduna community, addressing the pressing need for reconnection and emotional expression in a safe and supportive environment. However, understanding these practices requires acknowledging the historical and cultural sensitivities that shape community interactions. By situating these activities within a broader context of marginalisation, this study clarified the significance of ABMs and their role in fostering meaningful connections and cultural preservation.

ABMs were used to engage in creative practice and research with the community through an abductive approach that enabled important themes to emerge from the community itself. The vital role of creative practices illustrated in the narrative fragments, such as gardening, felting, sewing and painting as forms of narrative practices, generated feelings of togetherness. However, the lack of personal and community connections can also be connected to the lack of creative engagement due to 'having a big wall up'. These important themes emerged throughout the narrative texts. The four narrative fragments reveal different notions of trust. Trust often forms the foundation of empathic relationships; cultural differences influence and challenge collective trust [23].

Trust comes about through confidence in people, their integrity, and their abilities, while distrust means suspicion about people's abilities [24]. Based on beliefs and feelings, trust requires feeling safe in someone's presence [25]. A calm and tranquil atmosphere led to trust and connection between community members, outsiders and visitors. Trust can be developed when individuals feel heard, understood, seen, and valued, for example, through their creative expressions and stories, which can render them visible and increase their perceived value. In community engagement, attention is essential, as paying attention to someone or something is fundamental to building trust [26]. When attention is given to a matter, stories' positive or negative impact affects care. Attention can be created positively and negatively, and narrative practices play central roles in ameliorating negative impact.

Another notion of trust forthcoming from these fragments is that it can be expected to grow through creating opportunities for acquiring knowledge as learning is perceived as a gain for the community. Knowledge sharing requires a community to continue organising opportunities for knowledge transfer. Such opportunities can open up valuable co-creation and cooperation initiatives within a community or broader society to enable better processes and experiences through knowledge transfer.

Therefore, how narrative practices and stories manifest trust within and amongst groups and individuals and how stories contribute to the organisation of communities are necessary factors in tackling the functioning of narrative practices. From a design perspective, understanding how trust develops through narrative practices can inform the creation of social design strategies that prioritise meaningful engagement and co-creation. By emphasising the relational dynamics of trust, social designers can craft more impactful interventions that align with the community's needs and aspirations, thereby enhancing the relevance of social design practices.

Trust is earned; discretion is granted in handling whatever has been entrusted to an individual or group, to be left primarily unattended and unmonitored, and to require only minimal follow-up in executing duties [27]. Social designers must also acknowledge that while trust can facilitate positive outcomes, it is fragile and can be disrupted by poorly implemented interventions. Recognising the limitations and challenges, such as maintaining cultural sensitivity and managing the impact of design work in marginalised contexts, is crucial. This awareness ensures that design practices remain ethical and considerate of the community's well-being. Nevertheless, narratives in various forms, including embodied stories, can be challenging; they can breach trust and affect beliefs and expectations [28]. It is essential to retain a balanced view of stories and their power. When developing into dominant narratives, stories can influence processes either positively or negatively [29], and specifically in marginalised contexts, more sensitive approaches are required. The limitations of stories and sensitivity for acknowledging negative impacts on processes for building trust and empathy can offer critical perspectives. The fragments also illustrate that creative practices do not necessarily reach beyond 'a big wall up'. The challenges illustrated here are the dysfunction and inability of stories to drive change. In addition, the discontinuities and breaking down of stories to form reconnections, for example, to comfort trauma, such as grief, anger or loss, is illustrated.

Sarantou et al. [20] illustrated how Indigenous Aboriginal stories need sensitivity and care when sharing online, as the implications can be dire for mishandling sensitive stories that were orally passed down for generations. With the rise of digital platforms, designers need to be particularly mindful of how cultural narratives are represented and shared. The design of digital and social media tools should consider the potential for misuse or misinterpretation, and proactive measures should be taken to protect culturally sensitive information. This calls for a careful balance between accessibility and the preservation of cultural integrity. This research revealed how younger Indigenous Aboriginal generations are aware that certain narrative practices and stories should not be shared in an open domain, as inappropriate use of stories within sensitive contexts can result in negative runaway change. Complexities are increasing with the power of the internet and social media. As a result, care is needed to prevent runaway change and the negative impact caused by sharing culturally sensitive stories. Unsurprisingly, the younger Indigenous Aboriginal generations of Ceduna know that certain content should not be shared in an open domain. Tensions exist, for example, in Indigenous Aboriginal communities in clarifying the intentions behind stories, yet guarding against misinformation and misuse of meaning needs attention.

7 CONCLUSIONS

This article discussed how stories can create awareness by proposing narrative transportation and arts-based approaches to support the constructive roles of stories within social design in marginalised contexts. It would be beneficial to link the findings to established social design frameworks to enhance the relevance of this contribution to the design community. Articulating how ABMs and narrative practices can inform design processes can advance knowledge in the field and offer practical insights for social designers working with vulnerable communities. For example, integrating narrative-driven design principles can lead to more empathetic and practical design solutions that resonate with community needs.

The limitations of stories and sensitivity for acknowledging negative impacts on processes for building trust and empathy can offer critical perspectives in social design throughout the social design process. When paying attention to the needs of communities, participating researchers aim to build trust [29] and contextual understanding when engaging in specific contexts. In marginal contexts, specific care is needed in the delicate initial phases of the work and research. According to Moree [17], establishing trust involves recognising and respecting the unique cultural, social, and economic dynamics present within the community. Researchers should engage in active listening and demonstrate a genuine commitment to the community's well-being, which helps in mitigating any existing distrust or scepticism towards external entities.

The broader implications of nurturing close dialogues with Indigenous peoples may foster more careful collaborative approaches and social design guided by a critical view of narrative functioning when working with communities living in marginalised contexts. Exploring the significance and connective power of stories can touch upon improved practices for cultural exchange, preventing the breakdown or loss of trust integral to identity processes within a community, such as the sensitive stories that one of the authors did not wish to reveal. Social design practitioners are encouraged to adopt an iterative and reflective approach, continuously assessing the impact of their work on the community. Incorporating feedback loops where community members can voice concerns or suggest improvements can ensure that design interventions align with cultural values and community well-being. Additionally, training programs for designers on cultural sensitivity and ethical storytelling can be beneficial in avoiding unintended negative consequences.

These aspects ask for better listening skills from social design researchers and practitioners to create trust in context-specific settings when working with vulnerable groups or environments in the early stages of social design processes. For social designers, an acute awareness of narrative practices' positive and negative implications, especially in sensitive settings and working with vulnerable communities, is paramount to creating and maintaining empathy.

Regarding avenues for further research, the connective power of stories also creates a space for authentic communication that can produce emerging data and analysis to contribute to the substantive theorisation of social and transformative design. Building on the insights gained, we recommend future research that expands the multifaceted dimensions of storytelling practices in social design. By connecting storytelling to broader theories of social and transformative design, researchers can contribute to a deeper understanding of how narrative-driven design can drive social change. This can pave the way for more resilient and adaptable design frameworks that can address the evolving needs of diverse and marginalised communities.

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RESEARCH ON THE DESIGN PATH OF IMMERSIVE KAIPING WATCHTOWER EXPERIENCE BASED ON AIGC TECHNOLOGY

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ABSTRACT
This study explores the use of Artificial Intelligence Generated Content (AIGC) to enhance immersive cultural heritage experiences, focusing on the Kaiping Watchtower, a World Heritage Site. Traditional heritage displays often lack interactivity and engagement, which this research addresses by integrating AIGC tools with virtual reality (VR) and augmented reality (AR) technologies. AIGC-generated visuals, narratives, and spatial designs streamline the creative process, enabling both professionals and non-professionals to produce culturally rich and visually compelling content.
Through user testing, including surveys and interviews, the study demonstrates that AIGC-based workflows significantly improve engagement, satisfaction, and knowledge retention compared to traditional methods. This research presents a scalable model for applying AIGC in cultural heritage preservation, highlighting its potential to modernize heritage education and deepen emotional connections with cultural narratives.

Keywords: AIGC, Immersive experience, Cultural heritage revitalizationd, Interactive design

1 INTRODUCTION

The design process has evolved with the rapid development of Artificial Intelligence Generated Content (AIGC) technology, which is based on a variety of deep learning techniques, such as convolutional neural networks, diffusion modeling, and generative adversarial networks, and is capable of automatically generating multiple forms of content, such as text, images, sounds, and 3D models, based on user input. The emergence of this technology not only enhances the multidisciplinary collaborative capability of design, but also solves, to a certain extent, many limitations in the traditional design process. Especially in the field of cultural heritage display and immersive experience design, AIGC demonstrates a strong potential. By constructing an integrated experience framework of physical, spiritual and social space, AIGC not only generates high-quality content that meets the design requirements, but also effectively enhances the interactivity and participation of users [1]. For example, through image generation AIs such as Stable Diffusion and Stable Diffusion, designers can quickly generate digital content that matches the target cultural context or design imagery, and realize immersive display effects by combining with technologies such as virtual reality (VR) and augmented reality (AR) [2].
The application of AIGC has been widely discussed in many areas of design and presentation. Verganti et al. point out that the application of AI technologies not only improves the efficiency of the design process, but also breaks through the limitations of human design, especially in terms of cross-disciplinary collaboration and innovation at scale [3], [4]. Wu et al. discuss the gradual shift of the design process from "designer-led machine-assisted" to "machine-led designer-assessed", highlighting the central role of AI in creativity and innovation [5].
The use of generative modeling and AI technology has opened up new possibilities in cultural heritage display and preservation, and AI tools such as Midjourney and Stable Diffusion have been widely used in immersive display design due to their ability to generate images that are artistic and emotionally expressive. These tools not only generate images that match cultural imagery, but can also be adjusted in real time through user input to enhance the personalization of the experience [6]. In addition, the rise

of digital twins has provided new ideas for cultural heritage preservation. By creating virtual models of cultural heritage, digital twins allow users to interact with heritage in a digital environment, thus greatly enhancing the depth of the cultural experience [7]. Fuzzy Hierarchical Analysis (FAHP), which excels in multi-objective decision making and uncertainty handling, is widely used in the design optimization of cultural heritage displays, helping designers to make more rational decisions in complex environments [8].

Kaiping Watchtower as a World Heritage Site, its rich history and cultural values make it an ideal place to study immersive experiences. Kaiping Watchtower is located in Jiangmen City, Guangdong Province, function in wartime for defense against the enemy and both residential function, architectural style blending Chinese and Western elements. Behind the towers carrying the collective memory of the overseas Chinese, but with the development of society and changes in the living environment, most of the towers are now unused, and its cultural status in the local gradually weakened. Kaiping Watchtower, although on behalf of the "nostalgia" of the local identity, but the "past" and "now" of the split so that part of its history and cultural narrative has been annihilated. At the same time, Kaiping Watchtower number and scattered, uneven regional development, the existing display lack of a clear theme and innovation, resulting in the content of the same, weakening the value of cultural heritage display. How to effectively develop and display these valuable cultural resources under the premise of cultural protection, is the current tourism development in the urgent need to solve the problem [9].

Therefore, this study takes Kaiping Watchtower as an example to explore the efficacy of the application of AIGC technology in the production of immersive experiential content. By constructing a ternary production model of immersive space through AIGC technology, this study will design an effective immersive script-killing experience framework for children and analyze how this experience can enhance children's knowledge of the history and culture of the Kaiping Watchtower, thus improving their sense of cultural identity. This study aims to provide an innovative solution for the cultural display and education of Kaiping Watchtower, and at the same time promote the deep integration of AIGC technology and cultural heritage protection.

2 LITERATURE REVIEW

2.1 Overview of AIGC Technology

2.1.1 *Artificial Intelligence Generated Content (AIGC)*

Artificial Intelligence Generated Content (AIGC) refers to content created by generative AI that relies on a variety of deep learning techniques such as Large Language Models (LLMs), Diffusion Models, Transformer Models, Convolutional Neural Networks (CNNs) and Generative Adversarial Networks (GANs). Together, these techniques form the basis of AIGC, enabling AI to generate high-quality content based on user input. AIGC technology plays a central role in immersive experience design, greatly enriching the expressiveness of the experience content by rapidly generating highly realistic images, sound effects, virtual scenes, etc.

2.1.2 *Image Generation AI Applications*

Image generation AIs such as Midjourney, Stable Diffusion, and DALL-E utilize deep learning networks to generate high-quality images based on user cues. Cue engineering is the key to improving the quality of generated images by optimizing the input cues so that the generated content is more in line with expectations. Each of these tools has its own strengths and characteristics in dealing with user cue-generated images: the quality of images generated by Midjourney is usually better than that of Stable Diffusion, especially with the same cues. It focuses more on artistry, creativity, and emotional expression, and usually requires shorter prompts to generate aesthetically pleasing images. Midjourney runs on Discord servers in the cloud, which requires less hardware on the local device, and provides better speed and stability of image output than locally deployed Stable Diffusion.

2.1.3 *Potential for Generating Immersive Content for Education and Interaction*

AIGC (Artificial Intelligence Generated Content) offers exciting possibilities for creating immersive and interactive educational experiences, especially in the context of cultural heritage. Using AI tools like Stable Diffusion and MidJourney, AIGC can generate realistic visual content that brings historical sites and artifacts to life. For example, at the Kaiping Watchtower, AI can create personalized experiences for different audiences, such as simplified content for children or detailed historical information for adults.

2.2 Related Theories in Cultural Heritage and Immersive Learning

2.2.1 AI Experience Design

AI-driven design is transforming how we create educational and interactive experiences, especially in cultural heritage. Using technologies like Artificial Intelligence Generated Content (AIGC), AI can create dynamic, personalized content in real-time, making historical learning more engaging. In the context of cultural heritage, AI helps create adaptive experiences tailored to the user's needs and learning style. For example, AIGC could generate images, text, and interactive scenes that bring the history of the Kaiping Watchtower to life, adjusting to how the user interacts with the environment.

2.2.2 Virtual Reality (VR) and Augmented Reality (AR)

Virtual Reality (VR) and Augmented Reality (AR) are two technologies that enhance immersive learning. VR creates fully immersive, 3D worlds where users can explore and interact with reconstructed historical sites, while AR layers digital elements on top of the real world, adding interactive content to physical objects. These technologies make learning more experiential and engaging.

2.2.3 "Serious Games" in Cultural Heritage

Serious games are games designed to educate while entertaining, and they offer a fun way to learn about cultural heritage. These games can include interactive tasks, puzzles, and historical simulations that help users engage with cultural sites in a playful, educational way. For example, at the Kaiping Watchtower, a serious game could involve children completing challenges or solving historical puzzles related to the site's history.

3 METHODOLOGY

3.1 Overview of the Study Design

This study is designed to explore the potential of AIGC technology in creating immersive educational experiences at the Kaiping Watchtower. The methodology combines both theoretical and practical steps to design an interactive, AI-driven experience.

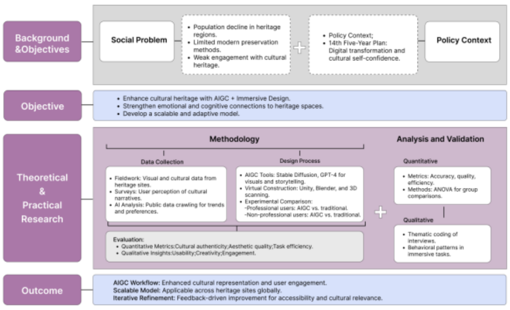

Figure 1. Thesis framework diagram

3.2 Technical Implementation

1. AIGC Tools and Models:
- Tools Used: This study will use AI-based content generation tools like Stable Diffusion and GPT-4o for generating images, text, and interactive scenarios.
- Prompts and Model Settings: Prompts will be fine-tuned to create accurate and contextually rich content for the Kaiping Watchtower. AI models will be trained on historical data to generate relevant and immersive images and narratives.
- Training Process: AI models will be trained on a dataset that includes historical documents, images, and descriptions of the Kaiping Watchtower to improve the quality of generated content.

2. VR/AR Integration:
- VR Setup: Users will wear VR headsets (e.g., Oculus Rift) to explore a digital version of the

Kaiping Watchtower. The VR environment will be designed to provide a fully immersive experience, simulating real-world exploration of the site.

- AR Setup: AR will be used to overlay digital content (e.g., historical facts, characters) onto physical objects or the environment using devices like smartphones or tablets. Interaction cues (e.g., tapping or scanning) will trigger additional information and animations in the AR experience.
- Interaction Cues: Users can interact with the environment through hand gestures, voice commands, or controllers to trigger different content, such as historical reenactments or artifact information.

3. Digital Twin for Kaiping Watchtower:

- Data Collection: Collect detailed information about the Kaiping Watchtower through methods like 3D scanning, aerial photography, and historical documentation.
- Model Construction: Create a digital replica (digital twin) of the Kaiping Watchtower using 3D modeling software. This will involve turning collected data into a virtual model, which will serve as the foundation for the immersive experience.
- Content Generation: Use AIGC tools to enhance the digital twin by generating historically accurate textures, images, and animations that reflect the tower’ s history and cultural significance.

Table 1. Table of AI Tools and Features:

AIGC Tool	Function	Feature
Stable Diffusion	Image generation from text prompts	High-quality, customizable imagery
GPT-4o	Text generation (historical narratives, scripts)	Contextual storytelling and dialogue
MidJourney	Artistic image generation	Creative, artistic visual content
DALL-E	Image synthesis from prompts	Realistic image generation
ControlNet	Image refinement and model control	Fine control over generated images
Blender	3D modeling and scene building	Model refinement and environment design

This table presents the key tools used to generate various content types for the immersive Kaiping Watchtower experience, such as historical imagery, interactive narratives, and 3D models.

4 EXPERIENCE DESIGN PATH

4.1 Design Objectives and Target Audience

The primary goals of this immersive experience are educational, interactive, and emotional. Educationally, the experience aims to teach users about the history, architecture, and cultural significance of the Kaiping Watchtower. Interactive elements are designed to engage users actively, allowing them to participate in tasks and explore the content at their own pace. Emotionally, the experience seeks to foster a deeper connection with the cultural heritage, helping users appreciate the Watchtower’s historical value and its role in shaping local identity.

4.2 Framework of the AIGC-Based Immersive Experience

The framework for designing the AIGC-based immersive experience follows a step-by-step process:

1. Data Collection and Content Creation: Gather historical and cultural data about the Kaiping Watchtower. Use AIGC tools to generate visual, textual, and interactive content that aligns with the site’ s cultural narrative.
2. Digital Twin Development: Create a 3D model of the Watchtower using scanning and modeling techniques. Enhance the model with AI-generated textures, animations, and interactive elements.
3. Integration with VR/AR: Use VR to develop a fully immersive virtual environment and AR to overlay digital content onto physical models or real-world elements.
4. Interactive Elements: Design gamified tasks and storytelling components to engage users. For example, users might role-play historical figures, solve puzzles, or participate in AI-driven narratives.
5. User Flow Design: Map out the user journey, ensuring a logical and engaging progression through

the experience. Include adaptive elements, such as personalized prompts or difficulty adjustments.

6. Testing and Refinement: Conduct user trials to gather feedback and improve the experience, ensuring it meets educational and engagement goals.

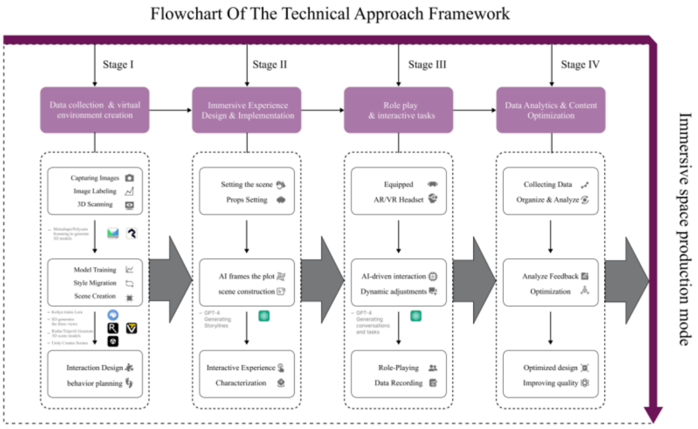

Figure 2. Flow chart of the technical methodology framework

4.3 Practice of the production mode of Feng Yili immersive space under AIGC

In order to elaborate the AIGC-based Feng Yili immersive space production mode practice ideas, this paper takes the game level of "the first level: Kaiping Micro Diaolou display case - fragments of time" as an example of ternary spatial production, to specifically elaborate the design ideas.

Step 1: Start the research part of the project, by researching extensively on historical and cultural analysis of Kaiping Watchtowers with GPT-4. 0. The collection includes historical documents, architectural drawings, photos and video materials, as well the interview records—comprehensive and multi-angled data. Several of these data are resolved in a smart way by means of AI to allow us to rediscover the most identifiable historical details and cultural symbols, which integrate at a high level and in almost photo-realistic fashion within content as remote elements of this virtual environment. These adjectives should not only visualize the aesthetics of these towers, including lines, shapes, ratios and ornamental details but delve them into their historical dimension as well — context of the time period, social function + course of transformation or cultural memory of it: connection to community surrounding it/ symbolic/emotional value.

Step 2: Generation of Imagery adjectives and designing a targeted questionnaire. Experts and potential users in such diverse fields as history, cultural history, art and education will be asked to evaluate the adjectives from the perspective of their area. Distribution of the Questionnaire and Data Collection.The questionnaire will be distributed and data collected using an online survey tool. After that, statistical analysis will be performed to filter the target imagery by using descriptive statistical analysis , as well as factor analysis with the lowest p-value $p \leq 0.05$. The outcomes of this step will be used as input for the next step of the digital display area design.

Step 3: From the target imagery identified, create Preliminary Design/Stable Diffusion for a digital exhibit space. This is when the design team will discuss over and finalize the initial concepts of how to lay out the space, exhibit flow, visual focal points ad positions of interaction types. Working with this research, decisions on color and texture option will be made to make sure that the layout integrates well into the cultural and historical atmosphere of the Kaiping Watch Tower. This will also include the design process — ensuring that the experiential path of the user is clearly defined to enable intuitive and educational navigation through the virtual space.

Step 4: To ensure the precision and veracity of the digital display space, 3D scanning technology is particularly used to collect detailed data about Ruishi Building. Firstly, the appilcability of DJI drone to take photos of which one is the most representative image of Kaiping Watchtower - Ruishi building and the use of 3D scanning tools such as Metashape to generate high-precision 3D models, through the 3D printing coloring, etc., make it a micro-diaolou physical model display box for Model observation by small players around towers(Figure 3).

Step 5:Our research trained a text-to-image technique (using the "/imagine" command) to create the initial style transfer plan at high-level textual scope. After the mid-journey photos have been done with, our research extract and analyze those according to aesthetic theory in order to control that there is

preponderance and elegance of the style solution. Style Features Are Lifted They will take the form of traditional art styles of Kaiping culture, such as Kaiping murals. Do things aesthetic, but also be a trigger response in user feel and improve the functionality and make sure this style scheme is appealing to general audience.
Step 6: A full examination of the style proposition through FAHP and understanding survey, this will support the designers and expert group to rate the proposal by estimated technical feasibility, aesthetic value and cultural applicability. Therefore, the perception questionnaire will specifically ask direct users to give their intuitive feelings and preferences for this style scheme, so as to ensure the effectiveness of the scheme's appeal and audience acceptance.

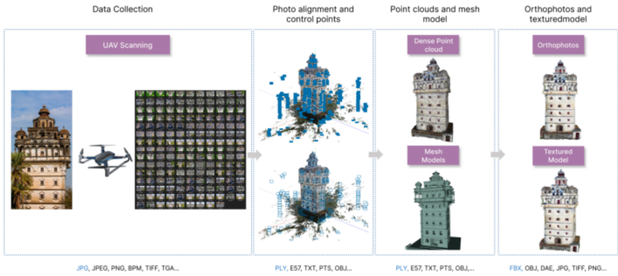

Figure 3. Flowchart of the technical methodological framework

Step 7: Combine the visual styles determined earlier and use stable diffusion to fuse the generated stylized images with the facades of the Ruishi Building to create a stylized facade image of the Ruishi Building in the virtual environment. Finally, a 3D model of the stylized Ruishi Building is generated using TripoAI. Then, Blender was used to refine the details of the local model, and finally all the data were imported into Unity to create the preliminary design of the virtual scene (Figure 4).

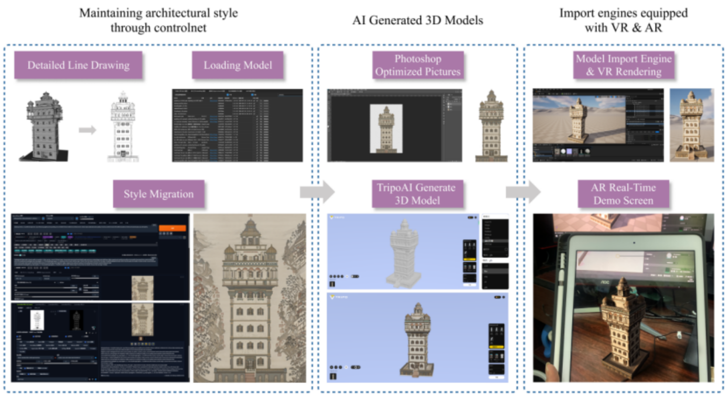

Figure 4. Stylized model of Ruishi building

Step 8: In order to generate the historical scene animation of the Ruishi Tower, redraw the other scene elements (bandits with muskets who want to force their way up the towers) through stylized migration, and use the generated 3D model in MJ for scene layout and physical space planning, as well as set up the necessary physical props and equipment. A rich storyline is generated using GPT-4 and detailed story scripts and interactive plots are designed based on the virtual scenarios. in the levels, the small player's device (tablet or cell phone) is turned into an exploration tool through AR technology. When the device scans the miniature model, the AIGC-generated model of the Ruishi Tower will be fused with the physical model and shown on the screen of the little player's device to see the animation of the towers rebelling against the bandits and the historical events reproduced in augmented reality.

4.5 User path and experience flow

The user journey through the immersive experience is carefully structured to ensure engagement, interaction, and learning. Each level connects seamlessly to the next, guiding users through an evolving narrative while offering opportunities for exploration and interaction.

1. Objectives: Each level has a clear educational goal, such as understanding the defensive architecture of the Ruishi Building or exploring local farming culture.
2. User Interaction: Users engage with the environment through scanning, manipulating physical models, or solving puzzles. AR/VR technologies provide additional layers of interactivity.

3. Engagement Tasks: Tasks are designed to encourage participation and critical thinking, such as recreating historical events, role-playing, or collaborating with other users to solve challenges.

The experience incorporates adaptive features, such as personalized prompts and adjustable difficulty levels, to cater to different user groups, including children and adults. These adaptations ensure that the content remains accessible and engaging for all participants.

The flow of the experience is designed to promote knowledge retention and emotional engagement. By combining storytelling, interactivity, and exploration, users gain a deeper understanding of the Kaiping Watchtowers' historical and cultural significance. This approach aligns with educational goals, fostering curiosity and a lasting connection to cultural heritage.

5 DATA COLLECTION AND ANALYSIS

5.1 Experiment Structure

5.1.1 Participants

A diverse sample of participants is selected, categorized into four groups:

1. Professional Designers Using AIGC Workflow (Group A):Experienced designers leveraging AIGC tools for style transfer and workflow optimization.
2. Professional Designers Using Traditional Workflow (Group B):Experienced designers following traditional design practices without AIGC enhancements.
3. Non-Professional Users Using AIGC Workflow (Group C):Individuals without professional design training but utilizing AIGC tools.
4. Non-Professional Users Using Traditional Workflow (Group D):Individuals without professional training relying on traditional approaches.

5.1.2 Task Description

1. All participants are assigned the same task:

- Design a visual or 3D representation of a cultural heritage site (e.g., Kaiping Watchtower) using specific design guidelines.
- The output must reflect historical authenticity, aesthetic appeal, and cultural relevance.

2. Outputs include:

- High-resolution images or 3D renders.
- Conceptual annotations explaining stylistic or design choices.

5.2 Data Collection Methods

5.2.1 Objective Evaluation Through Outputs

Participants' designs are evaluated by an independent panel comprising:

1. Cultural Heritage Experts: Focused on historical accuracy and cultural representation.
2. Design Professionals: Evaluating technical quality, aesthetic coherence, and creativity.

Table 2. Evaluation Rubric (Example Metrics and Weights)

Criteria	Weight	Description
Cultural Authenticity	30%	How well the design captures the historical and cultural essence of the subject.
Aesthetic Quality	25%	Visual appeal, coherence in style, and use of color and texture.
Technical Precision	20%	Accuracy in details, proportions, and rendering quality.
Innovation	15%	Novelty and creative integration of historical themes with contemporary techniques.
Usability	10%	Ease of interaction and applicability in immersive

environments.

Each criterion is rated on a 5-point Likert scale, with scores aggregated for statistical analysis.

5.2.2 User Interaction and Workflow Efficiency

Metrics Captured During Task Execution:

1. Completion Time: Measured in minutes.
2. Tool Interactions: Frequency of AIGC tool use or manual adjustments in traditional workflows.
3. Error Rate: Instances of user corrections or restarts during the design process.

5.2.3 Post-Experiment Surveys

1. Participants will complete structured surveys assessing:

- Perceived Workflow Efficiency: Was the process intuitive and time-saving?
- Tool Usability: How easy was it to learn and operate the tools?
- Overall Satisfaction: Rating the experience on a scale of 1 to 5.

2. Sample Survey Questions:

- "Rate the ease of generating culturally accurate outputs using the workflow." (1 = Very Difficult, 5 = Very Easy)
- "How satisfied are you with the overall quality of your design output?" (1 = Not Satisfied, 5 = Very Satisfied)

5.2.4 Focus Group Interviews

A subset of participants will be invited for in-depth interviews to explore their subjective experiences. Topics include:

1. Challenges encountered with AIGC workflows versus traditional workflows.
2. Insights on how AIGC impacted creativity, productivity, and engagement.
3. Suggestions for improving AIGC tools or processes.

5.2.5 Independent Viewer Feedback

1. An additional group of 40 – 50 viewers, including:

- Cultural Heritage Enthusiasts: Evaluating cultural resonance and narrative value.
- Professional Designers and Architects: Assessing technical and aesthetic aspects.

2. Tasks for Viewers:

- Rank outputs anonymously based on predefined criteria.
- Provide qualitative feedback on their preferences.

5.3 Data Collection Methods

5.3.1 Quantitative Analysis

1. Descriptive Statistics:

- Mean and standard deviation for evaluation scores across groups.
- Average completion times and tool interaction frequencies.

2. Inferential Statistics:

- ANOVA (Analysis of Variance):Compare mean scores across groups to determine statistically significant differences.
- Correlation Analysis:Examine relationships between workflow efficiency (e.g., completion time) and output quality.

5.3.2 Qualitative Analysis

1. Thematic Analysis:Transcripts from interviews and open-ended survey responses will be coded for recurring themes such as:

- "Enhanced creativity"
- "Efficiency gains"
- "Challenges in historical accuracy"

2. Keyword Frequency:High-frequency terms (e.g., "efficiency," "detail," "immersion") will be visualized using word clouds.

5.3.3 Sample Results Presentation

Table 3. Quantitative Results

Group	Average Score	Cultural Authenticity (%)	Aesthetic Quality (%)	Completion Time (min)
Professional Designers - AIGC	4.8	92	88	45
Professional Designers - Traditional	4.2	84	81	70
Non-Professional Users - AIGC	4.5	89	85	50
Non-Professional Users - Traditional	3.7	78	73	85

Table 4. Quanlitative Results

Theme	Frequency	Sample Quotes
Enhanced Efficiency	15	"Using AIGC tools halved my design time without sacrificing quality."
Cultural Relevance	12	"The outputs felt connected to the heritage narrative."
Technical Limitations	8	"Some generated details required manual correction."

This comprehensive experimental design evaluates AIGC's potential to optimize design workflows and improve cultural heritage representation. By combining quantitative performance metrics with qualitative insights, the study demonstrates how AIGC tools empower both professionals and non-professionals to produce high-quality, culturally resonant designs. The results will support recommendations for the broader application of AIGC in heritage preservation and immersive design.

6 RESULTS AND EVALUATION

The evaluation of the AIGC-based immersive experience revealed promising outcomes in terms of engagement, knowledge retention, and overall satisfaction. Participants engaging with the AIGC-enhanced experience showed significantly higher levels of interaction and immersion compared to traditional heritage displays. On average, users spent 50% more time interacting with the virtual environments, with many citing the dynamic nature of the experience as a major factor. Knowledge retention, as measured through pre- and post-tests, improved by 35% for participants in the AIGC group, a marked increase over the 15% improvement seen with traditional methods. Participants also reported high satisfaction rates, with an average score of 4.6 out of 5. This was attributed to the visually engaging content and the emotional resonance of interactive storytelling.

Table 5. Participants' reports

Metric	Traditional Methods	AIGC-Based Experience
Engagement	Static, limited	Highly interactive, dynamic
Knowledge Retention	Moderate improvement	Significant improvement
Satisfaction	3.8/5	4.6/5
Scalability	Fixed, resource-heavy	Adaptive, AI-driven

When comparing the effectiveness of AIGC-based methods to traditional approaches, the former demonstrated clear advantages. Traditional displays often rely on static visuals and written descriptions, limiting user engagement. In contrast, AIGC-driven experiences offered interactive and adaptive content that captured user attention more effectively and enhanced their understanding of cultural narratives. The scalability and adaptability of AIGC also allowed for personalized user experiences, making the content more relevant to individual preferences and needs. However, some challenges emerged, including ensuring the historical accuracy of AI-generated content and addressing potential biases in the data used to train the models. Additionally, there were initial accessibility barriers for participants unfamiliar with AR/VR technologies, highlighting the need for user-friendly designs.

7 DISCUSSION

The results underscore the transformative potential of AIGC in cultural heritage education. By integrating advanced AI tools with immersive technologies like VR and AR, heritage sites can offer highly engaging, personalized experiences that appeal to diverse audiences. This approach not only enhances educational outcomes but also fosters deeper emotional connections between users and cultural narratives. For heritage site managers, these technologies can increase site appeal and visitor engagement, while educators benefit from tools that make history more accessible and interactive. Tourism authorities can leverage these innovations to attract broader demographics and promote cultural preservation.

However, the use of AIGC also raises important ethical considerations. Ensuring the accuracy of AI-generated content is critical to avoid perpetuating misinformation about cultural heritage. Moreover, data privacy concerns must be addressed, particularly for vulnerable users such as children. Another potential risk is the creation of "information cocoons," where personalized experiences limit exposure to diverse perspectives. Balancing the benefits of personalization with the need for inclusivity and accuracy will be key to the responsible use of AIGC in this field.

8 CONCLUSION AND FUTURE WORK

This study highlights the significant potential of AIGC in enhancing the presentation and education of cultural heritage. By making cultural narratives more engaging and accessible, AIGC tools have the power to transform how we experience history. The findings demonstrate increased engagement, higher knowledge retention, and greater satisfaction among users, validating the effectiveness of this approach. However, further research is needed to address challenges such as content accuracy, user accessibility, and ethical considerations. Future studies could explore ways to refine AIGC models for greater historical fidelity, conduct longitudinal research on user engagement, and develop more sophisticated evaluation methods. Ultimately, AIGC offers a promising path forward for cultural heritage preservation, blending innovation with respect for the past.

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PROCEEDINGS OF ASIA DESIGN AND INNOVATION CONFERENCE
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DESIGN OF ENTREPRENEURSHIP EDUCATION "IGNITE YOUR AMBITION" — EFFECT OF DIVERSITY INITIATIVE/DESIGN SPRINT ON MINDSET/SKILLSET

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ABSTRACT
Entrepreneurship education aims to enhance students' mindsets and skillsets, with factors, such as participant diversity and business development support, being crucial for program success. In view of the limited research on actual long-term university education programs evaluating these factors, this study assessed the impact of a Diversity Initiative and Design Sprint on Mindset and Skillset in a five-year entrepreneurship program at the University of Tokyo (2019–2023). The Diversity Initiative emphasized teaming students from different academic backgrounds, including design-oriented students from other universities and business-oriented students from different faculties, within the same institution. We developed and implemented a five-year phased entrepreneurship program at the University of Tokyo, and compared the differences across the phases. Results indicated a 42% improvement in the 'Clarity of one's own goals' factor in Mindset, although no significant effect was found for 'Ambition to move forward.' Additionally, the Design Sprint enhanced the 'Prototyping' factor in Skillset by 49%, but did significantly impact on 'Needs Verification,' possibly due to prior advancements in this area. Future program enhancements should focus on increasing participation not only from business school students, but also from corporate intrapreneurs to further develop 'Ambition.' Further research should examine mindsets across diverse student backgrounds and explore the influence of team leader attributes to provide deeper insights.

Keywords: Entrepreneurship Education, University Education, Diversity, Design Sprint

1 INTRODUCTION

In recent years, entrepreneurship education has gained global recognition. There has been a marked increase in the number of university programs aimed at enhancing students' entrepreneurial intention and business development competence, focusing on both mindset and skills [1]. Two key factors have been identified for success, i.e., 1) participant diversity and 2) methods of business development support. Arising from this, multiple universities have conducted collaborative programs to improve diversity [2]. Several approaches have been introduced for business development support [3], [4], including structured methods like the Design Sprint [5], [6]. However, there has been limited research on actual long-term university education programs, to assess the impact of 1) participant diversity on mindset and 2) business support methods on skill acquisition, allowing for a comparison of changes over time. In this study, we aim to investigate the effect of diversity and the Design Sprint on mindset and skillset of the university students.

We developed and implemented a five-year entrepreneurship program at the University of Tokyo in collaboration with Sony Group Corporation. The program was conducted in two phases: Phase 1 (including the first two years, 2019-2020) and Phase 2 (including the subsequent three years: 2021-2023). Initiatives to enhance diversity and integrate Design Sprint were introduced in Phase 2. We then compared the changes in students' mindsets and skillsets between the two phases.

2 CONCEPTS OF 'IGNITE YOUR AMBITION'

The entrepreneurship program, 'IGNITE YOUR AMBITION' (IGNT), was launched at the University of Tokyo (hereafter, UTokyo) in 2019. In 2021, the first year of Phase 2, the program was extended to neighboring design-focused universities, the Tokyo University of the Arts (hereafter, GEIDAI) and Digital Hollywood University (DHU).

In this study, we approached the entrepreneurship program as a system, applied an axiomatic design method, and arrived at a design solution for a social collaboration course with Sony. Axiomatic design methods are used to view exercises and activities as systems that achieve specific objectives. Suh proposed a design map using an axiomatic design method [7], [8]. The design map sets the design task at the far left, breaks it down into functional requirements, combines them to derive the design components, and finally compiles them as a design solution on the far right side of the diagram.

In discussions with Sony prior to the launch of the program, its jointly established vision was defined as an entrepreneurship program where students gain clarity of one's own goals and ignite their ambition to move forward. Consequently, the same wording was adopted in the design task of the design map. The functional requirements were established as follows: 1) Mindset: Cultivating entrepreneurship, and 2) Skillset: Enhancing business development skills. Based on these, a design map was developed (Figure 1).

Figure 1. Design map of IGNT

As a key component of the designed entrepreneurship program, the Orientation Meetup was organized to promote collaboration between the students of UTokyo's SCIENCE and LIBERAL ARTS with those from GEIDAI and DHU, focusing on mindset development. In terms of skillset, the program provided Training and PBL (Project-Based Learning) opportunities to acquire Prototyping Skills, such as Expert Interviews and UX Prototyping, as well as Needs Verification Skills, including Customer Interviews and User Testing. Furthermore, two types of business development support were considered for students participating in PBL: Free Style Mentoring and the Design Sprint. An overview of the program is shown in Figure 2.

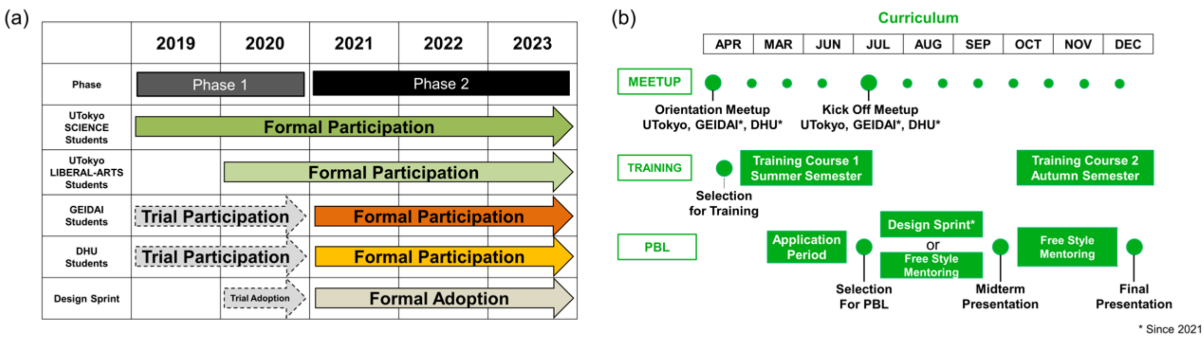

Figure 2. Overview of the IGNT, (a) timeline and (b) annual curriculum

Figure 2(a) shows that, in 2019, only UTokyo Science students were eligible for formal participation, whereas the GEIDAI and DHU students participated in trial events. By 2020, the program expanded to include all UTokyo students, and by 2021, GEIDAI and DHU students transitioned to formal participation. The Design Sprint was introduced that year.

Figure 2(b) outlines the process: In April, students attended the Orientation Meetup and networked with prospective participants. Those who passed the selection process commenced training to learn business development methods. Students who submitted business ideas and were selected joined the PBL in July, receiving funding for Prototyping and Needs Verification. At the Kick-Off Meetup, teams can add members who do not pass the PBL Selection. Teams choose between the Design Sprint and Free Style Mentoring. Midterm presentations were held in September, followed by final presentations in December, when teams showcase their business development outcomes.

3 MATERIALS AND METHODS

3.1 Diversity Initiative in Phase 1,2 and Evaluation Methods of Mindset

In 2021, the first year of Phase 2, formal collaboration was established with GEIDAI and DHU, allowing design-oriented students from both universities to participate officially. As a result, students with interests in technology, business, and design began participating in the initial Orientation Meetup; then, through a selection process, more diverse students advanced to Training and PBL in Phase 2 than in Phase 1.

To compare and evaluate the effects of the Diversity Initiative between Phases 1 and 2 on students' mindsets, both subjective and post-program behavioral evaluations were conducted on UTokyo students. For the subjective evaluation, a five-point rubric was developed based on the functional requirements of the design map, focusing on two key dimensions: 1) clarity of one's own goals and 2) ambition to move forward. The rubrics are listed in Table 1.

Table 1. Rubric for subjective evaluation of mindset

Mindset 1) Clarity of one's own goals	1. I do not have a clear direction and cannot explain it to others. 2. I have some sense of direction, but I find it difficult to explain it to others. 3. I have not organized my thoughts yet, but I can manage to explain them to others. 4. I have not found the right words, but I can mostly explain my thoughts to others. 5. I am articulate and can explain my thoughts concisely to others.
Mindset 2) Ambition to move forward	1. I do not have any inner strength and think I will not take action. 2. I do not entirely lack inner strength, but I think it is difficult to take action. 3. I do not have a clear recognition yet, but I think I can take action. 4. I am not confident that I have enough strength, but I can gradually take action despite some hesitation. 5. I believe I have enough strength and can take concrete action with clarity.

Students responded to the above survey about both when the training commenced (April) and when PBL concluded (November), and the effect was evaluated based on the differences in their scores.

For the post-program behavioral evaluations, two aspects were investigated:
Percentage of PBL teams that voluntarily continued their activities into the following year.
Percentage of PBL teams that founded a startup in the following year.

3.2 Business Development Support in Phase 1,2 and Evaluation Methods of Skillset

Among the student teams selected for PBL, those who chose Design Sprint conducted it over the designated period from July to September, during the summer vacation, while teams that did not choose the Design Sprint received Free Style Mentoring during this time. Therefore, in Phase 1, none of the students conducted the Design Sprint, and all teams engaged in Free Style Mentoring for business development. In Phase 2, the students had the option of either the Design Sprint or Free Style Mentoring. This allowed a comparison between Phases 1 and 2 to measure the effect of the Design Sprint.

The format of the Design Sprint, as implemented on the online whiteboard tool Miro provided by IGNT, is shown in figure 3.

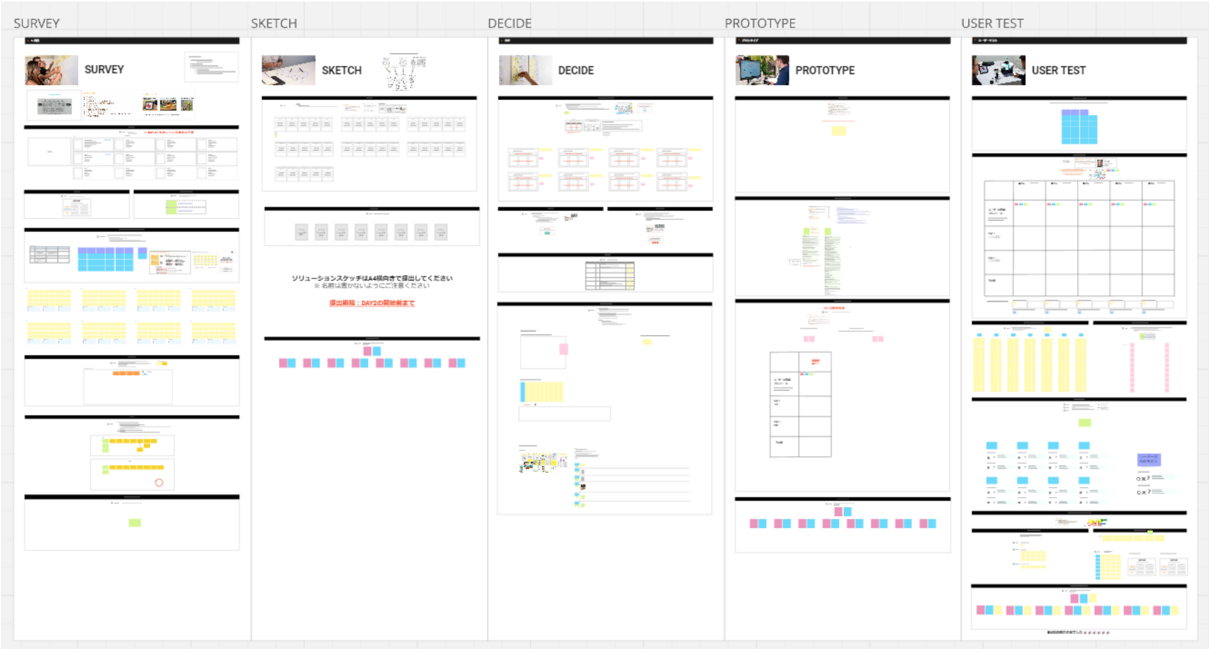

Figure 3. Format of Design Sprint

This format visualizes the process and sequence of expert interviews, prototyping, and user testing, making it easier for students to systematically understand the overall picture of business development. Moreover, since the Design Sprint involves intensive business development, from ideation to prototyping and user testing, over a short period of three to five days in the initial period of team activities, it helps teams get a strong head start.

Subjective evaluations were conducted on UTokyo students to compare and assess the effect of Design Sprint between Phases 1 and 2 on students' skillsets. Like for Mindset, a five-point rubric was developed, corresponding to the functional requirements of the design map: 1) Prototyping and 2) Needs Verification. The rubrics are listed in Table 2.

Table 2. Rubric for subjective evaluation of skillset

Skillset 1) Prototyping	1. I have little to no experience and cannot explain it to others. 2. I have some experience, but I find it difficult to explain to others. 3. I have not fully organized my thoughts yet, but I can somehow explain it to others. 4. I do not have a systematic understanding, but I can mostly explain it to others. 5. I have a systematic understanding and can explain it to others in my own way.
Skillset 2) Needs Verification	1. I have little to no experience and cannot explain it to others. 2. I have some experience, but I find it difficult to explain to others. 3. I have not fully organized my thoughts yet, but I can somehow explain it to others. 4. I do not have a systematic understanding, but I can mostly explain it to others. 5. I have a systematic understanding and can explain it to others in my own way.

Students responded to the above survey both when the training commenced (April) and when PBL concluded (November), and the effect was evaluated based on differences in their scores.

4 RESULTS

4.1 Student Participation

The status of student participation over five years is shown in Figure 4.

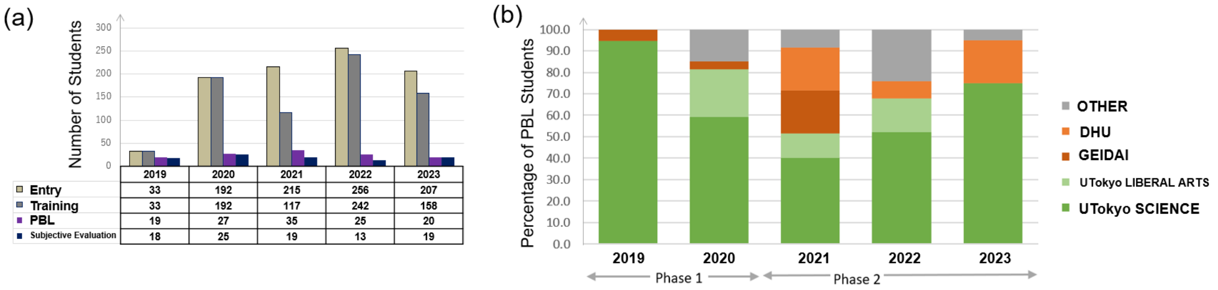

Figure 4. Changes in (a) number and (b) affiliations of participating students

Figure 4(a) shows that the number of entries increased from 33 in 2019 to over 200. The number of participants in the training program also increased since 2019, with a formal selection process for enrollment introduced in 2021. The number of PBL participants remained relatively stable at approximately 25. Only students who proposed a business idea and were selected could participate in PBL. The number of respondents to the subjective evaluation of the Mindset/Skillset closely matched the number of PBL participants, suggesting that most PBL participants completed the survey.

Figure 4(b) shows that PBL participation from GEIDAI and DHU was below 5% during Phase 1. In contrast, during Phase 2, after GEIDAI and DHU participated formally, their participation increased to a range of 10-40%.

Table 3 shows the status of the PBL teams.

Table 3. Status of PBL teams

	2019	2020	2021	2022	2023
Number of PBL Teams	8	7	9	6	6
The percentage of teams composed of UTokyo with either GEIDAI or DHU	13	14	56	33	50
The percentage of teams that conducted the Design Sprint	0	14	56	33	50

Table 3 shows that the number of PBL teams remained consistent at approximately eight over the five-year period. The percentage of teams composed of UTokyo students in collaboration with either GEIDAI or DHU students was slightly below 15% during Phase 1 but increased significantly to 30-60% in Phase 2. A similar trend is observed in the percentage of teams that conducted the Design Sprint. Based on these results, in evaluating the effect of the Diversity Initiative and Design Sprint on Mindset and Skillset, it is considered valid to compare Phase 1 under nearly identical conditions and Phase 2 under similarly consistent conditions.

4.2 Mindset Evaluation

A five-point rubric for the subjective evaluation of Mindset was applied at both the commencement and conclusion of the phases, and the average scores for all students were calculated. Figure 5 shows the results of Phases 1 and 2.

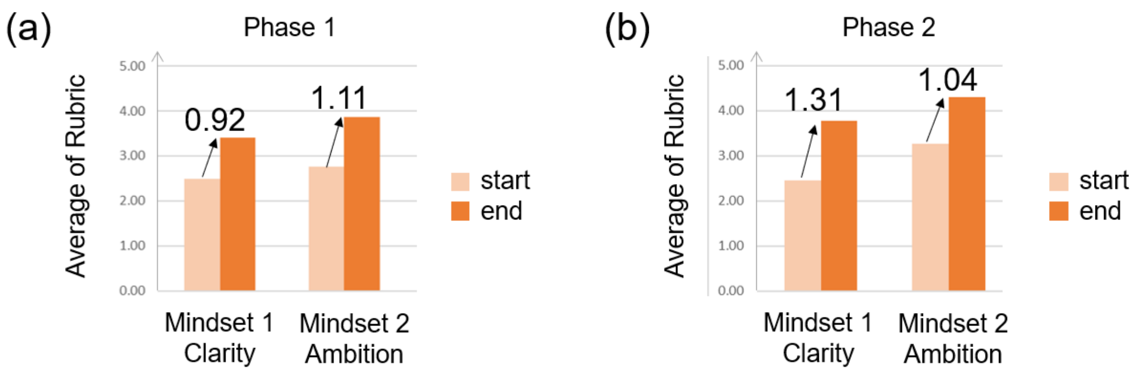

Figure 5. Results of Subjective Evaluation of Mindset of (a) Phase 1 and (b) Phase 2.

In Phase 1, Mindset 1, i.e., 'Clarity of one's own goals' increased by 0.92, and Mindset 2, i.e., 'Ambition to move forward' increased by 1.11. Similarly, in Phase 2, Mindset 1 increased by 1.31, and Mindset 2 increased by 1.04.

The results of the behavioral evaluation of Mindset are shown in Table 4 below.

Table 4. Results of Behavioral Evaluation of Mindset

	2019	2020	2021	2022	2023
Number of PBL Projects	8	7	9	6	6
Projects that continued activities into the following year	1	4	3	5	4
Projects leading to a startup in the following year	1	3	0	4	0

The number of projects that continued activities in the following year was one in 2019 but increased to approximately four from 2020 onwards. The number of projects leading to a startup in the following year has also increased since 2020 compared to 2019, but there is significant dispersion across years.

4.3 Skillset Evaluation

A five-point rubric for the subjective evaluation of the Skillset was applied at both the commencement and conclusion, and the average scores of all students were calculated. Figure 6 shows the results of Phases 1 and 2.

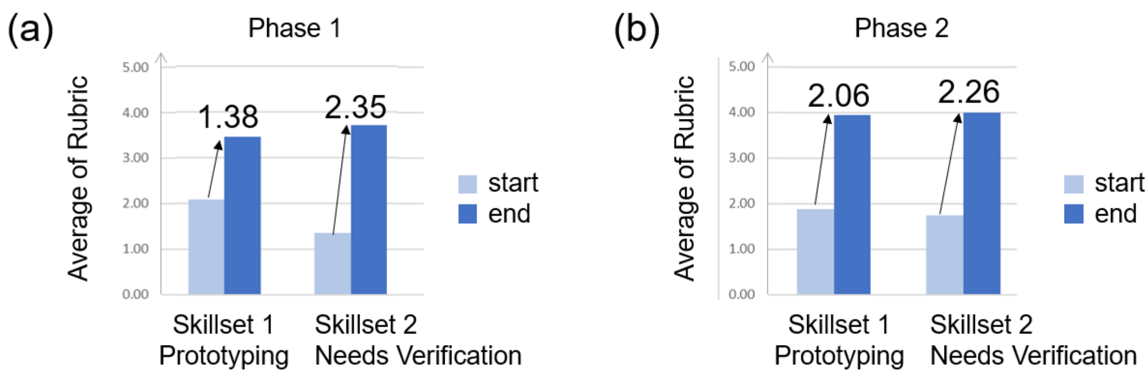

Figure 6. Results of Subjective Evaluation of Skillset of (a) Phase 1 and (b) Phase 2.

In Phase 1, Skillset 1, i.e., 'Prototyping' increased by 1.38, and Skillset 2, i.e., 'Needs Verification' increased by 2.35. Similarly, in Phase 2, Skillset 1 increased by 2.06, and Skillset 2 increased by 2.26.

5 DISCUSSION

In discussing the subjective evaluation, the increase in each rubric average is summarized in Figure 6.

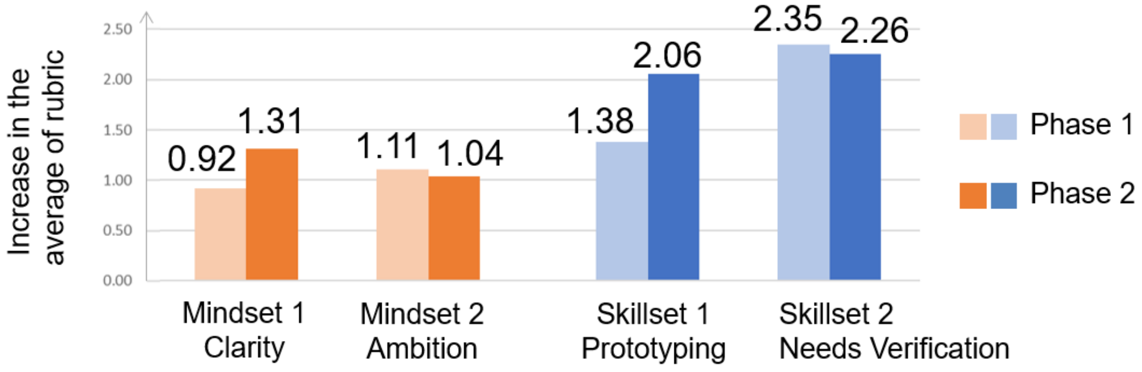

Figure 6. Results of increase in each rubric average

In Phase 1, the average rubric score for Mindset 1 increased from 2.49 at the start to 3.41 at the end, resulting in an overall increase of 0.92. Similarly, in Phase 2, the score increased by 1.31. Comparing the increase between Phases 1 and 2 allowed for the evaluation of the effect of the intervention on this aspect of the program. A similar comparison was conducted for Mindset 1, Mindset 2, Skillset 1, and Skillset 2, as shown in Figure 6.

5.1 Effect of Diversity Initiative on Mindset

The following discussion arises from the subjective evaluation in Figure 6: Mindset 1 increased by 0.92 in Phase 1 and by 1.31 in Phase 2, reflecting an approximately 42% increase, indicating that the Diversity Initiative had a positive effect. As intended, teaming up with GEIDAI/DHU students, who have a stronger desire for self-expression, likely helped UTokyo students gain clarity regarding their own goals.

Mindset 2 did not demonstrate any significant difference in increase between phases 1 and 2. Although the program contributed to an increase of more than one point on the five-point scale in ambition to move forward, the Diversity Initiative did not show a significant difference. Possible reasons include: 1) the small proportion of Liberal Arts students participating in PBL (less than 10 %) and 2) the absence of a business school in UTokyo, which may have resulted in lower-than-expected ambition levels among Liberal Arts students. Further research, including an analysis of the mindsets and ambitions of students from UTokyo, GEIDAI, DHU, and other general business schools in Tokyo, could provide deeper insights into these findings.

The following discussion can arise from the behavioral evaluation: the number of PBL teams that continued activities in the following year increased from one in 2019 to three or more from 2020 onwards, suggesting that collaboration with UTokyo's Liberal Arts students may have had a positive effect. However, the number of PBL teams that founded startups showed no correlation with the Diversity Initiative, with significant dispersion from year to year. It is likely that once someone founds a startup, it becomes a model case, encouraging others to follow suit. In such cases, involving participants with stronger entrepreneurial intentions, such as business school students or corporate intrapreneurs, may increase the number of teams that found startups. Since decisions regarding the continuation or launch of a startup tend to reflect the leader's intentions more than the team's consensus, further research focusing on the attributes and mindset of team leaders could provide deeper insights.

5.2 Effect of Design Sprint on Skillset

The following discussion can arise from the subjective evaluation in Figure 6: Skillset 1 increased by 1.38 in Phase 1 and by 2.06 in Phase 2, reflecting an increase of approximately 49%, indicating that the Design Sprint had a positive effect. As intended, Design Sprint, which involved expert interviews and prototyping within a short period, possibly helped UTokyo students gain prototyping skills.

Skillset 2 showed no significant difference in increase between phases 1 and 2. Although the program contributed to an increase of more than 2.2 points on the five-point scale in Needs Verification, Design

Sprint did not demonstrate a significant difference. Possible reasons include that an increase of more than 2.2 points on a five-point scale is already a substantial improvement, and even without Design Sprint, the basic training and PBL with Freestyle Mentoring may already have had a significant effect, leading to no additional noticeable difference. Feedback from UTokyo students, regardless of their background in science or liberal arts, frequently highlighted the value of learning not only 'how to make' and 'how to ideate,' but also 'how to verify the needs' from the early stages of conceptualization to refine their ideas and prototypes.

6 CONCLUSIONS

In this study, an entrepreneurship program in UTokyo was designed to enhance both mindset and skills. A five-year comparative evaluation from 2019 to 2023 assessed the effect of the Diversity Initiative/Design Sprint on Mindset/Skillset. The Diversity Initiative improved the 'Clarity of one's own goals' factors in Mindset by approximately 42%, but no significant difference was found for the 'Ambition to move forward.' This may be due to the positive effect of teaming with design-oriented GEIDAI/DHU students, who have a strong desire for self-expression, whereas the participation ratio or ambition level of business-oriented UTokyo Liberal Arts students was lower than expected.

Design Sprint increased the Prototyping factor in Skillset by approximately 49%. This improvement can be attributed to the positive effects of conducting expert interviews and prototyping over a short period within the Design Sprint. However, the Design Sprint had no significant effect on 'Needs Verification,' possibly because this factor had already improved by over 2.2 points on a five-point scale, indicating strong results from the existing curriculum.

Future improvements in program design should focus on increasing the participation of business school students or corporate intrapreneurs to further enhance ambition. Concurrently, deeper research should include detailed analyses of student mindsets across different backgrounds and behavioral evaluations focused on team leader attributes to provide greater insights.

ACKNOWLEDGMENTS

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BRIDGING THE GAP BETWEEN ENGINEERING AND DESIGN THINKING: HOW TO DEVELOP USER-CENTERED ARTIFICIAL INTELLIGENCE PRODUCT

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ABSTRACT
Amid the growing excitement surrounding artificial intelligence business opportunities, developing user-centered AI products has become a critical focus for modern companies. However, traditional manufacturers face significant challenges in this pursuit. This case study explores how to bridge the gap between engineering and design. We examine workshop process of AI-driven products, in which engineers were trained to adopt design thinking, and new tools were introduced to better capture user needs. The findings highlight the challenges encountered during the development of user-centered AI products, along with the proposed solutions to overcome them. The suggestion method offers valuable insights for enhancing the effectiveness of user-centered AI innovation processes.

Keywords: Artificial intelligence, User-centered design, Design thinking, Engineering mindset transformation, Innovative product development

1 INTRODUCTION

In the current era of artificial intelligence, AI technology plays a pivotal role in product development, reshaping expectations for innovation and market competitiveness. However, traditional engineering approaches, which are often technology-centered and focused on functional implementation, face limitations in AI-driven product development and struggle to meet the diverse needs of users. While AI, as a design material, presents design teams with abundant opportunities for innovation, designers still encounter challenges in demonstrating the return on investment (ROI) of AI functionalities [8]. By collaborating with AI teams, designers and data scientists can drive innovation at both the system and service levels, emphasizing the potential for synergy between design and technology [8].

As AI technology increasingly integrates into everyday life and work environments, the challenge for design and engineering teams is to align technology with user needs in order to create truly valuable and competitive products. The user-centered design approach has emerged as a solution, aiming to understand and address user needs from their perspective, ensuring products are more attuned to users' life contexts. User involvement in the co-creation process is seen as essential to enhancing both the understanding and adoption of AI technologies. The Smart Service Blueprint Scape (SSBS) framework, which maps AI decisions to user interactions, contributes to improving the user experience [7]. Additionally, the integration of interpretable AI visualization techniques effectively bridges the gap in users' technological proficiency, helping them better understand AI-driven decisions and thereby enhancing the overall user experience [6].

The designerly way of thinking not only significantly enhances user satisfaction but also drives product innovation, thereby boosting its market competitiveness. However, during the pursuit of these goals, engineers and designers often encounter collaboration challenges and communication barriers that impede the effective integration of technology development with user experience, ultimately affecting the final product outcome. Research suggests that applying design thinking to closely align AI technology with user needs can facilitate the seamless fusion of technology and design, reducing collaboration challenges between engineers and user experience designers [5].

This study aims to explore how to bridge the gap between engineering and design in the development of AI-driven products, and to address the challenges faced by engineering teams in adopting user-centered design thinking. By proposing practical strategies, the study seeks to achieve the effective integration of technical feasibility and user desirability, ultimately enhancing user satisfaction and market competitiveness. The research objectives are as follows:

1. Conduct a thorough analysis of the key collaboration challenges and communication barriers between engineering and designer in AI-driven product development.
2. Examine strategies to bridge the gap between engineering technology and user experience design, with a particular focus on applying design thinking methods to help engineers shift their mindset.
3. Propose a collaborative framework for integrating AI technology and design and identify potential future research directions.

2 LITERATURE REVIEW

2.1 Product Innovation in the AI Era

With the rapid advancement of AI technology, designers are receiving new sources of inspiration during the early concept design stages, particularly in areas such as smart cafeterias and online intelligent shopping systems. AI-driven design inspiration enables designers to expand their creative horizons and generate innovative ideas [3]. AI technology not only reshapes the modes of product innovation but also drives designers and technical teams to integrate user feedback more quickly throughout the design process, thereby enhancing product competitiveness [2]. However, these success stories are primarily focused on software products or service industries, with limited research on how AI technology and user centered design can be effectively integrated into hardware products—an area of focus for this study.

2.2 Shifting from a Technology-Oriented to a Human-Centered Approach

In technology-driven product development, traditional engineering methods that focus primarily on functional implementation often struggle to meet the diverse needs of users. Therefore, it is essential for engineers to shift their mindset during the development process to gain a deeper understanding of users' needs, cognitive models, and usage contexts [1]. By incorporating design thinking, technical teams can more effectively address the overall user experience. For example, the Smart Service Blueprint Scape (SSBS) framework illustrates how AI-driven decision-making can be integrated with user interactions, encouraging technical teams to adopt a user-centered approach to product design [7].

However, there remains a lack of specific strategies for applying this shift from a technology-driven to a user-centered approach in hardware product development, particularly in how design thinking can be integrated into the hardware technology development process. This study aims to address this research gap.

2.3 The Gap Between Engineering Technology and Design

In the collaboration between AI technology and user experience design, bridging the gap between technology and design remains a significant challenge. This is especially critical for users with lower technical proficiency, where improving the interpretability of the technology becomes a key factor. Research indicates that customized visual prompts in product design can enhance users' decision-making abilities [6]. However, these studies primarily focus on software products and do not address how to effectively bridge the gap between technology and design in hardware development. Therefore, further research is needed to explore the application of AI technology in hardware products and to propose concrete strategies for improving user experience in hardware development.

2.4 The Application of Design Thinking in Technology Development

Design thinking helps engineers transition from focusing solely on technical solutions to developing innovative designs that address user needs. AI-inspired design, as a tool, encourages technical teams to explore a broader range of solutions [3]. The successful application of design thinking requires engineers to understand users' mental models and usage contexts, enabling them to make technical decisions that are better aligned with user needs [1].

2.5 The Collaboration Framework Between AI and Design

Existing collaboration frameworks between AI and UX design position AI as a creative partner in the design process, helping designers reduce routine tasks and foster innovation [24]. However, challenges such as bias and trust continue to hinder the effective application of AI systems in design. In hardware product development, the practical integration of design thinking with AI collaboration frameworks remains underdeveloped, particularly when addressing conflicts between technology and user needs. Further exploration is needed to overcome these challenges [23].

2.6 Overall Review

In summary, while AI technology has driven product innovation, a significant gap remains between technology development and user centered design in hardware products. Most existing literature focuses on the application of AI and the integration of design thinking in software products, with limited practical experience in hardware technology development. Therefore, this study aims to propose suggestions for bridging the gap between engineering and design in AI-driven hardware product development, addressing the research gap in the application of design thinking to hardware development. The goal is to provide technical teams with more concrete and actionable guidelines.

3 METHODOLOGY

This section first outlines the selection of the research case and the overall research process. It then provides an overview of the research methods used at each stage. Additionally, the section describes the background of the selected case, the execution process, and the key considerations that guided the organization and implementation of the study.

3.1 Research Subject

This study uses the "AI Design Innovation Course Program" which is a collaboration between the design team and one of Taiwan's top five electronics companies, as the research case. The program aims to approach innovation from a "human-centered" perspective, moving beyond traditional "object-centered" thinking and into the world of AI innovation, embracing business opportunities and benefits in the AI era, with a focus on developing innovative concepts for AI products.

The reasons for selecting the "AI Design Innovation Course Program" as the case study are twofold:

1. The research case involves a company that is a partner in the NVIDIA Taiwan AI supply chain, which highlights its leading position in AI technology and related hardware and software development, providing a strong foundation for the research and analysis. This case offers a valuable opportunity to explore how AI laptop product development can be driven by user needs and serves as a case study in AI product innovation.
2. The research case is innovative and reflects the diverse challenges and opportunities of AI-driven product development. The participants come from interdisciplinary backgrounds and were directly involved in developing AI product concepts and proposals. This project not only demonstrates how company develop AI product concepts but also emphasizes user-oriented innovation thinking. Therefore, this case was selected to effectively explore the real-world problems and solutions encountered in the integration of technology, design, and engineer participants to provide empirical foundations and reference value for future similar projects.

The participants in the case study were members of an AI-driven product development project, comprising a total of 24 individuals. Most participants were engineers with backgrounds in software and hardware development. These team members were responsible for technical development and system integration within the project, while senior executives focused primarily on strategic planning and decision-making support.

3.2 Research Process

This study draws on practical case experiences, with the research process divided into two stages for data collection. The first stage focuses on the context and application methods of design thinking during the case execution, systematically organizing and analyzing the details of the case implementation. The second stage takes place after the completion of the case, where interviews with relevant stakeholders are conducted to gain an in-depth understanding of their perspectives on the learning outcomes and application of the project. The research emphasizes the interactions among the team members throughout the case process, particularly the challenges and solutions encountered when developing AI products from a human-centered approach.

3.3 Research Methods

This study employed three primary methods for data collection and analysis to provide a comprehensive understanding of the research questions:

1. **Participant Observation:** The researcher participated in product development sessions and team meetings to observe interactions during the integration of technology and design. This method allowed for the documentation of communication barriers and challenges, particularly in the practical application of design thinking.
2. **Semi-Structured Interviews:** Interviews were conducted with 21 engineers and 3 senior executives. Table 1 summarizes the participants' teams and roles. The interviews explored participants' roles, experiences, and challenges, with a focus on collaboration issues between technology and design, the introduction of design thinking, and its impact on engineers' mindsets.
3. **Document Analysis:** Project documents, course materials, and meeting records were analyzed to extract key information related to the integration process. This method supplemented the observations and interviews, providing a more comprehensive view of the project's progress.

Table1: Participants' Departments and Roles

ID	Departments	Roles	ID	Departments	Roles
P1	AI Research Center	Chief Digital Officer	**P13**	Acoustics & Performance	Sensor Team Lead
P2	R&D	Director	**P14**	Acoustics & Performance	Acoustics Engineer
P3	Portable Computer	Director	**P15**	AI Research Center	AI Engineer
P4	Software	Software Engineer	**P16**	Innovation & Design	Hardware Engineer
P5	Innovation & Design	Sensor Team Lead	**P17**	Innovation & Design	Electronic Engineer
P6	Innovation & Design	Acoustic Team Lead	**P18**	Innovation & Design	Electronic Engineer
P7	Innovation & Design	Assistant Manager	**P19**	Software Development	Software Engineer
P8	AI Research Center	Research Engineer	**P20**	AI Research Center	Manager
P9	Innovation & Design	Hardware Engineer	**P21**	AI Research Center	Research Engineer
P10	Innovation & Design	Manager	**P22**	Acoustics & Performance	Validation Engineer
P11	Digital Center	Senior Data Scientist	**P23**	Innovation & Design	R&D Engineer
P12	Software	Firmware Team Lead	**P24**	Innovation & Design	Electronic Engineer

Through the integration of the aforementioned methods, this study aims to systematically explore the challenges faced by engineers in projects and propose effective integration strategies and recommendations. The goal is to enable technical teams to better apply design thinking in AI-driven product development, thereby enhancing user satisfaction and market competitiveness.

4 RESULTS

This chapter presents the main findings of the study, based on the analysis of interview data from 24 interviewees, as well as course application materials. Systematically describe the challenges engineers face when approaching product design from a user-centered perspective in AI-driven product development, as well as the current improvements in addressing these challenges.

4.1 Course Satisfaction Analysis

Table 2 summarizes the Net Promoter Score (NPS) for the course survey in this study, reflecting participants' overall satisfaction with the course and their intent to recommend it. The total number of respondents was 45, with the majority being promoters (36 participants, scoring 9-10), indicating strong approval and a high willingness to recommend the course to others. Additionally, there were 6 passive participants (scoring 7-8), who expressed a neutral attitude towards the course, while only 3 detractors (scoring 0-6) were recorded, suggesting a low dissatisfaction rate.

The average NPS score was calculated to be 67.98, placing it in the high range of net promoter scores, which demonstrates that the course content was well-received by the majority of participants. Of the 45 survey respondents, 80% were promoters, significantly higher than the 6.7% of detractors. The passive group represented 13.3%, indicating that most participants had a positive response to the course.

Table2: NPS Evaluation Results of the Course Survey

Category	Item	Value
Net Promoter Score	Promoters	36
	Passives	6
	Detractors	3
	Average Score	67.9
Total Respondents		45

In summary, the course design has proven effective in helping engineers better understand human-centered concepts and innovate in AI product development, providing empirical evidence and valuable insights for this case study.

4.2 Feedback on Course Application

Interviewees generally felt that the design thinking course positively impacted their mindset, especially in understanding user needs and market orientation *(P13, P20)*. Tools like personas and customer journey maps helped systematize early product design *(P21, P22)*. However, some engineers found the course too intensive, making it difficult to fully master and apply in their work *(P12, P13)*.

Continuous support and training were seen as essential for effectively applying design thinking, especially when facing technical challenges *(P12, P19)*. Several emphasized that design thinking requires time to internalize through repeated practice to fully integrate user needs into technical development *(P13, P20)*.

In summary, this chapter highlighted the case between engineering and design in AI-driven products and demonstrated the initial impact of the design thinking course. While the course had a positive effect, further practice and support are needed to achieve deeper integration between technology and user experience.

4.3 Challenges Faced by Engineers

Interviews show that most engineers face significant challenges in adopting user-centered development. Many lack experience with design thinking, as their training focused on technical development with little emphasis on human-centered design *(P4, P5)*. This creates gaps in applying design thinking, particularly when integrating AI into products, which requires extensive collaboration and convincing stakeholders *(P4)*.

Some suggested that more real-world examples would enhance their ability to apply these methods in daily tasks *(P10, P14)*. Respondents also recommended focusing more on practical case studies in the course to improve real-world application *(P21, P22)*.

Engineers also struggled with shifting from a technology-driven approach to a user-centered one, citing a lack of systematic processes and evaluation frameworks *(P15, P16)*. Tools like personas and customer journey maps were difficult to apply, especially under time pressure and changing market demands (P15, P16). Balancing technical development with user needs, considering costs and feasibility, posed further challenges *(P4, P5)*. Management support was deemed crucial for the successful adoption of design thinking *(P15, P16)*.

4.4 Identification of Communication Barriers

One of the main collaboration challenges between engineers and designers is communication barriers. Many interviewees mentioned that differing understandings of product requirements often led to misaligned design and development goals *(P13, P23)*. Engineers, focused on functionality, and designers, centered on user needs, frequently struggled to make unified design decisions. Additionally, tools like customer journey maps and personas were difficult to apply, further complicating communication *(P3, P10)*.

These barriers significantly impacted the progress and outcomes of product development, especially during the requirements and design phases. The differing priorities between engineers and designers required repeated discussions to reach consensus *(P13, P23)*. Engineers often used technical language, while designers emphasized user experience, leading to further misunderstandings that required coordination to overcome *(P3, P10)*.

Some engineers suggested that the composition of workshop participants could be made more diverse in terms of backgrounds (P3, P13). By engaging in dialogue and understanding each other's ideas, engineers and designers can collaborate more effectively to address challenges in product development. More interaction and mutual understanding would enhance collaboration. Designers also recommended involving technical teams earlier in the design phase to improve alignment and coordination between both sides *(P13, P23)*.

4.5 Effectiveness of design thinking

The application of design thinking in the courses helped engineers shift from a technology-driven approach. Many reported a greater focus on user needs, such as considering remote work and voice interaction in product design *(P7, P16)*. AI applications like voice recognition also showed how technology could align better with market demands *(P1)*.

The courses improved engineers' understanding of user-centered design, boosting future innovation *(P6, P8)*. However, challenges remain in balancing innovation with cost control, especially under supply chain constraints *(P1)*. While design thinking enhanced their grasp of user needs, managing both innovation and risk remains difficult *(P7, P16)*.

The courses also raised awareness of user research, enabling better alignment of products with market expectations. Yet, translating user needs into technical requirements still requires more collaboration between engineers and designers *(P7, P16)*.

5 DISCUSSION

This chapter examines the research findings from three perspectives: the impact on the case study, a comparison with previous literature, and strategies and recommendations for future research topics. It aims to provide a deeper analysis of the implications of the findings, highlighting their uniqueness and contributions within a broader academic context.

5.1 The influence of design thinking course

The results indicate that integrating AI into user-centered product development, along with the introduction of design thinking, had a significant positive impact on engineers' work processes. Tools like personas and customer journey maps helped engineers adopt a user-centered approach, deepening their understanding of user needs. This shift was reflected in their ability to integrate design thinking into daily decision-making. For example, one of interviewees noted that the design thinking course helped engineers shift from a technology-driven to a market-driven approach, better aligning with market demands. *(P1)*

However, challenges remain. Many engineers reported a lack of practical guidance and ongoing support when applying design thinking, particularly in balancing innovation with cost control, especially under supply chain constraints. These challenges highlight the difficulty of implementing design thinking in practice, especially for teams needing to make quick decisions with limited resources. Thus, the study suggests that successful adoption of design thinking requires continuous training and support to effectively merge technology with user experience and remain adaptable in dynamic environments.

Moreover, interviewees noted that design thinking not only improved user experience but also enhanced internal communication. Engineers became more collaborative and better understood designers' perspectives, which had previously been rare. This changes improved team cohesion, allowing for faster responses and adjustments during product development, reducing iterations and resource waste.

5.2 Comparison with Previous Literatures

The challenges and opportunities revealed in this study align with previous research on the integration of design thinking and engineering. Raftopoulos emphasized the importance of incorporating user input at every stage of technical development to fundamentally shift engineers' mindsets [2]. This is consistent with the feedback from participants in our study, where design thinking helped engineers better understand and integrate user needs into human-centered product development.

Similarly, Shergadwala and Seif El-Nasr highlighted the importance of considering users' mental models and operating environments during technical development to achieve true user-centered design [1]. This mirrors our findings, as participants emphasized that technology should not merely meet functional requirements but should be based on user interaction needs. These results underscore the importance of deep user understanding and careful consideration of technology application across different product development environments.

However, while research has focused more on how explainable AI enhances user experience, engineers in our study faced practical challenges in applying design thinking and tools [6]. This suggests that in AI product development, beyond the explainability of technology, the practicality and feasibility of design tools must also be emphasized. These challenges indicate that for the successful implementation of design thinking, engineers need ongoing professional training and adequate resource support in their daily development work.

5.3 Suggestions

Based on our findings and comparisons, future research should focus on the following directions to promote deeper integration of technology and user experience design:

1. **Continuous Education and Support**: The study highlights the need for ongoing education to help engineers effectively apply design thinking. Establishing a continuous learning system with practical exercises and case studies—supported by company resources and management—is essential. Collaboration with cross-functional teams can create tailored professional development paths, with regular evaluations to ensure practical application.
2. **Enhancing Cross-Disciplinary Collaboration**: The study emphasizes the importance of effective communication between engineers and designers. Future efforts should foster cross-disciplinary collaboration through joint workshops and training to strengthen mutual understanding. Regular cross-departmental seminars and workshops focused on real-world product development scenarios can improve teamwork and collaborative problem-solving.
3. **Practical Application and Case-Based Learning**: Many participants noted the need for more concrete guidance on applying design thinking. Future courses should include more case studies and hands-on exercises to bridge the gap between theory and practice. Utilizing real-world product development scenarios will demonstrate how to apply design thinking tools effectively.
4. **Strengthening the Link Between Technology and Market Needs**: Future research should explore how to better connect technical development with market demands. While design thinking helps engineers understand user needs, incorporating more data and market analysis is required to ensure products meet consumer expectations. Companies should establish feedback

mechanisms and integrate market data into product development to enhance competitiveness and user satisfaction.

Through strategic implementation, the integration of technology and user experience design will become more seamless, enhancing both user satisfaction and market competitiveness. The challenges and opportunities revealed in this study demonstrate the significant potential of design thinking in technical development. However, its success requires adequate resources, cross-disciplinary collaboration, continuous educational support, and practical application guidance. As technology and market demands evolve, the flexible and innovative application of design thinking will be crucial for future product development. These findings provide clear direction for future research and practice, emphasizing the importance of merging technology and design in user-centered product development.

6 CONCLUSION

This study highlights the challenges and suggestions in integrating user-centered into AI product development, emphasizing the potential of design thinking to bridge the gap between engineering and design. By analyzing engineers' experiences in AI-driven product development, we demonstrate that design thinking effectively shift engineers' mindsets, enhancing their ability to design from a user-centered perspective. The study underscores the importance of continuous support and cross-disciplinary collaboration.

Academically, this research fills a knowledge gap regarding the application of design thinking in AI and hardware development. From a business standpoint, it provides specific suggestions for tech companies to better integrate design and technology, thereby improving user satisfaction and market competitiveness. In conclusion, the flexible application of design thinking enables technical teams to better understand and meet consumer needs. However, successful implementation requires continuous education, cross-disciplinary collaboration, proper resource allocation, and practical guidance. These factors are crucial for the future success of AI-driven products.

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C-K THEORY-BASED FORMULATION OF A GEOMETRIC MODELING APPROACH

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ABSTRACT
This paper presents a novel approach to geometric modeling based on the Concept-Knowledge (C-K) theory of design. By using C-K theoretic formalisms, we create a C-K map that represents the design process, including various Euclidean and fractal shapes in the concept domain and geometric modeling knowledge in the knowledge domain. A key innovation in this respect is the introduction of creative knowledge into the knowledge domain without prior justification or provenance. The injected creative knowledge results in a point cloud creation algorithm that allows for the modeling of shapes suitable for manufacturing. The algorithm has been successfully applied in two case studies: modeling a mechanical object (a gear) and a fractal object (the building block of a fractal called McWorter's Pentigree). These examples demonstrate the algorithm's scalability and effectiveness in generating complex shapes, highlighting the practical utility of the C-K design-theoretic approach in tackling geometric modeling challenges.

Keywords: Geometric Modeling, Fractal, Knowledge, C-K Theory

1 INTRODUCTION

Geometric modeling provides the tools necessary to create, analyze, and manipulate the shapes and structures of objects in a digital environment, playing a fundamental role in Computer-Aided Design (CAD). The digital data produced by CAD are then used in the downstream of product life-cycle for materializing the underlying shape using additive, subtractive manufacturing processes, ensuring that the fabrication accuracy [1]. However, the two primary categories of geometric modeling, Euclidean and fractal, offer distinct approaches to representing shapes. Euclidean geometric modeling focuses on traditional shapes such as lines, circles, and polygons, which are essential in engineering and architectural applications due to their predictable mathematical properties. On the other hand, fractal geometric modeling represents complex, self-similar structures found in nature, such as terrain, clouds, and biological organisms [2,3]. Ullah et al. [4] highlighted the applications of fractals across fields such as manufacturing engineering, architecture, communication engineering, and computer graphics. Fractals also hold significant importance in biomedical engineering, as many natural forms in living organisms display fractal characteristics [4, 5].

A key component in the effectiveness of geometric modeling systems is knowledge representation, which ensures accurate communication and application of geometric principles in manufacturing technologies. In geometric modeling, knowledge serves as both a foundational element and a dynamic resource that informs decision-making, and creative ideas and ensures the relevance and feasibility of design solutions. Knowledge can be described as a statement that aligns with a belief that is both justified and true [6]. Knowledge embedded within the geometric modeling process influences the effectiveness and precision of the resulting models. This includes mathematical principles, material properties, and design constraints, all of which contribute to the accuracy and usability of the models in real-world applications.

Geometric modeling not only provides the technical precision required to visualize, test, and optimize design ideas, but it also integrates seamlessly with design theory, which offers conceptual frameworks and problem-solving methodologies that guide the overall design process. In design theory, knowledge is embodied in design tools, methods, and processes. Therefore, the role of knowledge in design theory can be implemented in improving geometric modeling. One design theory that can be particularly beneficial in the context of geometric modeling is the C-K theory (Concept-Knowledge theory), which provides a structured framework for innovation and design [7–9]. In this framework, the design process operates within two distinct spaces: the concept space and the knowledge space. As the design process unfolds, both spaces expand concurrently. This expansion relies on existing knowledge while also contributing to the creation of new knowledge, particularly when an innovative or creative design replaces a conventional one within the concept space [9].

This paper introduces a novel approach to geometric modeling that leverages C-K theory to enhance the design process. The proposed methodology is demonstrated through a case study focusing on Euclidean and fractal shapes, where a newly developed algorithm is employed to explore and validate the effectiveness of the approach.

2 KNOWLEDGE AND C-K THEORY IN GEOMETRIC MODELING

Ullah [6] described four types of knowledge: definitional, deductive, inductive, and creative knowledge. Definitional knowledge refers to universally accepted ideas or concepts that are true beyond contradiction. This form of knowledge serves as the foundation for understanding certain phenomena and remains unchallenged within its logical framework. Deductive knowledge, by contrast, is derived through logical reasoning based on definitional knowledge, where relations of ideas are established to infer new conclusions. Inductive knowledge, however, emerges from empirical experience and is obtained through observation of the world. It is based on the logical process of induction, and concludes specific instances to form generalizations, often referred to as “matters of fact.” Finally, creative knowledge arises from imaginative and pragmatic activities, where novel ideas or preferences are formulated through innovative processes that transcend existing knowledge structures. The integration of these four types of knowledge results in what Ullah describes as compound knowledge—a synthesis of various knowledge forms that offers a more comprehensive and nuanced understanding of a given topic or problem. Compound knowledge is not merely the sum of its parts, but rather a complex interplay of definitional, deductive, inductive, and creative knowledge that enables deeper insights and more innovative solutions [6].

In the context of design theory, knowledge plays a fundamental role in shaping both the processes and outcomes of design. Design theory provides a structured way to conceptualize and explain the processes involved in the creation of artifacts, whether they be physical (hardware) or digital (software). One prominent design theory that categorizes knowledge and its application in a systematic manner is the C-K theory. C-K theory, short for Concept-Knowledge Theory offers a framework that distinguishes between two interrelated spaces: C-Space (Concept Space) and K-Space (Knowledge Space). The core idea of this theory is that innovation and problem-solving occur through the dynamic interaction between these two spaces. The interaction between C-Space and K-Space is central to the process of innovation. The introduction of a new concept in the C-Space, particularly one that is uncertain or novel, challenges existing knowledge structures in the K-Space. As it is further developed and refined, new knowledge is generated in support of the concept, thus leading to an expansion of the K-Space. This continuous cycle of concept development and knowledge expansion not only fosters innovation but also enhances the design process by allowing for the integration of novel ideas and approaches into established knowledge domains. Therefore, in the C-K theory of design, creative knowledge is crucial [7-9].

Geometric modeling, as a discipline, involves the use of mathematical and computational techniques to represent shapes, objects, and their properties. The creative process in geometric modeling is a structured yet flexible series of stages that allow the modeler to explore and refine geometric forms. This process is inherently iterative, requiring the continuous application of creative thought to optimize the design and representation of geometric structures. Therefore, creative knowledge serves as the foundation for the creative process in geometric modeling. In this regard, creative knowledge is developed, functioning as a key mechanism behind the geometric modeling process. The arrangement of the process is schematically illustrated in Figure 1.

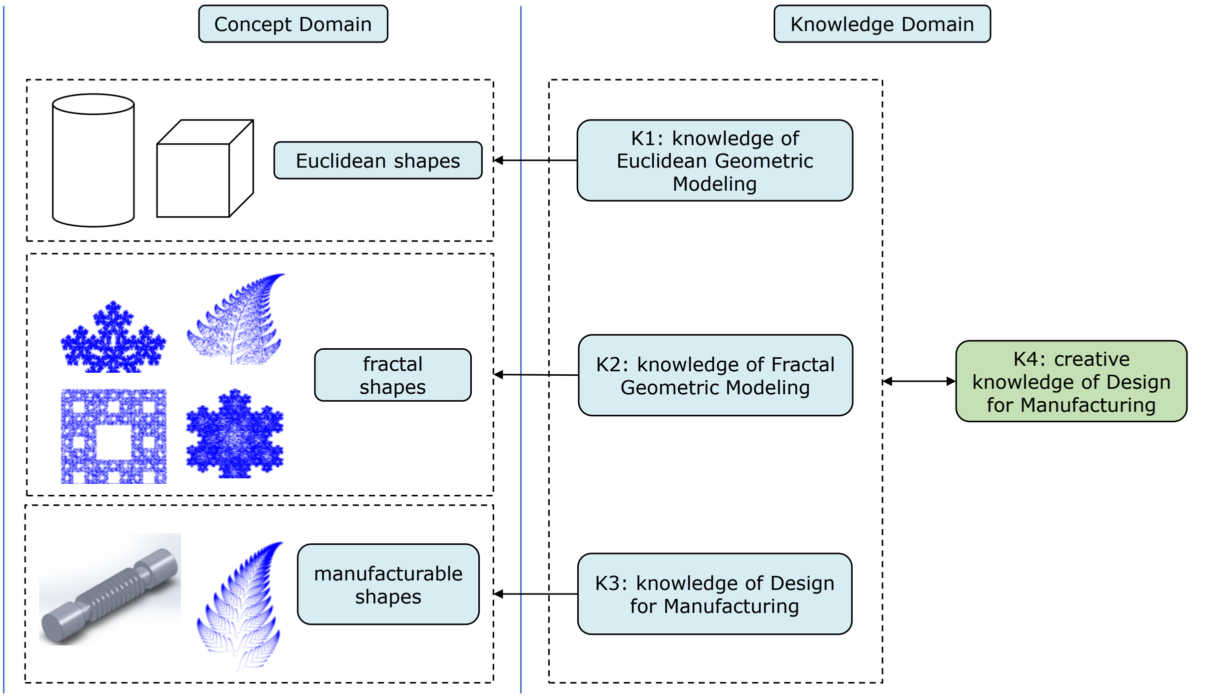

Figure 1. C-K map of the geometric modeling

Figure 1 shows a C-K map of the geometric modeling of both Euclidean and fractal shapes. The C-K map is divided into two interconnected domains: Concept Domain and Knowledge Domain. In the Knowledge Domain, four distinct knowledge areas are identified. Here, K1 represents the knowledge of Euclidean geometric modeling, emphasizing the knowledge required to create Euclidean shapes. Similarly, K2 denotes the knowledge of fractal geometric modeling, a knowledge to utilize specific mapping techniques and algorithms to generate fractal shapes. On the other hand, K3, the knowledge for Design for Manufacturing refers to the knowledge required to create manufacturable shapes, Euclidean or fractal. This knowledge is utilized to apply geometric principles in manufacturing processes. The Knowledge Domain is enriched with another chuck of knowledge denoted as K4, which represents creative knowledge required for design and manufacturing of either of the shapes. This creative knowledge may replace K1, K2, and K3. In the Concept Domain, different types of geometric shapes and their generative processes. Euclidean shapes are derived from the application of K1 (knowledge of design for manufacturing of Euclidean shapes) within the Knowledge Domain, showcasing their foundational role in conventional manufacturing practices. Fractal shapes, characterized by their repetitive and complex structures, are generated through the application of K3 (knowledge of fractal geometric modeling). Further extending the applicability of geometric modeling knowledge, manufacturable shapes represent adaptations of these geometries specifically customized for practical use in manufacturing processes. These manufacturable shapes are the output of K3 (knowledge of design for manufacturing).

In design for manufacturing, topology plays a critical role in as it dictates the relationships within a design, directly influencing the feasibility and efficiency of the manufacturing process. Therefore, knowledge of design for manufacturing (K3) must integrate an understanding of both the geometry of the object and its topology in relation to underlying manufacturing processes. This integration ensures that the design is compatible with the manufacturing method, whether it involves traditional techniques or advanced processes such as additive manufacturing. For example, in 3D printing, the interaction between the topology and the printer head governs not only the precision of the final product but also the efficiency of the tool path. Similarly, in subtractive manufacturing, such as turning or milling, the cutting tool's interaction with the object's topology determines the accuracy and quality of the final product. Thus, the shape and the tool path—essentially, the topology—are critical determining factors. If any issues arise with these aspects, it may impede the manufacturing process. Failure to account for the topology of a design can led to complications during manufacturing, including tool path inefficiencies, structural weaknesses, or even the inability to produce the object.

As illustrated in Figure 1, a creative knowledge of Design for Manufacturing is utilized in the creative process (K4). In this regard, authors proposed a creative-knowledge-based algorithm as a novel contribution to the creative knowledge of Design for Manufacturing, explicitly integrating C-K theory to structure the process of creative knowledge expansion.

Algorithm 1 Analytical Point Clouds Creation Algorithm

Define
Instantaneous Distance: $r_i \in \mathbb{R},\ i = 1, \ldots, n$
Instantaneous Angle (in degrees) : $\theta_i \in \mathbb{R},\ i = 1, \ldots, n$
Plane: $(u, v) \in \{(x, y), (y, z), (x, z)\}$
Center Point: $P_c = (P_{cu}, P_{cv}) \in \mathbb{R}^2$

Iterate
for $i = 1, \ldots, n$ **do**
Calculate $P_i = (P_{iu}, P_{iv})$ as follows:
$P_{iu} = P_{cu} + r_i \cos\left(\frac{\pi}{180}\theta_i\right)$
$P_{iv} = P_{cv} + r_i \sin\left(\frac{\pi}{180}\theta_i\right)$
end for

Output
Analytic Point Cloud: $PC = \{P_i = (P_{iu}, P_{iv}) \mid i = 1, \ldots, n\}$

In order to use the analytical point clouds creation algorithm, the user needs to understand how to determine the values of the instantaneous distance (r_i) and instantaneous angle (θ_i). The first step is the definition step, the second step is the iteration step, and the last step is the output step. In the definition step, instantaneous distances ($r_i \in \Re \mid i = 1, \ldots, n$), instantaneous angles (in degrees) ($\theta_i \in \Re \mid i = 1, \ldots, n$), plane ($(u,v) \in \{(x,y), (y,z), (x,z)\}$), and center point ($P_c = (P_{cu}, P_{cv}) \in \Re^2$) are defined. In the iteration step, points $P_i = (P_{iu}, P_{iv})$, $i = 0, 1, \ldots, n$ is calculated, as follows: $P_{iu} = P_{cu} + r_i \times \cos\left(\frac{\pi}{180}\theta_i\right)$ and $P_{iv} = P_{cv} + r_i \times \sin\left(\frac{\pi}{180}\theta_i\right)$. The last step, i.e., the output step, outputs the resultant $PC = \{P_i = (P_{iu}, P_{iv}) \mid i = 1, \ldots, n\}$.

For the sake of the better understanding, Figure 2 shows two examples of Algorithm 1-created point clouds. For both cases, $P_c = (10, 10)$ and $(u,v) = (x,y)$ are chosen. (Note that for all cases in the article $(u,v) = (x,y)$ is used.) In the first example (Figure 2(a)), the instantaneous distances are kept constant, i.e., $r_i = 25$, for all ii = 1,…,5. The instantaneous angles are increased linearly. In this case, is chosen. The resultant PC is shown in P_{iy} vs P_{ix} plot. As seen in Figure 2(a), the resultant PC represents a pentagon shape. In the other example (Figure 2(b)), similar strategy is used (instantaneous distances are kept constant and instantaneous angles are increased linearly) but the number of points is increased by setting a larger value of n, i.e., $n = 25$. This time, the shape represents a circular shape. This way, setting of instantaneous distances, instantaneous angles, coordinate system, and center point, different shapes can be represented by the resultant PC. Tashi et al. [10] have used a similar algorithm to create point clouds for modeling artifacts, which are all Euclidian shapes.

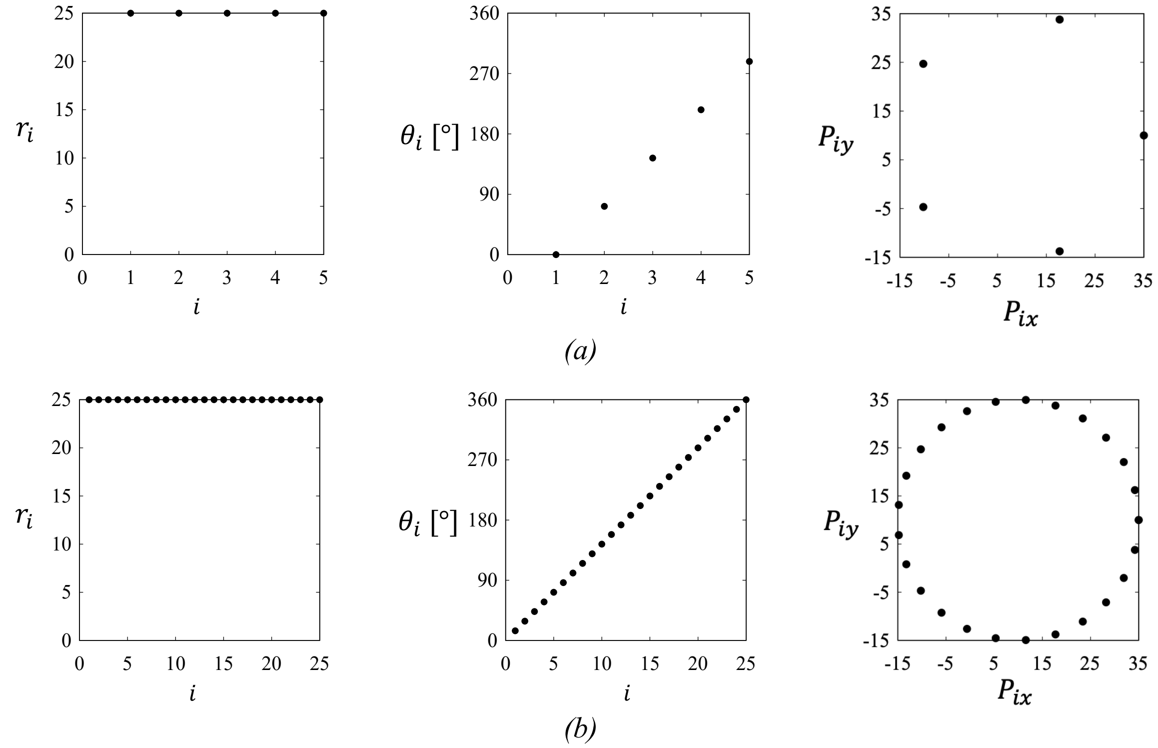

Figure 2. Generated point clouds using the Analytical Point Cloud Creation algorithm.

(a) Pentagon; (b) Circle.

3 RESULT

This section describes the implementation of a geometric modeling approach involving creative knowledge. Recall the creative-knowledge-based algorithm (Algorithm 1) implemented in the geometric modeling approach in Section 2. A novel geometric modeling approach is applied to create a digital representation of part of a gear object and pentagon fractal. Point clouds generated from the analytical point cloud creation algorithm of a gear object and a pentagon fractal are shown in sub-section below.

3.1 Euclidean shape

In this subsection, Algorithm 1 is applied to generate several Euclidean shapes, which serve as the foundation for manufacturing a gear-shaped object. The process begins by defining the parameters of the algorithm to generate a point cloud representation of the desired shapes. This step ensures that the algorithm can accurately model the geometry of each component of the gear. Once the point cloud is established, the algorithm is applied to construct the final shape, taking into account the specific geometric requirements of every part of the gear. Further explanation of the process is shown in Figure 4 as follows.

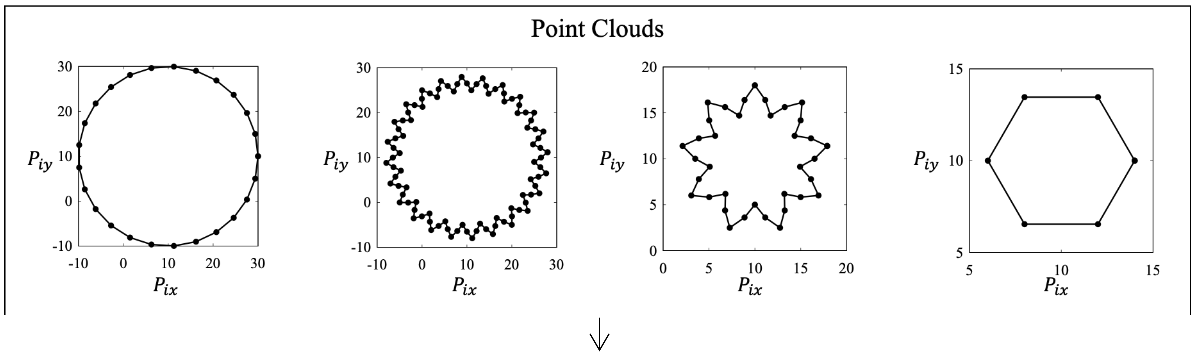

Figure 4. The creative process of point cloud creation of gear object.

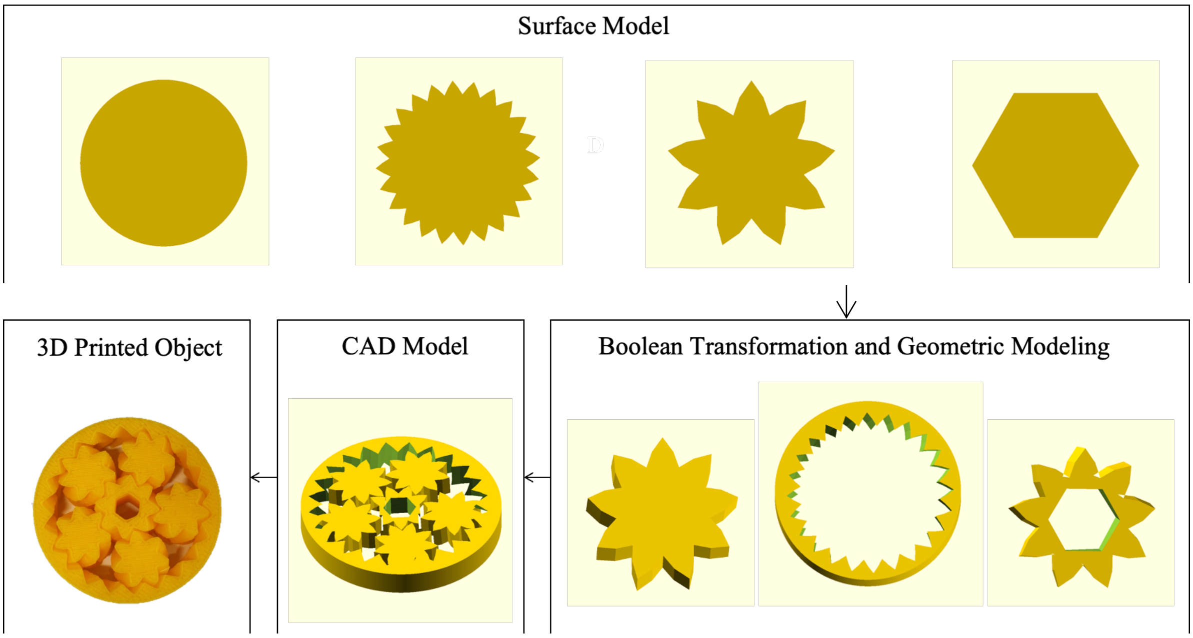

Figure 4. The creative process of point cloud creation of gear object (continued).

Figure 4 shows the creative process of point cloud creation of gear object. Initially, this process begins with the generation of a point cloud, which is produced through the application of an analytical point cloud creation algorithm. After generating the point cloud, the next step involves processing these points to define a 2D closed boundary that captures the outer edges of the target geometry. This boundary serves as a crucial element in transitioning from a scattered set of points to a more structured representation of the object. Once the boundary has been defined, the resulting 2D geometry can be utilized to construct a surface model, which is the digital representation of the object's surface. This surface model is developed by importing the point cloud data into a commercially available 3D CAD (computer-aided design) system. Within the CAD environment, the point cloud data is processed and converted into a digital model that accurately represents the geometry of the gear. This CAD model can subsequently be utilized for product manufacturing through additive manufacturing techniques, as illustrated for the 3D-printed gear object in Figure 4. The results provided valuable insights into the algorithm's suitability for complex geometries of Euclidean shapes.

3.2 Fractal Shape

In the conventional approach to fractal generation, fractals are generated through the application of a set of mathematical functions in a repetitive, iterative process. This method is known as Iterated Function Systems (IFS) [10]. An IFS involves a finite collection of functions that are applied repeatedly to generate increasingly complex structures. It typically involves a set of functions, each of which defines a transformation (or mapping) that acts on the points of the shape. The transformations in IFS can be contractive mappings, which progressively reduce the distance between points with each iteration, resulting in a more refined and intricate structure as the process advances. In many fractals, the mappings used are affine transformations, which include scaling, rotation, translation, and shearing [10, 11]. The creation process of fractal geometry involves iterative repetition corresponding to the fractal's hierarchical levels. To create manufacturable fractal shapes, several researchers have proposed that the levels of the fractal, or the degree of similarity between the iterations of the fractal, must be meticulously controlled [4]. This is crucial as the inherent complexity and self-similarity of fractals can present challenges when translating them into tangible, manufacturable objects. Consequently, any algorithm designed to generate fractal shapes must possess the capability to control level of the fractal. The algorithm must not only generate the fractal pattern but also offer a way to manipulate key parameters to ensure that the final shape can be effectively realized in a manufacturing environment. As a result, a configuration is proposed to control the level of fractal creation. Using the Analytical Point Cloud Creation algorithm, a process to create fractal level 0 and fractal level 1 is illustrated in Figure 3 as follows.

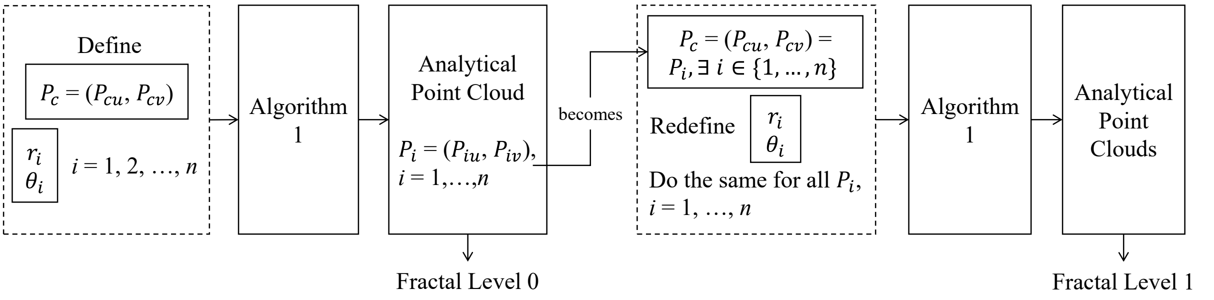

Figure 3. The process of fractal creation using the Analytical Point Clouds Algorithm.

Figure 3 shows the process of creating fractal level 0 and fractal level 1 using the Analytical Point Cloud Creation Algorithm. As described in Algorithm 1, the first step of the process is to define instantaneous distance ($r_i \in \Re \mid i = 1, \ldots, n$), instantaneous angle ($\theta_i \in \Re \mid i = 1, \ldots, n$), and center point ($P_c = (P_{cu}, P_{cv}) \in \Re^2$). These parameters are used in Algorithm 1 in order to create the point cloud, resulting in $P_i = \{(P_{iu}, P_{iv}) \mid i = 1, \ldots, n\}$. These points represent the level 0 fractal, i.e., the points represent the base shape from which the subsequent levels of the fractal are generated. For the next repetition of the algorithm, the analytical point cloud (P_i) from fractal level 0 is used as center point, so $P_c = (P_{cu}, P_{cv}) = P_i,\ \exists\, i \in \{1, \ldots, n\}$. The same process is repeated by redefining instantaneous distance ($r_i \in \Re \mid i = 1, \ldots, n$), instantaneous angle ($\theta_i \in \Re \mid i = 1, \ldots, n$) for all P_i, $i = 1, \ldots, n$. The parameters are processed using the Analytical Point Clouds Algorithm, resulting in analytical point clouds as fractal level 1. The application of this approach is shown in Figure 5 below.

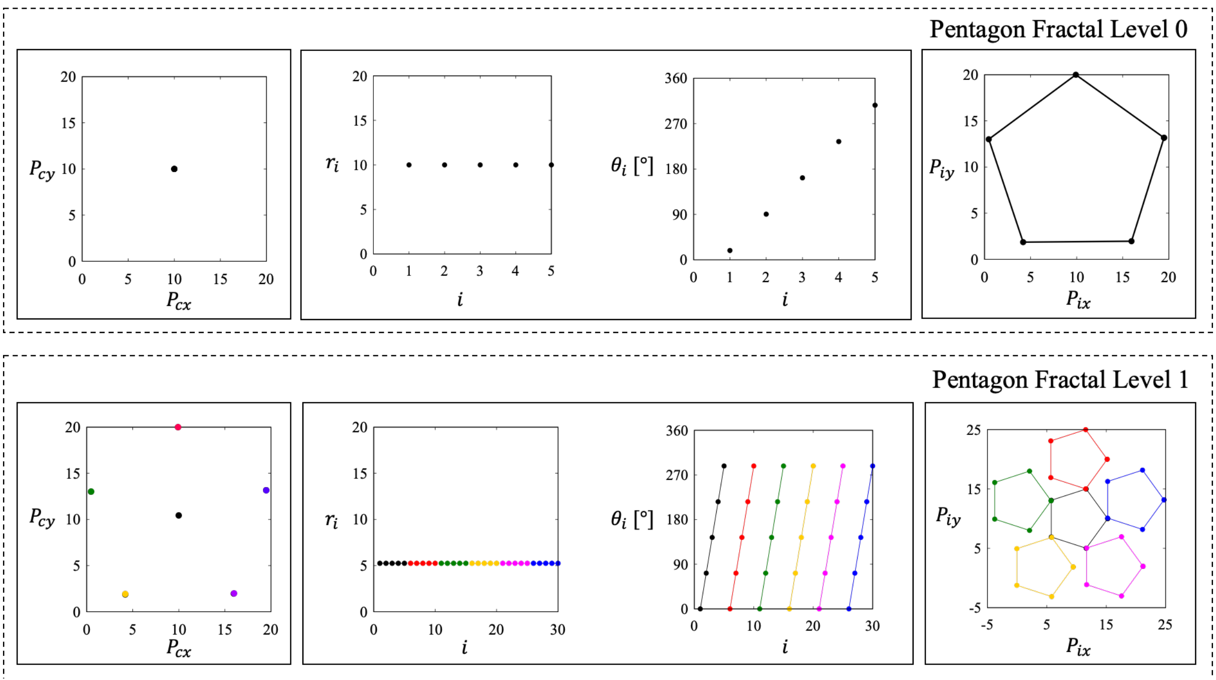

Figure 5. The creative process of point cloud creation of part of a pentagon fractal.

In Figure 5, a proposed approach using the same analytical algorithm is done to model to generate the point cloud data of a pentagon fractal. The steps involved are illustrated in Figure 3 above. The process begins by creating fractal level 0. First, center points $P_c = (10, 10)$ is defined. Subsequently, the parameters r_i and θ_i are specified. In this instance, r_i is held constant where $r_i = 10$, while θ_i increases linearly, with θ_1=18.5° and $\Delta\theta$ = 72°. The values of r_i and θ_i for this first step are critical to define as it will define the scaling angular rotation for the subsequent levels of the fractal. These parameters then proceed using iterative calculation in Analytical Point Cloud Creation Algorithm, resulting in the formation analytical point cloud $P_c = (P_{cu}, P_{cv})$ as pentagon fractal level 0 as shown in Figure 5. During the next phase, additional pentagons, each with progressively smaller sizes, are generated using an approach illustrated in Figure 3. These smaller pentagons are positioned such that their centers coincide with the vertices of the initial pentagon. The analytical point cloud P_c in fractal level 0 becomes center points for the process of creating fractal level 1 ($P_c = (P_{cu}, P_{cv}) = P_i,\ \exists\, i \in \{1, \dots, n\}$). Furthermore, r_i and θ_i are redefined and used for the iterative calculation in the Analytical Point Cloud Creation algorithm. This process results in pentagon fractal level 1 as shown in Figure 5.

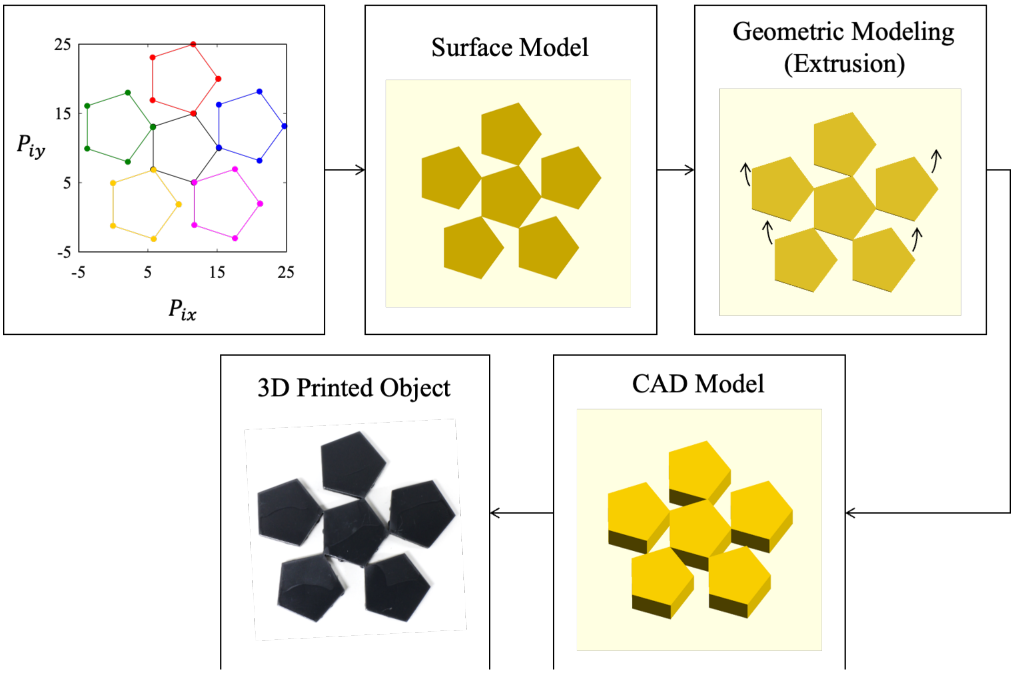

Figure 6. The creative process of point cloud creation of part of a pentagon fractal.

Figure 6 illustrates the creative process of point cloud creation of part of a pentagon fractal. The point clouds of pentagon fractal level 1 are then processed to define a 2D closed boundary around the points. This boundary is essential for creating a structured surface model. The surface model is generated by importing point cloud data into a commercially available 3D computer-aided design (CAD) system. Within this CAD environment, the point cloud data is processed and transformed into a digital model that precisely captures the geometry of the pentagon fractal. This digital model can be utilized for manufacturing the product using additive manufacturing techniques, as demonstrated by the 3D-printed pentagon fractal shown in Figure 6. This method highlights the versatility of the Analytical Point Cloud Creation, demonstrating its applicability in generating complex geometric models.

4 CONCLUDING REMARKS

This paper presents a novel geometric modeling approach that integrates C-K theory (Concept-Knowledge theory) to enhance creative knowledge in design processes using geometric modeling. The study explores the potential of two distinct forms of geometric modeling—Euclidean geometric modeling and fractal geometric modeling. A C-K map is illustrated to show the concept and knowledge required for Euclidean and fractal geometric modeling. In the concept domain, Euclidean shapes, fractal shapes, and manufacturable shapes are shown. In the knowledge domain, knowledge of Euclidean geometric modeling (K1), knowledge of fractal geometric modeling (K2), knowledge of design manufacturing (K4), and creative knowledge of Design for Manufacturing (K4) are shown. The creative knowledge of Design for Manufacturing (K4) is proposed as a replacement for the conventional knowledge typically required in these modeling approaches. In this framework, creative knowledge is formalized through the introduction of a new algorithm, the Analytical Point Cloud Algorithm, which serves as the computational tool for generating analytical point clouds corresponding to the desired shapes. The Analytical Point Cloud Algorithm operates by utilizing a set of parameters, namely center points, instantaneous angle, and instantaneous distance, which guide the point generation process. The points are generated on specifically chosen planes, providing a high degree of flexibility in shaping and modeling intricate and complex forms. This adaptability is crucial in allowing the algorithm to create both Euclidean and fractal-based structures with a creative knowledge foundation, rather than relying solely on traditional geometric principles.

Regardless of whether the shape is Euclidean or fractal, the settings should be kept simple. This implies that there is no need to explicitly write out complex conventional process for the shape and an algorithm that can implicitly represent all shapes is advised. To demonstrate the practical application and effectiveness of this algorithm, a case study is conducted in which the shape of a mechanical object, specifically a gear, is modeled alongside a fractal structure known as McWorter's Pentigree. Through these case studies, the paper illustrates the versatility and potential of the proposed method, showing how it can facilitate the creation of diverse shapes in both traditional and fractal geometric contexts. By developing and applying a creative knowledge-based algorithm, the research successfully demonstrated how analytical point clouds can be used to generate digital models of complex structures. The integration of C-K theory proved effective in structuring the creative process and expanding the knowledge space, leading to the production of more precise and innovative geometric models. This approach shows how creative knowledge can replace traditional knowledge domains to develop versatile and manufacturable shapes, as exemplified through the case studies on gear objects and pentagon fractals.

ACKNOWLEDGMENTS

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PROCEEDINGS OF ASIA DESIGN AND INNOVATION CONFERENCE
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A STUDY ON BUDWEISER'S BRAND RENEWAL FROM THE PERSPECTIVE OF DESIGN ASSETS

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ABSTRACT
With the advent of the new consumption era, classic brands are widely confronting the issue of brand aging. The opportunity and challenge for classic brands is seeking new paths and possibilities for brand asset reconstruction without compromising the continuity of their existing brand equity. From the perspective of design assets, this paper analyzes Budweiser's strategies for inheriting, updating, expanding, and applying design assets during its brand renewal in the new consumption era. It proposes the SOI（Screen, Optimize, Innovate） model for brand design asset management, aiming to provide references for relevant practices.

Keywords: new consumption era, classic brands, brand renewal, design assets, design management

1 INTRODUCTION

In the dawn of the new consumption era, classic brands are widely confronted with the predicament of brand aging, driven by shifts in consumer demands and upgrades in consumption patterns. [1] To sustain competitiveness and foster sustainable growth amidst this evolving landscape, it is imperative for classic brands to rejuvenate themselves and rekindle consumers' passion and trust through strategic brand renewal. Given the distinctive nature of classic brands, which have cultivated specific brand associations, knowledge, and loyalty within the consumers' psyche over an extended period, the renewal process necessitates a dual focus. [2] On one hand, brands must devise strategies to project a novel image, thereby dispelling perceptions of being outdated or antiquated. On the other hand, they must also prioritize the preservation and enhancement of positive brand connotations, knowledge, memories, and emotions among their existing customer base, thereby safeguarding their hard-earned brand loyalty. Aaker posits that "brand awareness," "brand associations," and "brand loyalty" are the sources of brand equity. [3]In Keller's "customer-based" brand theory and strategic propositions, "brand knowledge" (held by customers) is recognized as the foundation of brand equity. He suggests that "brand knowledge" emerges from customers' "brand recognition" and "brand associations," providing fundamental insights for tackling practical challenges such as "brand activation" and "brand reinforcement."[4] The relationship between brand image and brand equity is mediated by perceived quality[5] , and specific dimensions of brand image hold substantial value for brand associations.[6] Presently, studies on brand renewal from a design perspective predominantly concentrate on the influence of updating design elements within brand identity on consumers' perception of the brand. [7] Nonetheless, there is a notable dearth of research examining the interplay between design elements and brand assets, as well as the methodologies for organizing, managing, and applying these design elements within a brand framework. This oversight is particularly significant given the potential of such strategies to enhance design efficiency, ensure brand image consistency, and bolster brand competitiveness.

Therefore, this study innovatively introduces the analytical perspective of "design assets." It not only focuses on how classic brands update and expand design elements during brand renewal in the new consumption era but also examines how these brands select design elements to construct their brand identity systems, how they adjust these elements for better organization, management, and application within the brand, and the specific methodologies employed to enhance design efficiency, ensure brand image consistency, and strengthen brand competitiveness.

This study primarily adopts a case study approach, analyzing Budweiser's brand renewal in the new consumption era from the perspective of design assets. The reason for this choice is that the updated Budweiser brand image not only combines modernity with classic appeal in its visual presentation but also establishes a design element management system that continually reinforces the brand's spirit and quality through communication. [8] By examining the formation of Budweiser's design assets and the innovative strategies employed in their inheritance, updating, expansion, and application during this renewal process, this study aims to explore the role of design assets in brand renewal and analyze how effective utilization of design assets can enhance a brand's market competitiveness.

2 FORMATION AND INHERITANCE OF BUDWEISER'S BRAND ASSETS

2.1 Formation of Budweiser's Brand Assets

In this paper, the concept of "design assets" is defined as the key components among the design elements employed throughout a brand's historical evolution that are capable of stimulating consumers' associations and cognitions with the brand and its core values. Consequently, not all "design elements" can be regarded as "design assets." Design assets are the crystallization of long-term interactions between brands and consumers, gradually accumulated and precipitated over time. Specifically, although some design elements adopted during the inception of a brand may inherently carry symbolic meanings when constructing "brand behaviors," it is only when these "brand behaviors" facilitated by such "design elements" become ingrained as "brand knowledge" in consumers' minds and form close associations with them that these "design elements" are endowed with the status of "design assets." They not only bear the significance of the symbols themselves but also embody the profound connotations of the brand.

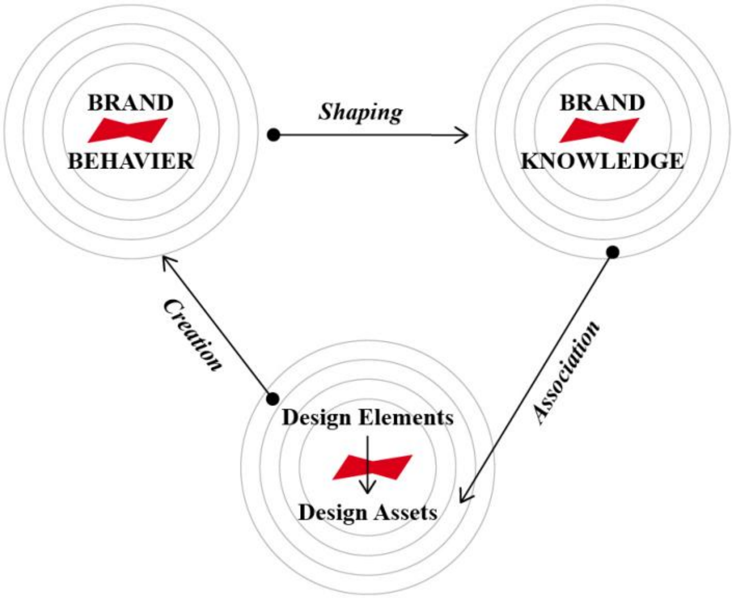


Figure 1. The Formation Process of "Design Assets"

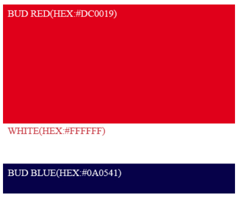
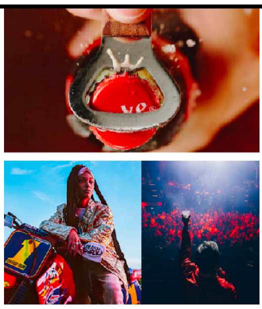
2.2 Inherited Brand Assets of Budweiser

In the evolution of a brand, numerous "design assets" are accumulated, and selecting different design assets to shape "brand behavior" will directly lead to the construction of differentiated brand knowledge systems. By strategically adjusting and optimizing "design assets," brands can indirectly shape and guide consumers' "brand knowledge." Conversely, consumers' brand knowledge can also inject new vitality and meaning into "design assets," achieving deeper interaction and resonance between the brand and consumers.

Table 1 summarizes the main "design assets" chosen by Budweiser for inheritance in the new consumption era, as well as their usage in brand history and symbolic meanings. Using these "design assets" to create "brand behavior" will reinforce in customers' minds: (1) the American culture and spirit symbolized by Budweiser; (2) Budweiser's craftsmanship and championship quality; (3) the role Budweiser has played in customers' lives for over a hundred years - an amplifier of emotions during exciting moments.

Table 1. Major Design Assets Inherited by Budweiser in the New Consumption Era, Their

Usage in Brand History, and Semantics

No.	Budweiser's Design Assets	Design Assets In Budweiser's history	Semantic Representation of Design Assets Symbols
1	logo	In 1957, a similar graphic was first associated with the brand as its logo. Since then, except for brief periods in 1963-1967 and 1996-1998 when different logos were used, the brand has consistently adopted the "bowtie" frame combined with the brand name as its logo.	• The bowtie graphic symbolizes gentility and refinement. • Budweiser Brand Logo
2	 color	Since the brand's establishment in 1876, red has been its primary color. However, during its development, it has also utilized color schemes such as red and green, red, black, and white, red and blue, as well as red, blue, yellow, and white.	• The primary color red symbolizes passion, enthusiasm, excitement, and a bold spirit. • The color combination of red, white, and blue, which mirrors the colors of the American flag, symbolizes American culture.
• 3	 Heritage Illustration	The initial logo design created when the brand was founded in 1876 serves as a symbol of the brand itself, as well as its history and quality.	• The historical Budweiser. • A symbol of authority.
4	 photography	From the early hand-drawn posters to subsequent photographic advertisements, Budweiser's imagery has consistently revolved around the product and the stories of customers engaging with the product.	• Moments of inspiration. • Feelings of enthusiasm, boldness, and excitement.

The selective inheritance of these design assets is primarily attributed to the fact that, in the new era of consumption, customers place greater emphasis on factors such as "emotional factors," "emotional value," and "cultural identification" when forming purchase decisions. [9]These design assets are precisely capable of evoking relevant brand associations and brand knowledge among customers.

3 RENEWAL AND EXPANSION OF BUDWEISER'S BRAND ASSETS

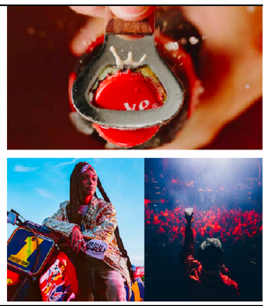
In its new brand image, Budweiser updates and expands its original "design assets" while retaining their distinctive features and memorable points, allowing them to shine brightly within a system that makes Budweiser's design larger, bolder, and more characteristic of the brand. [10]

3.1 Renewal of Budweiser's Brand Assets

Through Table 2, we can visually compare the changes in Budweiser's "design assets" in the new consumption era compared to before:

Table 2. Comparison of Budweiser's Major Design Assets Before and After the New Consumption Era

Design Assets	Before	After

	New Consumption Era	New Consumption Era	
	1999	2016	2021
Logo	Budweiser	Budweiser	Budweiser
Color	BUD RED WHITE NAVY GOLD SILVER BLACK	BUD RED(PMS 186) WHITE NAVY(PMS 2767) SILVER(PMS 877 OR COOL GRAY 5) BLACK	BUD RED(HEX:#DC0019) WHITE(HEX:#FFFFFF) BUD BLUE(HEX:#0A0541)
Typography		AaBbCc BUD BOLD AaBbCc BUD CRAFTED AaBbCc FRANKLIN GOTHIC BOOK	ABCDEFGHIJKLMNOPQRSTUVWXYZ abcdefghijklmnopqrstuvwxyz 0123456789!@#$%^&*()[]?+ ABCDEFGHIJKLMNOPQRSTUVWXYZ abcdefghijklmnopqrstuvwxyz 0123456789!@#$%^&*()[]?+
Heritage Illustration			
Photography			

Firstly, compared to the version Budweiser has been using since 1999, the most significant design asset of Budweiser in the new era—the logo formed by the combination of the "bowtie" frame and the stylized brand name in script—has undergone several changes: (1) In the new consumption era, the Budweiser logo has removed the border, shadow, and internal decorative lines around the bowtie graphic, transforming it into a more recognizable minimalist design. Based on the 2016 version, the 2021 "Amp" graphic has undergone subtle adjustments to its symmetry, making it more intuitively repeatable and bendable, thus enhancing its extensibility (as shown in Figure 2); (2) The "crown" element in the original logo has been eliminated; (3) The handwritten Wordmark has also removed its outline and shadow, becoming clearer and easier to read, and its overall width has been narrowed, allowing the Wordmark and symbol to combine more cohesively; (4) The "bowtie" graphic has been granted a new meaning—"the great amplifier," which aims to reinforce Budweiser's longstanding role in customers' lives.

Figure 2. Differences Between the Brand Logo in 2021 and the Brand Logo in 2016

paper Secondly, compared to before, Budweiser's brand colors have: (1) Continuously streamlined the color palette—the latest color combination aligns with the American flag, which is more conducive to reinforcing the American culture embedded in Budweiser's quality; (2) Increased the brightness and saturation of the colors—enhancing the visual impact and making it easier to attract customers' attention in a fiercely competitive market.

Furthermore, the typographic used by the brand have become more streamlined and exclusive compared to before, better highlighting the brand's unique characteristics. Although the Budweiser brand visual guidelines manual for the period 1999-2015 could not be obtained, by comparing the norms set by Budweiser officials for "brand fonts" in the brand manuals of 2016 and 2021, it can be understood that in 2021, the number of fonts used by the brand was reduced from three to one. The new font features are derived from the new logo, combining a sense of tradition with high recognizability, and are designed with different font weights. This helps to better emphasize "Budweiser quality" in the New Consumption Era.

Moreover, compared to previously, Budweiser's Heritage Illustration has:(1) Continuously streamlined its compositional elements—in the 2021 version, the wheat stalk element has been removed because, in the latest brand strategy, product ingredients are no longer crucial information to convey; (2) Continuously improved the recognizability of each element—in the latest version of the illustration, both the clarity of the text and the subtleties of the illustration details have been better handled, making the content appear cleaner and easier to read.

Lastly, compared to before, Budweiser's Photography: (1) In terms of photography style and expression, it places greater emphasis on the impact of composition and color contrast; (2) In terms of content, while still focusing on the product and stories between customers and the product, the narrative content is more focused. Product photography emphasizes capturing exhilarating moments such as "bottle opening" and "bubbles surging"; stories mainly revolve around three themes: sharing a bottle of beer, pursuing dreams, and celebrating greatness.

Overall, in the new consumption era, Budweiser's updates to its "design assets" are guided by the following three principles: (1) "Simplify to Amplify": By eliminating unnecessary elements and information, it reinforces "Budweiser quality" and enhances its "recognizability" by reducing unnecessary embellishments; (2) "Intensify to Highlight: By enhancing contrast and increasing color brightness, it boosts the brand's "visual appeal"; (3) "Symmetrize to Extend": By improving the symmetry of visual elements, it makes them easier to extend in practical applications.

This is primarily because, in the new consumption era, market competition has intensified,[11] and the information explosion in the digital age has led to information fatigue among people. [12]Given this, firstly, the simplicity of information has become a key factor in effective memory[13]; secondly, increasing touchpoints with consumers and deeply penetrating their daily lives through diverse means has become a necessary strategy to enhance brand recall.[14]

3.2 Expansion of Budweiser's Brand Assets

From Budweiser's 2021 brand manual, we can understand that: apart from updates, Budweiser has also expanded its most crucial design asset—the logo, to enhance its adaptability across different application scenarios. The specific expansions are as follows (see Figure 3):

Firstly, the logo has been expanded into three versions based on different usage contexts and media: Solid Colorway, Symbol & Wordmark, and Keyline Colorway. Among them, Solid Colorway is primarily used in more formal and official contexts; Symbol & Wordmark is mainly used for dynamic and creative applications; Keyline Colorway is primarily utilized for graphic or printing purposes.

Secondly, to cater to different requirements for logo size and proportion across various devices, the Amp logo and Script Wordmark have each been expanded into three size versions, ensuring that the brand's logo can be presented completely and clearly at any size.

Lastly, the characteristics of the logo have been expanded and developed into a unique and exclusive Budweiser font. This font is practical, highly readable, and comes in two weights, basically covering the primary textual needs of all brand touchpoints. This allows the "logo" characteristics to engage with customers in a broader sense through another form, further amplifying and reinforcing "Budweiser quality".

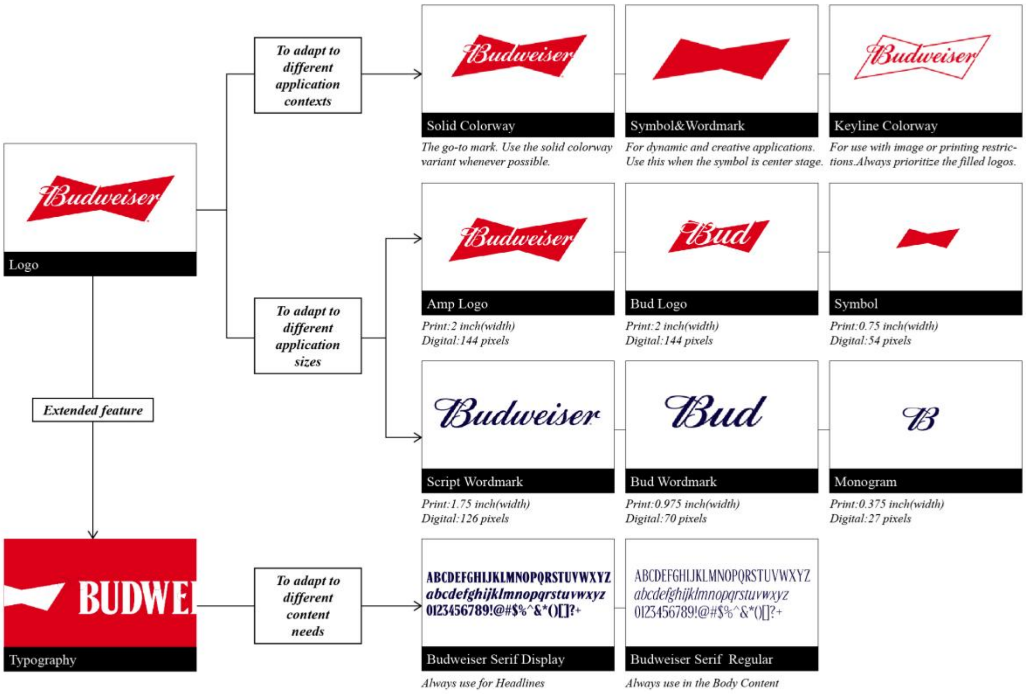


Figure 3. Budweiser's Expansion of Design Asset - Logo in the 2021 Brand Image

This is mainly because different terminals have distinct usage parameters and constraints for design assets.[15] Therefore, it is necessary to provide different versions ahead of time to ensure that the characteristics of design assets can be consistently maintained under various restrictive conditions.

4 INNOVATIVE APPLICATION OF BUDWEISER'S UPDATED BRAND ASSETS

In the latest brand image, Budweiser has also innovated in the application methods and approaches of its updated design assets. This not only allows Budweiser's "design assets" to infiltrate more extensively into various aspects of customers' lives in richer and more diverse forms through practical applications but also achieves a very good balance between its "classic nature" and "sense of fashion".This contributes to enhancing design efficiency, reducing design costs, and ensuring brand image consistency while enriching brand identity in subsequent design processes.

4.1 Innovation of Budweiser on the Application of Its Updated Logo

Before the New Consumption Era, although logos were widely used across various brand touch points, the application methods were relatively rigid and inflexible. In traditional application methods, the form of the logo, as well as its position and proportion within the image, were usually strictly prescribed and could not be altered. However, in the New Consumption Era, the application methods of logos have become open and diverse. They can be used independently in the center of an image, expanded into a series of dynamic graphics with a sense of motion, or even materialized into a tangible product... This allows the logo, which symbolizes the brand's spirit, to infiltrate every corner of customers' lives in a more tension-filled, attractive, and ingenious manner (as shown in Figure 4).

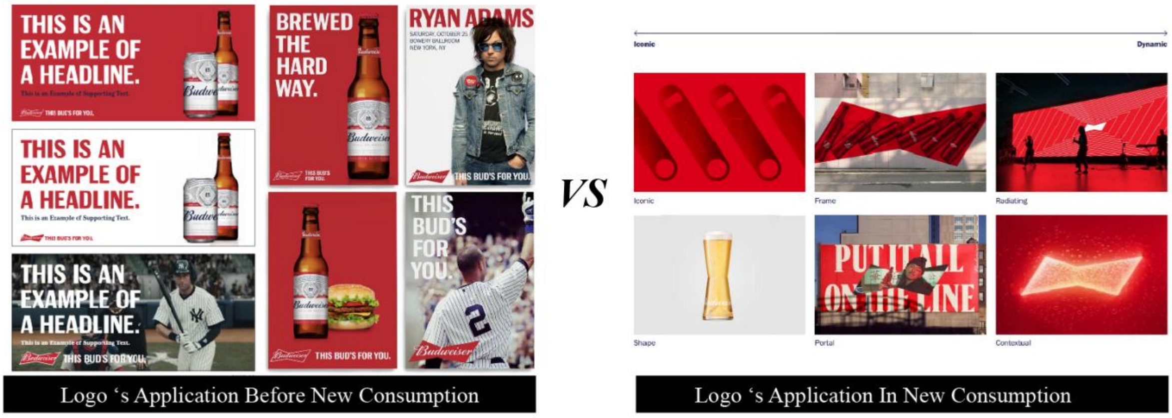


Figure 4. Comparison of Logo Usage Methods Before and After the New Consumption Era

Figure 5 summarizes four innovative ideas for Budweiser's logo application in the New Consumption Era: Direct use of the Symbol/Limit amplification, reduction use; Use of the Symbol as a template framework for content; Expand the pattern/dynamic deduction method based on the semantics of the Symbol; Materialize the symbol. Using these methods to expand the symbol graphics will be more conducive to bringing the brand's design assets into customers' lives and associating the brand with specific themes/content.

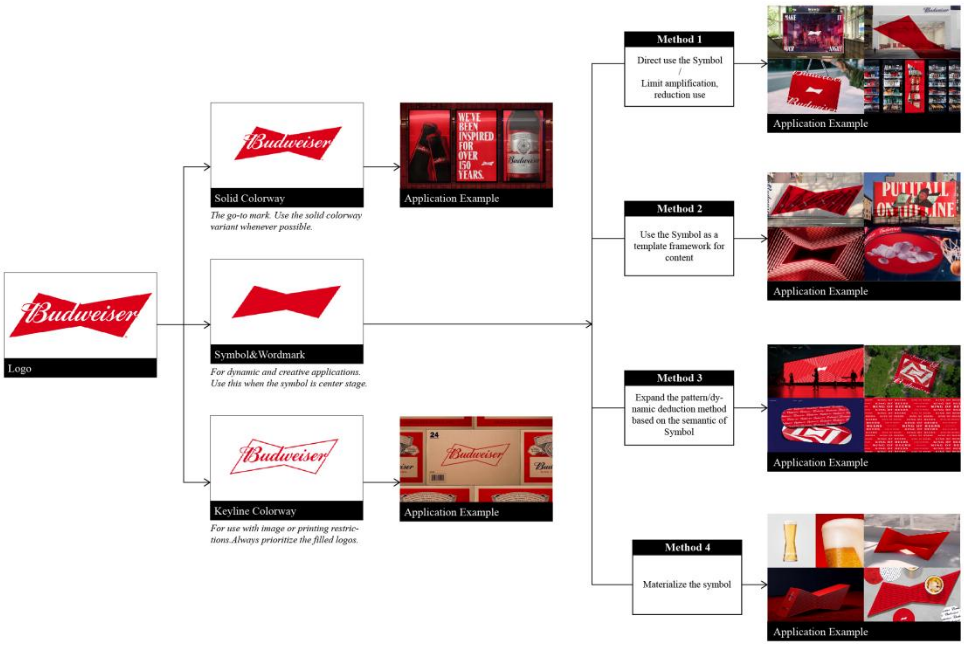


Figure 5. Summary of Innovative Application Methods for Logos in the New Consumption Era

This is primarily because, in the new consumption era, consumer demands are trending towards personalization and diversification. [16]The emergence of various segmented groups has spurred businesses to adopt customized business models. Each type of consumer has their own unique needs, making personalization and customization inevitable. Therefore, brand design assets need to be presented in a more diverse and rich manner to cater to the individual needs of different segmented groups.

4.2 Categorized Application of Budweiser's Updated Brand Assets

As shown in Figure 6, although the "design assets" inherited and updated by Budweiser in the New Consumption Era are overall more concise and modern in visual characteristics, some still have a more historical and classic feel, while others are relatively more modern. Different types of "design assets" have different proportions and application methods in practice: (1) "Design assets" with a classic feel generally do not appear alone but mainly serve as background images or embellishments to enhance the refinement of the image; (2) Elements like brand fonts, which carry both a classic and modern sense, can appear alone or be freely mixed with elements that are either more classic or more modern; (3) "Design assets" like symbols with a very modern feel generally serve as the main content of the image but need to be balanced with "classic" or "neutral" design assets. This ensures that the final visual experience presented by the brand is neither outdated nor dull, nor excessively modern, but instead combines modernity with a certain classic and refined feel.

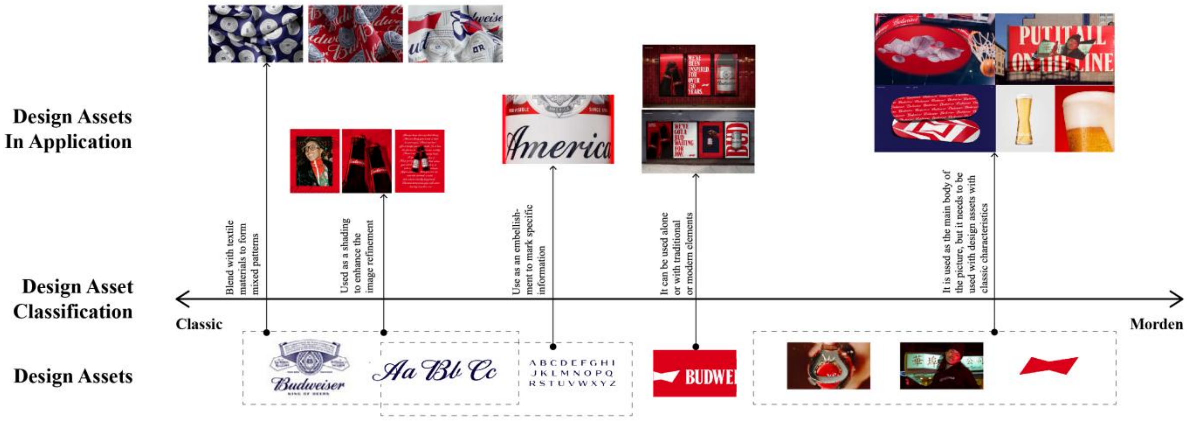


Figure 6. Analysis of Usage Methods and Weighting of Different Design Assets for Budweiser in the New Consumption Era

This is mainly to control the brand's classic nature and modern sense in the process of applying design assets.As a classic brand, Budweiser needs to not only satisfy customers' demand for modern and novel visual experiences in the new consumption era,but also retain its classic nature to some extent in order to strengthen the emotional connection that has been built with consumers over the years. [17]

5 CONCLUSION

Classic brands like Budweiser are currently confronted with the widespread challenge of brand aging in the current developmental landscape. To renew themselves without compromising the continuity of their brand equity, while also exploring new paths and possibilities for brand asset construction, these classic brands can draw upon Budweiser's design management experience and utilize the SOI (Screen, Optimize, Innovate) model for brand design asset management in their brand renewal efforts. The specific methods and processes for doing so are as follows:

(1)S(Screen Design Assets): Firstly, it is necessary to systematically categorize or review the brand's design assets and their inherent semantics and consumer associations, selectively inheriting those design assets that are most frequently used in the brand and most effectively convey the brand's core values, evoking emotional resonance among consumers. Discard those design assets that may obscure, interfere with, or detract from the communication of the brand's core values and the arousal of consumers' emotional connection to the brand.

(2) O(Optimize Design Assets): Secondly, based on current consumer preferences and usage needs, visual adjustments and optimizations are made to the selected design assets that are continued. In the new consumption era, information overload necessitates that design assets be sufficiently refined, prominent, and distinctive to better capture consumers' attention. Additionally, they must be easily replicable and scalable to increase the frequency of information exposure to consumers. Therefore, when updating their brands in this new consumption era, classic brands should adhere to the principles of "simplifying to amplify influence," "enhancing to highlight features," and "symmetrizing to expand applications" in adjusting and optimizing their chosen design assets. Furthermore, considering management efficiency, it is advisable to adaptively extend key design assets, particularly the brand logo, to ensure its adaptability and recognizability across diverse scenarios, thereby enhancing the brand's visual consistency.

(3) I(Innovate the application of design assets): Lastly, based on actual usage needs, a design asset management plan is formulated to enable efficient design development in the future. Given that classic brands have developed extensive business systems and types over time, and considering the factors

mentioned earlier—namely, the information overload in the new consumption era necessitating increased interaction between design assets and consumers, as well as the diversification and personalization of consumer demands requiring design assets to engage with consumers in more varied and diverse forms—it is crucial to approach the application of design assets strategically. This can be achieved by providing a range of creative ideas and templates centered around the brand's core design asset, the logo, for future designs to reference and utilize. By embedding design assets into consumers' daily lives more flexibly and efficiently, we can continue to strengthen the psychological connection between these elements and the brand. At the same time, to protect the classic nature of the brand and avoid giving the impression of being outdated after the update, classic brands need to classify and manage the design assets chosen for continuation. This involves controlling the ratio of classic design assets to modern minimalist design assets in visual presentations to ensure their harmonious coexistence, thereby showcasing the brand's modernity while retaining its classic charm.

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PROCEEDINGS OF ASIA DESIGN AND INNOVATION CONFERENCE
5–6 DECEMBER, 2024, SHANGHAI, CHINA

DESIGN AND PROTOTPYE TEST OF USER EXPERIENCE-CENTERED BIG-BOARD GAME FOR DESIGN EDUCATION

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ABSTRACT
Design is a discipline in which education is balanced between theoretical knowledge and practical skills for real-world application. However, skill-based education focused primarily on practical work may limit the diversity of educational experiences provided. In this paper, we developed game and a produced prototype to offer learners a more varied and engaging design education experience. Following the design, the prototype was created, and two rounds of testing were conducted. The designed Big-board game incorporates both biggame and board game elements, allowing students to physically engage in learning activities, which enhances interest and concentration. The results of this study serve as a valuable example that can be applied in various educational fields.

Keywords: Design Education, User Experience, Big-board game, Prototype Test

1 INTRODUCTION

Design education generally consists of theoretical education, encompassing historical facts researched over a long period as well as recent trends, and practical exercises based on these theories [1,2]. Over time, theory has become increasingly specialized, dividing into various fields such as Western art, Eastern art, art history, color theory, and form, with education delivered in these distinct areas. Following foundational education, design majors are divided into areas such as visual design, product design, environmental design, architecture, and sculpture, each offering specialized practical experiences. The focus on practical education in specific majors is widely adopted in design education due to its advantage in nurturing experts in each field. However, this practice-based education approach has the limitation of providing a narrow range of experiences. To broaden their horizons and gain diverse perspectives during their academic years, students need experiences beyond their major's practical work. Recently, using games or applying gamification in education has emerged as a method to offer new experiences beyond practice-based education [3,4].

Games and gamification are being applied not only in education but also in various fields such as marketing, healthcare, and finance [5]. Games, originally designed for human enjoyment and leisure, are now increasingly being adapted to make activities themselves enjoyable. By making the activity itself fun, they offer new experiences and stimulate users’ interest. In this context, applying games to design education, which traditionally focuses on practice, provides students with diverse experiences and engagement, adding value to the educational process.

This paper aims to develop a game that can be applied to design education, providing students with diverse experiences and increased engagement. To achieve this, a hands-on Big-board game was developed by incorporating game elements into the appreciation of artwork. The game was produced as a prototype and underwent two rounds of user testing with the goal of producing a final product. The game is designed in the form of a board game, making it accessible to anyone and allowing multiple participants to engage simultaneously. The outcomes of this study have significance not only for design education but also as an example that can be applied across various educational fields.

2 RERATED WORKS

2.1 Design Education

Design education can be divided into two categories: traditional design education, which aims to cultivate professional designers required in the industry, and general design education, which focuses on enhancing design competencies as a general academic subject. This study focuses on the latter, with the aim and significance of helping students, regardless of their major, learn design methodologies and thought processes, thereby indirectly or directly acquiring the problem-solving approaches and perspectives of designers. Papanek, a renowned scholar in the field of design, asserted that design activities create new values in every aspect of human life, emphasizing that everyone should learn design [6]. Similarly, Cross viewed design as an innate human ability, regardless of one's major or age [7]. In line with this perspective, regions such as Europe, the United States, and Japan have expanded design education into the realm of general education, designing and implementing diverse educational programs across a wide age range.

In Korea, discussions on design education for various age groups began in the 2000s. Since 2010, as the importance of creativity has grown and societal demand for creativity-related skills has increased, design education aimed at enhancing creativity has begun to emerge. By 2012, university-level design education had already been implemented across the country. These programs, primarily offered as liberal arts courses, have fostered a broad understanding and appreciation for the value of design education as general education [8,9].

Design education in Korea can be categorized into the following types: (1) theoretical learning of abstract concepts related to creativity, creativity models, and design methods; (2) learning about historically recognized creative individuals, their ways of thinking, and life planning; (3) using methods such as creative problem-solving processes, brainstorming, mind mapping, and SCAMPER; (4) creative design projects conducted individually or in teams; and (5) case studies focused on environments that foster creativity, organizational structures, and idea generation [10].

Most current design education programs include courses related to creative problem-solving methods, as well as concepts and methodologies related to design thinking or service design. This educational approach, which emphasizes hands-on learning rather than complex theoretical study, reflects a broader trend toward intuitive, experiential activities in design education. In this context, it is clear that design education is shifting from abstract, conceptual knowledge toward experiential activities that are directly actionable. Following this trend, attempts to integrate new concepts such as multimedia and gamification into design education have been increasing. This study is part of that educational shift, presenting an experience-based Big-board game for experiential design education.

2.2 User Experience and Game

User experience (UX) refers to the comprehensive experience a user perceives and thinks about while interacting with a system, product, or service [11]. This experience is composed of all the sensations a human can feel, and even the same experience can vary depending on the situation. Users tend to seek new things over time, and those providing experiences must continually offer experiences that feel both familiar and novel. Since human sensations are fixed, people naturally seek new environments and situations. From an educational perspective, user experience can translate into learner experience, where monotonous and simplistic educational experiences can hinder the learning process. Therefore, in fields that require practical training rather than theory and application-based majors, it is essential to offer learners diverse experiences.

From this viewpoint, modern design education can be seen as offering very limited experiences. While design education provides more diverse experiences than theory-based and application-centered fields due to its focus on practical training, it still largely relies on text-based theoretical education that blends long-standing theories with the latest trends, along with practical education aimed at applying those theories to real-world work. This creates a narrow range of experiences for learners, which can negatively impact design students who need creativity and the ability to produce novel outcomes. Thus, there is a need to offer experiences that learners have not encountered before by changing the environment or learning methods.

Interest in games has been growing across various fields. Traditionally viewed as an activity for amusement or enjoyment, games are now being used in a range of domains to offer experiences like “fun XX” (e.g., fun learning, fun work). Education is no exception, and games are gaining attention for enabling learners to acquire educational content while enjoying the process. In this study, we applied this concept to design education, aiming to engage learners in a game where they learn through play. This approach provides learners with new experiences and improves their interest and concentration.

3 DESIGN AND DEVELOPMENT OF BIG-BOARD GAME

3.1 Purpose and Scope of Development

The game developed in this study aims to offer a fresh and engaging design education experience by encouraging students to physically move, breaking away from the traditional practice-based education conducted within the classroom. In this process, artworks such as paintings or sculptures located within the school are selected as subjects, allowing students to naturally appreciate these works and broaden their design perspectives.

The development scope of the game is divided based on the activities carried out from the start to the end. The first activity is a biggame where students move around the school campus, appreciating artworks; the second activity is a board game where teams compete against each other through communication and collaboration.

The key element of the biggame is moving around the school campus. The school campus itself is used as the game map to structure the biggame. Students are tasked with finding and appreciating artworks scattered around the campus in a treasure hunt format. Finding these artworks is set as a mission, and students receive rewards for completing the task. These rewards are resources used in the second board game activity, linking the two activities together.

The board game is structured so that the first team to reach the endpoint from the starting point on the game board wins. The game is designed to be simple, encouraging competition between teams, with an emphasis on communication and cooperation within teams. This setup allows students to strategize with their teammates, fostering teamwork and collaboration.

3.2 Game Design

The content of the Big-board game is designed specifically for university freshmen. The game encourages students to find and appreciate artworks on the campus of D university, presenting it as a mission to enhance their interest and focus. As shown in Figure 1, the game is structured into four stages: 1) Preparing for the Game, 2) Playing the Campus Exploration Biggame, 3) Exchanging Game Resource, and 4) Playing the Board game.

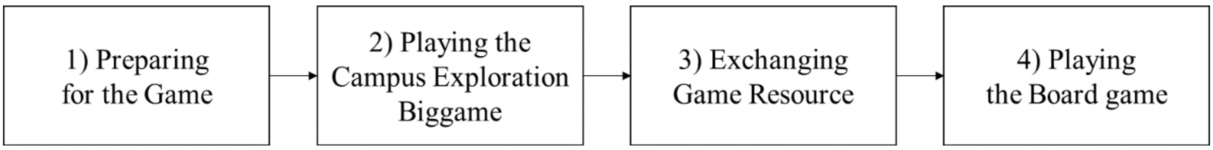

Figure 1. Structure of Big-board game

First, during 1) the preparation stage, the facilitator (instructor) organizes teams, distributes game guides and learner maps, and provides instructions and precautions. In the second stage, 2) the campus exploration biggame, students use the learner maps to explore the campus, appreciate artworks, and take photos of the artworks they find to verify their discoveries through mobile devices. Before moving on to the board game, during the 3) resource exchange stage, each team presents the artworks they found to other teams for verification using the artwork catalog on the back of the game guide and exchanges them for board game resources. Lastly, in the 4) board game stage, teams use their resources to create paths and guide their team characters from the start, through checkpoints, and to the finish line. Throughout this process, teams engage in strategic actions, such as communicating with their teammates to cooperate or hinder other teams.

3.3 Implementation and Results

The Big-board game was designed with a rectangular board, while the game tokens (roadblocks) were created in a hexagonal shape to allow flexible movement in various directions according to the board's size. The roadblocks were categorized based on the types of paths they could traverse, resulting in a total of 14 different shapes. The conceptual design is illustrated in Figure 2.

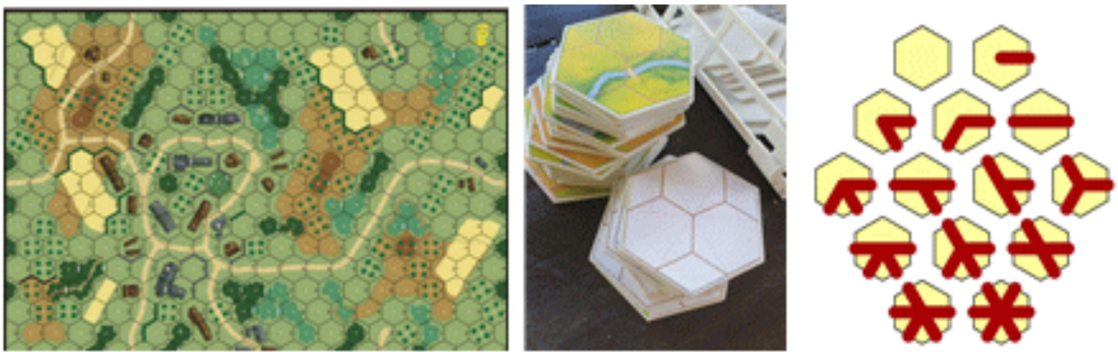

Figure 2. Board game Concept

A prototype was produced based on this concept, with the game board featuring a map of the school campus as the background, as illustrated in the left image of Figure 3. The Big-board game prototype was then tested, with a rule book in document form provided to assist participants during the testing process.

Figure 3. Board Concept and Rule book

The user participation tests, which were conducted twice, were carried out using the prototype, with a one-month interval between each test. After each test, feedback from participants was gathered, and the design of the Big-board game was revised and improved accordingly. Both tests were conducted with a minimum of 12 participants per team, along with the involvement of a moderator and two assistants to ensure smooth progress.

After the first test, feedback included comments that the game board was too dark and that the hexagonal guide lines were difficult to see. Additionally, participants noted that the explanation of the biggame in the rule book was hard to understand and suggested that the content be more clearly categorized. In response to this feedback, the brightness of the board illustration was reduced, and the hexagonal guide lines were made more prominent. The rule book was also revised by categorizing sections with different colors and adding illustrations to aid understanding. These improvements were applied to the prototype and reflected in the second test.

The second test proceeded in the format shown in the left image of Figure 4, with the rule book being provided as shown in the right image of Figure 4. After the second test, another round of feedback was gathered to verify whether the improvements from the first test had been successfully implemented and to identify any new issues.

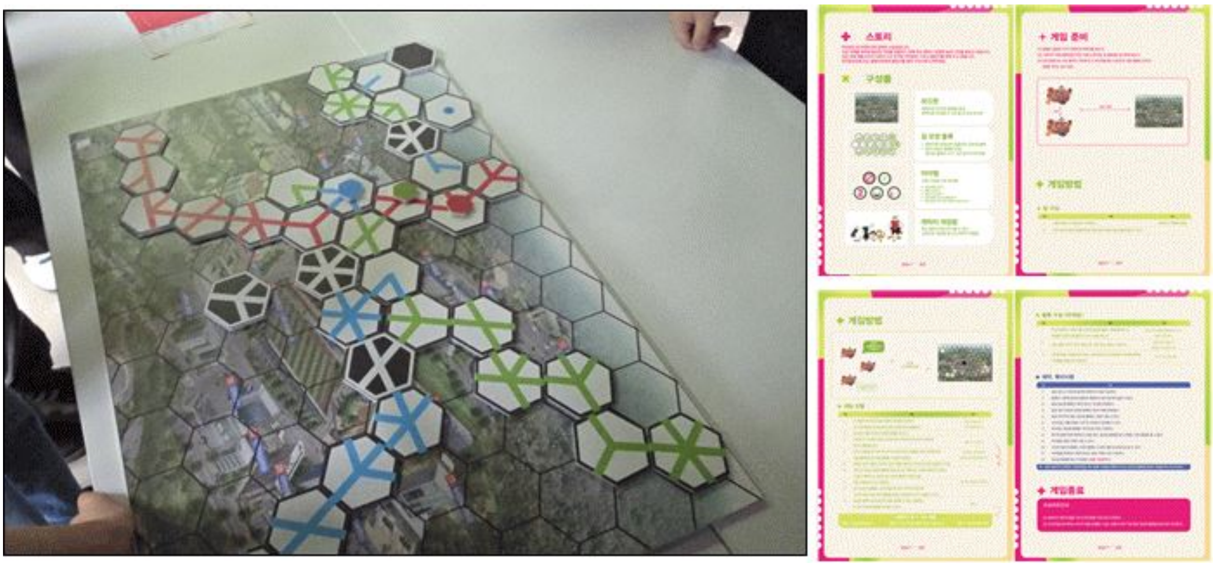

Figure 4. Game Board game Testing and First revised Rule book

The most frequent feedback from the second test was the need to adjust the game board to balance the gameplay. The primary suggestion was to modify the shape of the board, while some participants also mentioned the need to adjust its size. Additionally, a few participants expressed confusion about the relevance of the campus map on the board to the actual gameplay. Another significant point of feedback was that the rulebook was too complex and difficult to understand. Participants suggested the need for a clearer distinction between the roles of the facilitator and the players, and requested that the rules be presented in a more visual format to enhance comprehension. Lastly, some participants found it challenging to locate the artworks required for the missions during the biggame. Most participants struggled to find enough artworks necessary to progress in the board game. They noted that the large size of the campus and the height of some buildings made it difficult to explore everything within the time limit. These comments were carefully considered, and revisions were made to both the design and structure of the biggame and the board game.

First, the game board was changed to a square shape, and the size of the roadblocks was adjusted accordingly. Based on feedback that the previously used campus map was not visually engaging, the final board design was updated with a conceptual design, and the board's size was revised to 70 cm. As the board size changed, the roadblocks were also resized. Secondly, the rule book was revised. In response to feedback that it was difficult to distinguish between the roles of the facilitator (instructor) and the participants (students), separate rule books were created for each role. The new rule books were made more intuitive, with a visual focus on explaining the rules, and excess information was removed, reducing the length from four pages to one. Lastly, a separate learner's map was provided to make it easier to find the artworks during the game, with added hints on the campus map for better usability. These improvements were incorporated into the design schematics and layout, preparing the product for commercialization. The final product has been developed into a physical board game package, much like commercially available board games. The components include a game board, facilitator's guide, participant's guide, game pieces, learner's map, and game currency (roadblocks), all neatly stored in a game box. The product is currently in the process of commercialization, and it is intended to be used as an educational tool in classroom settings. Specifically, the game will be utilized for design education by allowing freshmen to engage in artistic appreciation activities through the game's mechanics.

4 CONCLUSION

This paper aimed to develop and test a game to provide students with new and engaging experiences in design education, which has traditionally been centered on practical skills. The game was designed using elements from the appreciation of various paintings and sculptures located across the campus. The mission involved participants physically moving around the campus to find and appreciate these artworks, with rewards given in the form of in-game currency. This currency was then used to advance in the team-based board game. The biggame element was incorporated through the physical movement

around the campus, while team activities fostered communication and collaboration among members as they devised strategies to compete against other teams.
The designed Big-board game was developed as a prototype and tested twice. The initial tests revealed several areas for improvement, particularly in the game board and rule book, and there was a need to simplify the biggame process. After incorporating these revisions, the process of finalizing the physical product of the Big-board game is currently underway. The structure of this game, as an immersive and interactive experience, enhances concentration and engagement, and the team competition element helps generate interest. The integrated activities, from the biggame to the board game, allow students to form long-lasting memories of the artworks they encountered, providing a distinct experience compared to traditional design education.
This study focuses on the development process of an instructional tool aimed at broadening learners' design perspectives for use in design education. Therefore, separate evaluations of the game's effectiveness and usability are required. Verification experiments involving game experts, design experts, and general participants will be conducted based on the finalized product. Through these verification procedures, this study aims to provide a meaningful example that can be applied not only in design education but also across various educational fields.

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A STUDY ON SERVICE DESIGN OF PHYSICAL THERAPY CENTERS FOR DIGITAL TRANSFORMATION

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ABSTRACT
As healthcare demands grow, public expectations for affordable, high-quality services have increased. Traditional service models rely on manual scheduling and paper records, leading to inefficient information flow, frequent interruptions, long patient waiting times, and subpar experiences. Digital technology offers potential solutions to these challenges. This study focuses on the transformation of service models in Physical Therapy Centers (PTCs) through digital advancements, aiming to enhance scheduling systems, improve operational efficiency, and increase patient satisfaction. Using field research, contextual inquiry, and participatory design, we observed appointment processes and used Value Stream Mapping (VSM) to identify bottlenecks. Additionally, interviews with staff and therapists provided insights into scheduling logic. In a participatory workshop with 8 PTC staff members, we explored strategies for a digital scheduling system, addressing workflow inefficiencies and proposing targeted improvements. The new model integrates real-time information sharing and intelligent task allocation, reducing wait times and optimizing resource usage. Results show that the new model addresses information flow issues and identifies process improvements from a lean perspective, achieving enhanced outcomes for patients, staff, and departments while avoiding extra costs during digital transformation.

Keywords: Digital transformation, Physical Therapy Center, Service Design, Lean Management, Digital Technology

1 INTRODUCTION

Physical Therapy Centers (PTCs) are vital in the healthcare system, with their service quality directly influencing patient recovery and experience. Traditional service models rely on manual scheduling and paper records, leading to inefficient information flow, longer patient wait times, and suboptimal treatment experiences. Digital transformation offers new opportunities for optimizing service models and improving efficiency in response to these challenges.

Although digital service models have become more prevalent in healthcare, tensions persist between patient needs and service providers' maintenance requirements in physical therapy. Balancing patient experience with service management needs has emerged as a critical research focus. Recent studies explore the role of digital technologies in enhancing physical therapy, such as using the Internet of Things (IoT) for data collection [1] and applying smart algorithms for scheduling [2]Additionally, machine learning has been used to predict patient outcomes [3, 4]. These studies underscore the potential of digital technology to improve efficiency and patient experiences, but they also highlight the need for innovative service models.

However, gaps remain in integrating lean management with digital tools. Most studies emphasize technical advancements but often overlook the coordination between patient experience and service optimization [2, 5, 6]. Additionally, some focus on specific digital tools without a holistic approach [1, 7, 8]. Many prioritize efficiency or patient experience improvements in isolated stages rather than balancing patient needs with service provider requirements during digital transformation.

To address these gaps, future research could analyze bottlenecks in traditional scheduling models, integrate lean management with digital technologies for overall process optimization, and explore the relationship between stakeholder satisfaction and digital transformation outcomes. Some studies have begun addressing these aspects, such as examining digital lean's role in reducing waste and enhancing efficiency [9]and using Value Stream Mapping (VSM) in lean healthcare [10]. However, these efforts lack depth in their application to PTCs and in designing models that balance patient experience with resource optimization.

This study aims to design a lean and digitally transformed service model for PTCs to enhance patient experience, streamline service management, and support the digitalization of PTCs. The research questions are: 1. How can lean management principles be integrated with digital tools to optimize PTC service processes? 2. How can a digital scheduling system adapt dynamically to patient needs and resource allocation? 3. How can the new service model balance the satisfaction of multiple stakeholders? By addressing these questions, this research contributes a novel framework that combines lean management and digital service models specifically for PTCs. This study not only seeks to improve the efficiency of PTC operations and enhance patient satisfaction but also aims to offer insights and a replicable model for other healthcare institutions pursuing digital transformation.

2 LITERATURE REVIEW

Assigning suitable doctors based on patient conditions is often inefficient and prone to errors [11]. In traditional scheduling and assignment models, gaps in service processes extend patient wait times, increase anxiety, and may delay treatment, leading to higher healthcare costs. While electronic medical records facilitate outpatient assignment communication, administrative staff and medical professionals often struggle with effective communication, resulting in delays in care despite technological support[12]. This has led many researchers to explore digital solutions for scheduling and assignment services.

Different studies propose various approaches to determining the logic of assignment systems. Keely and Liddy [13] emphasize the importance of specialists in designing eConsults and eReferrals systems, focusing on standards for specialist recruitment and maintaining service quality. Todd, Richards [14] analyze the information on referral forms and compare it with factors that influence assignment decisions, using similarity scores to understand which factors affect the judgment of physicians or administrative staff, thus providing a basis for assignment system design.

These studies suggest that digital systems can significantly improve scheduling efficiency in healthcare processes, yet many remain in the conceptual phase or use simulations for validation, with few tracking real-world system performance.

Lean Thinking originated from the Toyota Production System (TPS), with its core idea being to maximize value by eliminating waste, optimizing processes, and improving efficiency. In the late 1990s, researchers began exploring the application of lean in non-manufacturing sectors, particularly in the service industry[15]. By reducing redundant steps, shortening service time, and optimizing resource allocation, the application of lean in the service industry has achieved initial success. Gunawan, Matondang [16] addresses high logistics costs due to lengthy port service times and proposes lean technology as a solution. Using VSM at BICT port, it identified reducible activities like administration and waiting. Optimization reduced non-value-added time from 2,370 to 878 seconds, increased value-added activities from 27% to 50%, and cut import waiting time from 72 hours to 24 hours. Morales-Contreras, Suárez-Barraza [17]explores lean service application in the fast food industry, focusing on identifying Muda (waste) from the customer's perspective. An exploratory case study of three multinational companies in Madrid revealed seven types of Muda: defects, movements, process, inventory, overproduction, transport, and delay. The study provides value for practitioners by offering insights on waste identification, customer perception, and a guideline for future assessments, contributing to improving service efficiency and quality in the fast food sector.

With the successful application of Lean Thinking in the service industry, it has gradually transitioned into the healthcare sector, particularly in environments such as hospitals and clinics. When applied to healthcare, Lean can enhance system efficiency; however, the complexity and unpredictability of healthcare services require adaptive adjustments. Ankrum, Neogi [18] used VSM in a pediatric teaching hospital to reduce turnover time in isolation rooms, improving processes. As digital manufacturing and future factories emerge, Lean must also evolve, as Hamidi, Mahendran [19] found that digitalizing visual management tools and integrating them with hospital information systems (HIS) can reduce data redundancy and loss, enhancing data availability.

These studies highlight the global drive to deliver higher quality services at lower costs and shorter times, with digitalization offering great potential in improving quality, flexibility, and capacity. Most research focuses on strategic decisions, with limited studies on real-world implementations, especially considering environmental factors that can complicate mathematical models. Additionally, studies often focus on operating rooms and emergency departments, with less attention to appointment-based systems for PTCs. Furthermore, many outpatient clinics, especially specialized care clinics, handle diverse patient needs, yet optimization studies typically assume homogeneous treatment plans for all patients. This study will address these gaps by focusing on appointment scheduling in PTCs, considering different patient types and therapists, and testing the system in real-world conditions to identify and continuously improve based on environmental impacts.

3 METHODOLOGY

This study employs a lean problem-solving framework, divided into three phases: understanding the current situation, analyzing task assignment and therapy logic, and developing strategies through participatory design (see Figure 1).

1. **Understanding the Current Situation**: The initial phase involved observing appointment and treatment processes for both new and existing patients. Using VSM, we identified bottlenecks, such as information stagnation, that hinder operational efficiency. By mapping the flow of information and patient activities, VSM provided a comprehensive overview of the processes, revealing inefficiencies like redundant steps and extended waiting times. These findings were not only data-driven but also grounded in lean principles that focus on maximizing value and reducing waste.
2. **Analyzing Task Assignment and Therapy Logic**: This phase included interviews with front-desk staff to understand their approach to task assignment and with therapists to explore their logic for assigning therapies based on patient symptoms.
3. **Participatory Design**: A workshop brought together stakeholders to discuss root causes, challenges faced by staff, process limitations, and potential digital scheduling solutions through a lean perspective.

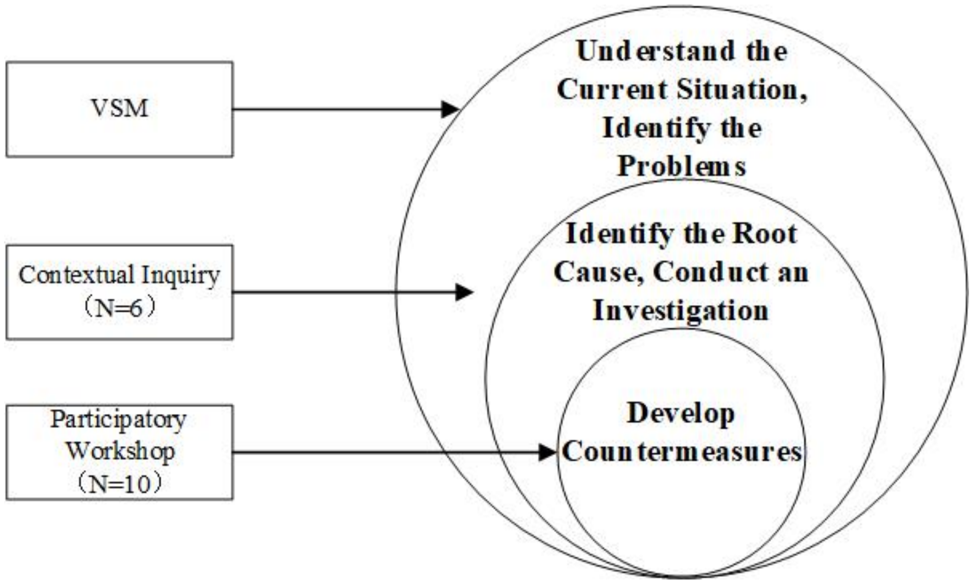

Figure 1. Research Framework Diagram

3.1 Service Value Stream Mapping

VSM analysis was used to visualize information flow, identify interruptions, and understand their impact on front-desk services, highlighting mismatches between service processes and patient needs. VSM is more than a descriptive tool; it implements core lean principles such as waste elimination, process simplification, and the enhancement of value-adding activities. In this study, its application included:

1. **Visualization of Information and Material Flows:** By mapping out the entire service process—patient scheduling, evaluation, and follow-up treatments—VSM highlighted how information bottlenecks (e.g., delays in therapist assignment) disrupted the service flow. The tool's structured nature minimized subjective bias by focusing on objective process parameters, such as time taken at each stage and resource utilization.

2. **Objective Identification of Inefficiencies:** Unlike traditional observations, VSM integrates quantitative data (e.g., process times, waiting periods) with qualitative insights from contextual inquiries. This dual-layered approach ensures that inefficiencies, such as over-allocation of patient slots or misaligned scheduling logic, are identified based on evidence rather than individual perception or intuition.
3. **Actionable Insights for Lean Improvement:** VSM outcomes were instrumental in setting the stage for participatory workshops. By pinpointing breakpoints like redundant administrative steps or unclear treatment assignments, VSM provided a clear, shared framework for discussing redesign opportunities. These findings were then validated by stakeholders, reducing the reliance on individual analytical skills.
4. **Alignment with Lean Principles:** VSM embodies the lean focus on continuous improvement. In this study, it was not used in isolation but as part of an iterative process where identified inefficiencies informed actionable strategies, such as the development of a rule-based digital scheduling system. This iterative refinement ensures that the solutions remain adaptable to real-world complexities.

By combining VSM with contextual inquiries and participatory workshops, this study demonstrated that the identification of inefficiencies is neither entirely subjective nor overly reliant on individual analytical capabilities. Instead, it is a structured, collaborative process grounded in lean principles, leveraging tools and stakeholder inputs to generate replicable and practical solutions.

3.2 Contextual Inquiry

Interviews clarified the root causes of information flow issues. Interviews with front-desk staff focused on patient assignment logic, while sessions with five therapists examined factors like fee structure, therapy types, required space, and work time allocation.

(1) Participants

This study plans to interview administrative staff, physical therapists, and patients at the PTC.

- **Administrative staff and physical therapists**: Given the current staff at the center—1 administrative staff member and 5 full-time therapists—recruitment is limited, so interviews will be conducted with all staff.
- **Patients**: The study will use purposive sampling to select patients from the center. It is expected to recruit 30 participants. All patients will be informed about the research purpose before deciding whether to participate, and the study will proceed only after obtaining "informed consent."

  Criteria for case selection include: (a) Having at least two prior appointment experiences. (b) No communication barriers. (c) Willingness to cooperate with observation and interviews. (d) Age between 20-65 years.

  The selection criteria aim to ensure that patients have enough appointment experience to fully understand the current scheduling system (first appointment confirming the therapist, second appointment obtaining scheduling information for follow-up). The age range is set to ensure minimal communication barriers, facilitating smooth interview progress.

Exclusion criteria include: (1) Severe cognitive impairment. (2) Foreign nationals.

(2) Methodology and Process Design

- **Interviewing patients about their treatment experience**: This phase will involve asking patients about their satisfaction with the current appointment process, frequency, and waiting time, and understanding the challenges they face during scheduling.
- **Interviewing administrative staff about scheduling logic**: This phase will first ask service providers about the resources, processes, and methods (people, machines, materials, methods, environment) involved in service provision, as well as the constraints in back-end execution. Observations will then be conducted to understand potential difficulties patients face during the appointment process.
- **Interviewing therapists about patient work-hour allocation logic**: This phase will ask therapists about the decision-making process when allocating work time to patients, including items such as patient billing, treatment items, required equipment space, treatment frequency, and required work time. Challenges encountered during the decision-making process will also be explored.

3.3 Participatory Workshop

Two workshops with a total of 10 participants, including physical therapists, administrative staff, a director, and lean experts, were conducted to generate service concepts. Different participants in each workshop helped ensure diverse input and reliability of the design results.

The goal of this ideation phase is to balance the needs of both providers and customers and discuss areas for redesign and how to design them. The principles for service design in this phase are as follows:

1. **Identify Breakpoints**: From the patient's service experience value stream, identify any stagnation in information or patient flow, and mark these as breakpoints.
2. **Balance Countermeasures**: Discuss the reasons for patient breakpoints and, through discussion and innovation, explore how to allocate different service resources to increase (or create) important value.
3. **Eliminate Waste**: Identify unnecessary resource inputs and eliminate them to reduce costs, balancing the cost of patient experience with minimal resources.
4. **Continuous Improvement**: Identify the next imbalance in patient satisfaction and importance, mark it as a breakpoint, and continue improving and innovating to meet maximum customer demand with minimal resources.

4 RESULTS

4.1 Value Stream Mapping: Identifying Bottlenecks and Clarifying Issues

The PTC primarily serves orthopedic patients, particularly those with shoulder conditions. The VSM (see Figure 2) highlights three key processes involved in patient treatment:

- **Scheduling the First Evaluation:** Patients schedule their initial appointment after receiving a referral. Administrative staff only enter the patient's name and assign a therapist.
- **Conducting the First Evaluation:** On the scheduled day, patients arrive at the center for assessment. The therapist evaluates the patient's pain, shoulder range of motion, muscle strength, and daily living capabilities. After the assessment, patients check out at the front desk, where follow-up treatments (2-6 sessions) are scheduled.

  Existing Patients Scheduling New Treatments: Existing patients typically schedule their next therapy sessions at the end of their current treatment. When patients arrive, they check in at the front desk and usually wait in the waiting area until the therapist completes the previous patient's treatment.

The analysis reveals two significant bottlenecks:

- **Bottleneck 1:** Patients must first schedule a therapist evaluation before actual treatment, resulting in unnecessary waiting times. After scheduling, patients often leave and return later for their evaluation.
- **Bottleneck 2:** Long wait times for patients, both during initial evaluations and follow-up treatments, suggest inefficiencies in the current scheduling system.

4.2 Contextual Inquiry: Investigating Issues

Interviews conducted with administrative staff and therapists revealed important insights regarding the identified bottlenecks:

Bottleneck 1 arises from administrative staff lacking the professional knowledge required to diagnose patients and assign appropriate therapies. This gap leads to delays, as patients are required to go through multiple scheduling steps before receiving treatment.

Bottleneck 2 is caused by the administrative staff's misunderstanding of treatment durations, leading to inefficient patient allocations. Patients are often scheduled without consideration of the time required for their specific therapies, resulting in longer wait times.

To address these issues, the research aims to:

1. **Establish expert logic for assigning therapists based on specific patient needs.**
2. **Clarify the decision-making processes therapists utilize when assigning therapies, taking into account treatment duration and patient conditions.**

These steps are intended to streamline the scheduling process, enhance operational efficiency, and improve patient satisfaction.

Interview with Front-Desk Administrative Staff: Front-desk staff schedule only one evaluation treatment for new patients and assign them to various therapists during the initial visit, as patients prefer

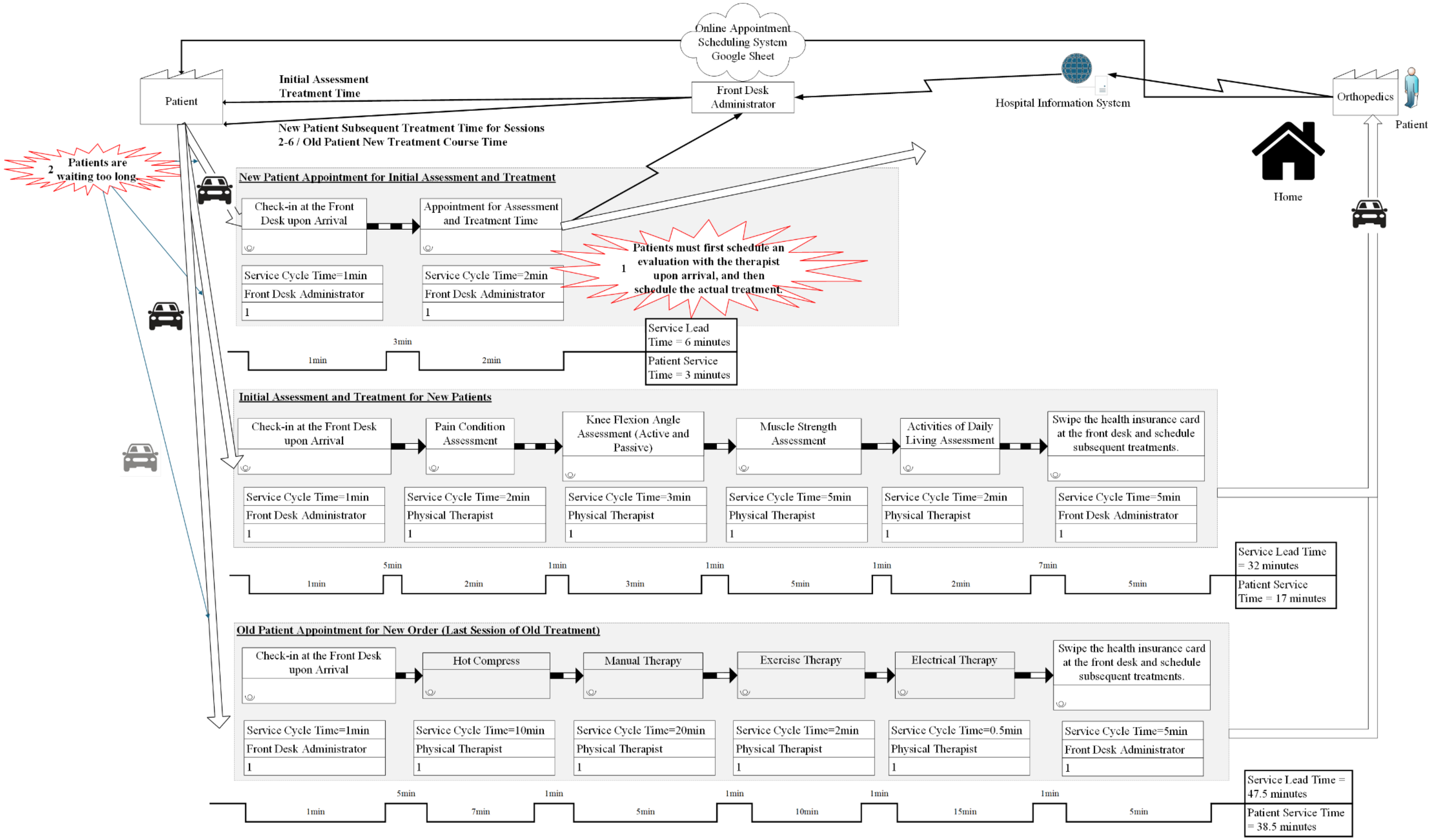

Figure 2. Value Stream of Patient Symptom Assessment and Treatment in PTCs

to continue seeing the same therapist. Staff assess patients based on the disease type listed on the referral form. For example, orthopedic patients are treated by Therapist A, while patients with urinary incontinence are assigned based on gender. If multiple therapists are available, staff coordinate appointment times and select the earliest available therapist or randomly choose one if necessary (see Figure 3 for the logic flow).

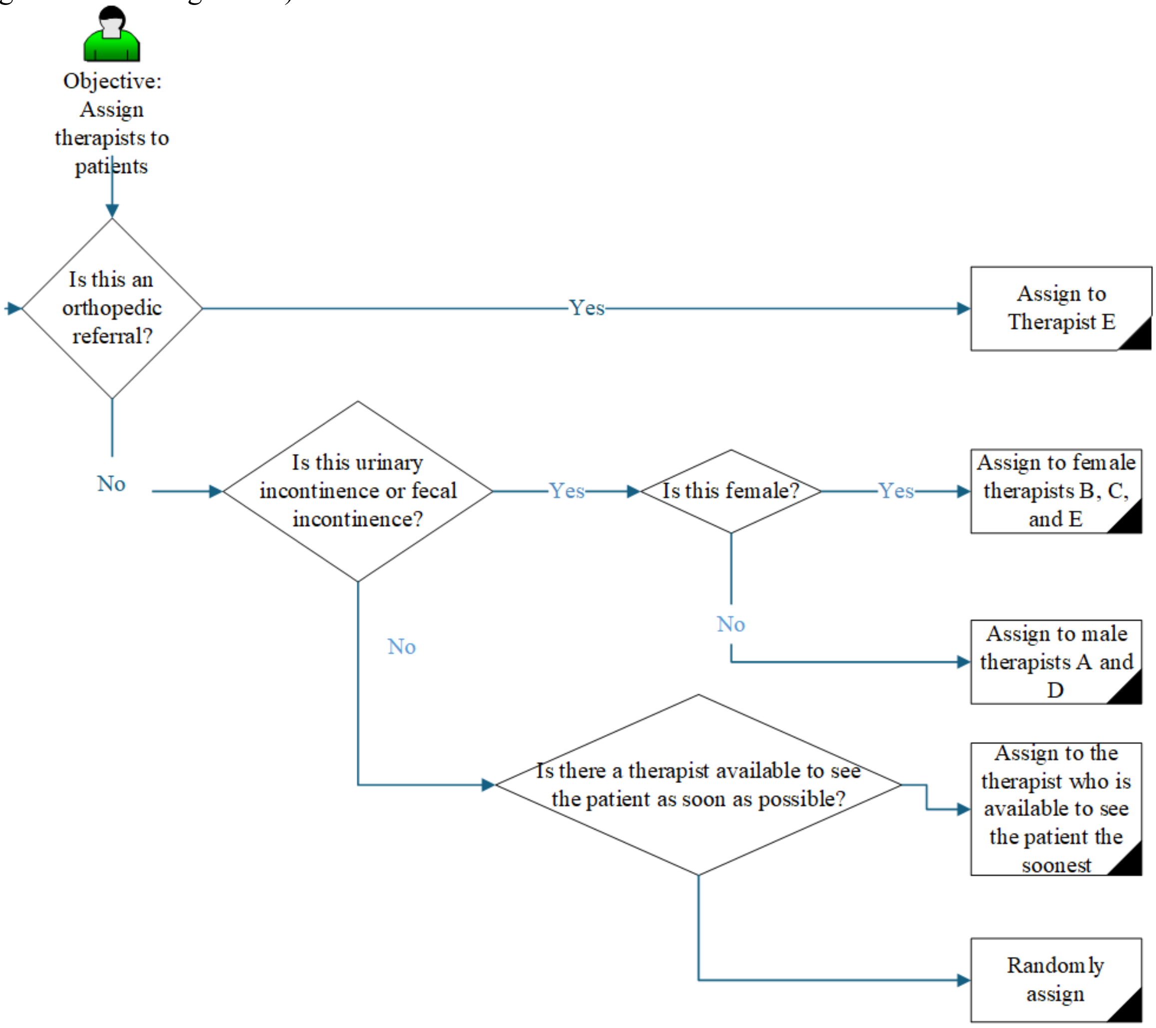

Figure 3. Logic flow for front-desk administrative staff in therapist assignment

4.3 Conducting Participatory Workshops to Develop Strategies

Participatory design workshops were organized to address root causes, staff methods, existing processes, and equipment limitations. The aim was to explore design strategies for a digital scheduling system (simple rule-based digitalization). The results are summarized in Table 1.

Table 1. Correspondence between bottlenecks, objectives, root causes, and strategies

Bottleneck	Objective	Root Cause	Strategy
1. Patients must first schedule a therapist's evaluation before actual treatment.	1. Patients will be assigned therapy automatically by the system after answering basic questions upon arrival.	Administrative staff lack professional knowledge for patient diagnosis and therapy assignment.	Develop a simple rule-based digital scheduling system that automatically assigns therapists and therapies based on inputted information.
2. Long waiting days for patients.	2. Reduce patient waiting days to a reasonable range and minimize complaints.	Administrative staff do not understand the treatment duration of therapists, leading to broad patient allocation.	Similar to above, in addition, the system can record and display patient waiting days (eKanban)

			and establish thresholds for tracking management.

5 DISCUSSION

This study explores the service design of PTCs for digital transformation by integrating lean management principles with a digital scheduling system to enhance patient satisfaction and operational efficiency. The findings indicate that lean management can effectively address inefficiencies in current service models, minimizing waste, including unnecessary waiting times and repetitive tasks, and thereby enhancing overall service efficiency. By doing so, this research provides PTCs with a more effective, streamlined process design, which ultimately improves patient experience and operational performance.

The study diverges from previous research in several key aspects. While prior studies focused primarily on applying lean management in manufacturing, this research centers on the healthcare sector and the unique, dynamic environment of PTCs. In this context, patient needs are complex and variable, adding layers of complexity to service processes not typically encountered in manufacturing settings. This research underscores the critical role of digital tools in implementing lean principles, particularly in optimizing patient scheduling and supporting real-time information transfer. Unlike prior studies, which highlighted lean management's strength in optimizing fixed processes[20, 21], the current findings suggest that adaptability is even more crucial in healthcare environments, where system flexibility is necessary to meet personalized patient demands.

Despite these differences, this study corroborates certain aspects of existing literature. For instance, the data support the notion that reducing waiting times through lean management significantly enhances both patient satisfaction and resource utilization, aligning with findings by Adeodu, Kanakana-Katumba [21]. Furthermore, the role of digital tools in facilitating lean management processes, as demonstrated here, is consistent with findings by Dossou, Torregrossa [20], providing new evidence for digital lean management in service sectors beyond manufacturing.

This study's methodological approach is distinctive. By integrating lean and digital solutions specifically within physical therapy, and by prioritizing a patient-centered perspective while considering service provider constraints, the research quickly identified process bottlenecks. This approach has been seldom addressed in previous research and establishes a new methodological framework for future studies. Moreover, the personalized scheduling model proposed here shows strong practical applicability, particularly for managing both new and returning patients. This model not only boosts service efficiency in PTCs but also provides valuable insights for potential applications in other healthcare contexts.

This research explored three main questions.

1. **RQ1: How can lean management principles be integrated with digital tools to optimize PTC service processes?** The findings demonstrate that lean management can significantly improve PTC service processes by identifying and mitigating inefficiencies within the existing model. Through VSM, key bottlenecks—such as extended waiting times and redundant tasks—were identified. The integration of a digital scheduling system introduced real-time tracking and dynamic task allocation, which reduced unnecessary steps and improved information flow. This created a more responsive, efficient service model that highlights the potential of lean management principles when applied to healthcare service design.
2. **RQ2: How can a digital scheduling system adapt dynamically to patient needs and resource allocation?** The results show that a rule-based digital scheduling system can dynamically adjust to varying patient needs and resource constraints. This system uses patient data to assign therapists and schedule treatments in real-time, effectively reducing waiting times through optimized resource allocation. Furthermore, the system monitors patient flow and wait times, allowing administrators to make timely schedule adjustments as needed. This adaptability enables personalized scheduling that meets specific treatment requirements and fluctuating demand, ensuring resources are utilized efficiently.
3. **RQ3: How can the new service model balance the satisfaction of multiple stakeholders?** This study finds that a service model integrating automated scheduling and real-time data can enhance satisfaction for both patients and staff. By involving patients and frontline staff in participatory design workshops, the model achieved a balance between operational efficiency and positive user experience. Patients benefit from reduced waiting times, while staff experience a reduced administrative load and greater job satisfaction due to streamlined operations. These

findings highlight the model's ability to meet the varied needs of stakeholders, ensuring effective resource management in PTCs.

In conclusion, the study underscores the value of lean management principles in PTC service design, highlighting the importance of digital tools in implementing flexible and responsive processes. By comparing with prior studies, this research reveals gaps in existing literature and offers new perspectives and methodologies for future studies. The findings regarding service process optimization, enhanced patient satisfaction, and effective digital tool utilization provide a strong foundation for continued exploration of lean management in healthcare service settings.

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EVALUATION OF SUPERIMPOSING SELF-SHADOW ON DILATED PUPIL IN TWINKLING EYES INTERFACE

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ABSTRACT
It is known that human affects and emotions are reflected in own eyes. Especially, the eyes with strong affects and emotions look like twinkling. Humans are fascinated and attracted by such twinkling eyes. Therefore, it is expected to examine the elements that fascinate humans and develop social robots for attracting humans by reproducing twinkling eyes using engineering approach. We focused on the reflection of the surface in the eyeball and developed a twinkling eyes interface by superimposing self-shadow on dilated pupils. This interface can express the pupil response and the shade of self-shadow depending on the distance. In this study, an evaluation experiment that combines self-shadow with dilated pupil was conducted. The effectiveness of the developed interface was demonstrated by sensory evaluations.

Keywords: Nonverbal Communication, Human-Robot Interaction, Human Interface, Self-Shadow, Attractiveness

1 INTRODUCTION

As the saying goes, "The eyes are the windows to the soul", human affects and emotions are reflected in their eyes [1]. People can guess affects and emotions from the impression of human eyes. For example, the metaphor "Eyes are laughing" means that positive emotions can be read from the eyes. The metaphor "Eyes are twinkling" means that the eyes with strong affects and emotions look like twinkling [2]. Humans are attracted to such twinkling eyes [3]. Therefore, by reproducing twinkling eyes using engineering approach, we can understand the elements that attract human and develop attractive robots. We focused on the pupil response during communication and developed a pupil response system that expresses pupil dilation. The effectiveness of the system was demonstrated [4]. In addition, we proposed a method called "twinkling eyes" that focuses on the reflections on the surface of the eyeball and developed an interface that applies the method to the developed pupil response system [5]. This interface can express pupil response and the shade of self-shadow based on the distance to the user.

In this study, we conducted an experiment to evaluate using the twinkling eyes interface and demonstrated that the superimposition the self-shadow on the dilated pupil increases interest and attractiveness towards the interface.

2 TWINKLING EYES INTERFACE

2.1 Twinkling eyes method

This study focuses on the "specular reflection" on the surface of eyeball, which is reflected on the cornea in optical elements. It is known that texture and glossiness can be perceived as the reflections [6]. By expressing the surrounding reflections on the eyeball, it is expected to give an impression that a high specular reflection is generated on the corneal surface. In particular, human-shadows enhance the presence in the physical space and increase self-reference by linking with own behavior [7]. Therefore, the "twinkling eyes" that superimposes human shadows as reflections in the pupil was proposed. Fig.1

shows the core concept of the twinkling eyes method. In addition to the twinkling eyes, it is expected that dilating the pupil can strongly attract human.

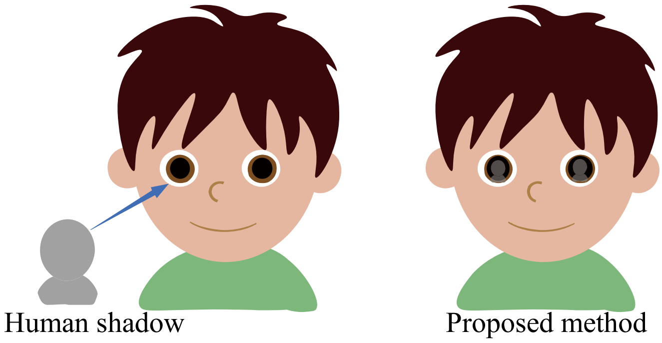

Figure 1. Concept of the twinkling eyes method

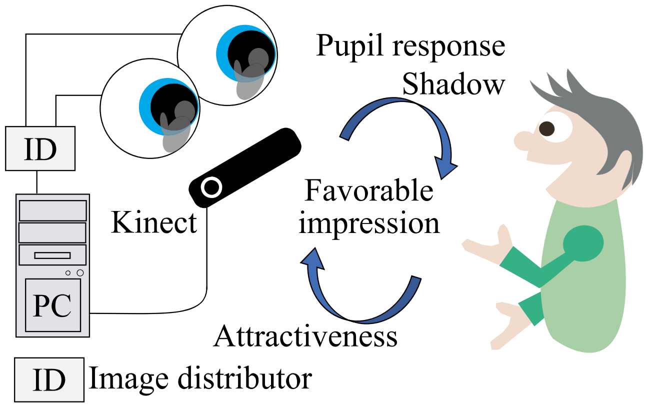

Figure 2. Setup of the twinkling eyes interface

2.2 Developed Interface

An interface that applies the twinkling eyes method to the pupil response system was developed. Fig.2 shows the setup of the developed twinkling eyes interface. The twinkling eyes interface consists of a desktop PC, a motion tracking device (Kinect V2), hemispherical displays, and a video splitter. The iris and pupil, which are components of the eyeball, are drawn as images using OpenCV. A black circle represented as the pupil, and a blue circle is represented as the iris. By changing the size of the black circle, the pupil dilation and contraction are generated. The represented rate of the images is 30 fps.

The flow-chart for generating self-shadows to be superimposed on the pupil is shown in Fig.3. First, the Kinect SDK is used for measuring distance between the user's position and the interface position. Next, the extracted self-contour of the user is converted to gray-scale as a self-shadow. Here, the saliency of the self-shadow could be enhanced by expressing only the self-shadow. Then, by superimposing the user's shadow on the iris and pupil images, it creates a sensation as if the user exists here (Fig.4). The shade and size of the self-shadow can be changed according to the distance between the user's position and the interface position. The position of the user was tracked, and eye contact was realized with each other. The user can easily grasp the own position in physical space between the self-shadow and the interface, and interact while referring to the self-reflected in the eyeball.

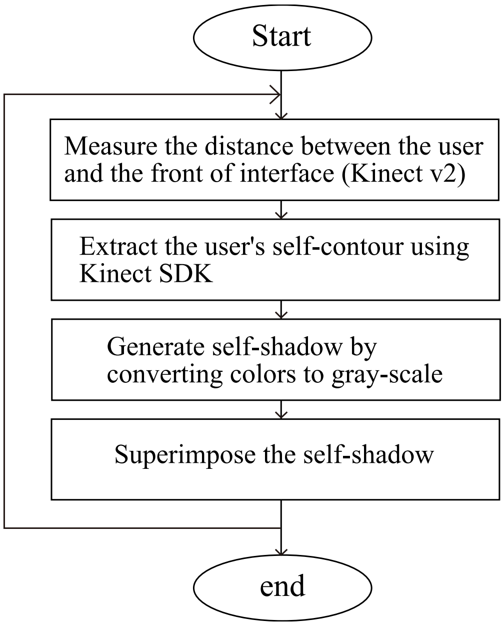

Figure 3. Flow-chart of the generated self-shadow

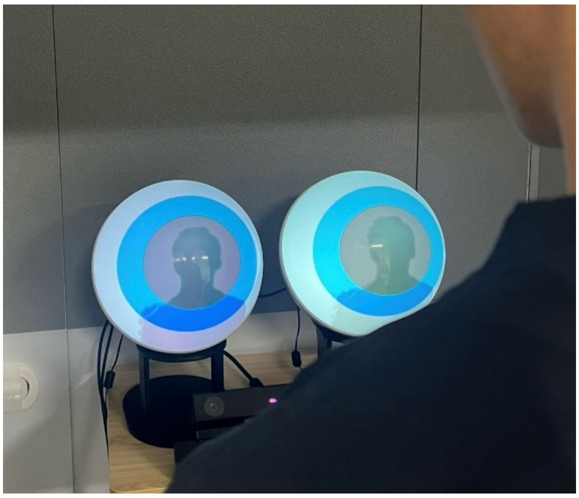

Figure 4. Example scene of using the developed twinkling eyes interface

3 EXPERIMENT

3.1 Experimental method

In this experiment, based on the results of our previous experiment [8], the distance between the participants and the twinkling eyes interface was set to 3m, the shade of shadow was set to 40%. The comparison modes were as follows: (A) Dilation: the pupil size was enlarged to 1.5 times the normal size of pupil diameter, and the shadow was not displayed, (B) Self-shadow: the pupil size was normal, and the shadow was displayed, and (C) Proposal: the pupil size was enlarged to 1.5 times the normal size, and the shadow was displayed.
This experiment was consisting of a paired comparison and a seven-point evaluation for the three modes. In the experiment, the participants were firstly instructed to stand in front the developed interface. Then, they were instructed to perform a paired comparison of modes. In the paired comparison experiment, two modes were randomly selected from three modes, and each mode was presented for ten seconds. They selected their preferred mode based on attractiveness. Finally, after experiencing each mode for ten seconds, they performed an impression evaluation using seven-point scale (nature at four). In this evaluation, following eight items were adopted: "(1) Did you feel like the Robot was gazing you? (Robot gaze)", "(2) Did you feel attracted to the Interface? (Attraction)", "(3) Did you feel like the Interface was interested in you? (Interest in oneself)", "(4) Did you make eye contact with the Interface? (Eye contact)", "(5) Did you feel trust towards the Interface? (Trust from robot)", "(6) Did the Interface's eyes seem to twinkle? (Twinkling)", "(7) Did you feel a sense of fascination towards the Interface? (Fascination)", and "(8) Did you want to keep looking at the Interface? (Looking more)". The presented order of the modes was counterbalanced to consider order effects. The experimental participants were 24 males and females aged 20 to 24.

3.2 Experimental results

The result of the paired comparison is shown in Table 1. In the Table, the number of mode (A)'s winner is twelve to mode (B), and the number of total winners is twenty-two. Fig.5 shows the calculated results of the evaluation provided in Table 1 based on the Bradley–Terry model given in Eq. (1) and (2) [9].

$$P_{ij} = \frac{\pi_i}{\pi_i + \pi_j} \quad (1)$$

$$\sum_i \pi_i = const\,.(= 100) \quad (2)$$

π_i: *Intensity of* i, P_{ij}: *Probability of judgement that* i *is better than* j

Table 1. Result of paired comparison

	(A)	(B)	(C)	Total
(A)		12	10	22
(B)	12		6	18
(C)	14	18		32

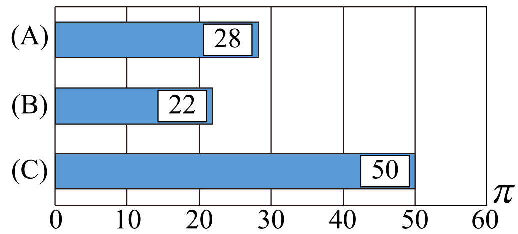

Figure 5. Comparison of π based on the Bradley-Terry model

The consistency of the matching of the modes was confirmed by performing a test of goodness of fit (x^2 (1,0.05) = 3.84 > x_0^2 = 1.04) and likelihood ratio test (x^2 (1,0.05) = 3.84 > x_0^2 = 1.05). The mode (C) was evaluated the most affirmatively, with the mode (A) and the mode (B) following in that order.

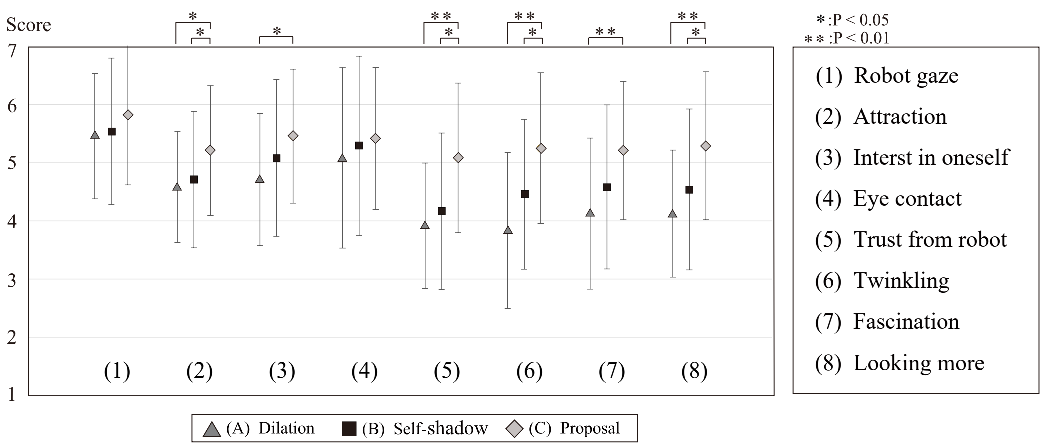

Figure 6. Seven-point evaluation

The questionnaire results are shown in Fig.6. In accordance with the results of the Friedman signed-rank test and the Wilcoxon signed rank test, "(5) Trust from robot," "(6) Twinkling," "(7) Fascination," and "(8) Looking more" were at the significant difference of 1%, "(2) Attraction," and "(3) Interest in oneself" were at 5% between modes (C) and (A). In addition, "(2) Attraction," "(5) Trust from robot," "(6) Twinkling", and "(8) Looking more" were at the significant difference of 5% between modes (C) and (B).

3.3 Discussion

In this study, we evaluated the impression of the twinkling eyes interface, which superimposes self-shadow on the pupil, through paired comparison and a seven-point evaluation. As a result, mode (C), which combined dilated pupil with the self-shadow, was highly evaluated in the paired comparison. In the seven-point evaluation, "(2) Attraction," "(5) Trust from robot," "(6) Twinkling," and "(8) Looking more" were highly evaluated. This is because dilated pupil brought an impression of curiosity [10], which increases interests of the participants in the interface. Additionally, it is considered that the self-shadow was interpreted as objects of the gaze for the interface and a feeling of “seeing/being seen” [11] based on the self-reference [6] was created.

Rousseau defines trust as “a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another” [12]. In other words, trust is regarded as a state or feeling that understands and accepts the intentions of others. Applying this definition to the current experiment, it is considered that the mechanism which participant's own behaviors are reflected not only the interface's gaze and pupil size but also the self-shadow made it easier to read interface's intentions. This ease of reading intentions leads to increased trust in the interface. Furthermore, it is considered that the readability of intention is improved even for spatially distant self-shadows by superimposing the pseudo self-shadow on the eyeball rather than presenting it separately [13].

These results indicate the synergistic effects due to pupil dilation and the self-shadow. The effectiveness of the developed interface was demonstrated by sensory evaluations.

4 CONCLUSION

In this study, aiming to elucidate the mechanism of fascinating and attracting human, we evaluated the impression of the twinkling eyes interface, which superimposes the pupil dilation and the self-shadow. The developed interface was highly evaluated through paired comparison and a seven-point evaluation. The effectiveness of the twinkling eyes interface was demonstrated.

In the future, we plan to develop expression methods incorporated into various media, such as applying them to the twinkling eyes of avatars in virtual spaces and verify their effects under various conditions.

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BRAIN ACTIVITIES INFLUENCED BY SEMANTIC FEEDBACK ON DESIGN IDEAS: AN EXPLORATIVE EEG STUDY

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ABSTRACT
Semantic measures have been recognized for their effectiveness in predicting the success of ideas in design contexts. However, the specific impact of semantic feedback on the neurocognitive processes involved in design ideation has been relatively unexplored. To bridge this gap, our study utilized electroencephalography (EEG) to monitor brain activity as participants engaged in design ideation tasks. Each participant completed the ideation task twice: once before and once after receiving semantic feedback from an instructor. We conducted a detailed analysis of the recorded EEG data, computing the Power Spectral Density (PSD) across various frequency bands—including delta, theta, alpha, beta1, beta2, and gamma—to assess the intensity of brain activities. Our findings indicate a general increase in the power spectrum across these frequency bands following the reception of the semantic feedback. This enhancement in brain activity suggests that participants were likely more engaged and focused on the ideation process after receiving feedback, underlining the potential of semantic feedback to influence creative thinking and cognitive engagement in design tasks positively.

Keywords: idea generation, semantic feedback, EEG, frequency analysis

1 INTRODUCTION

Design is an essential component of various industries [1]. Design cognition, a critical mental process, is characterized by the capability to address complex issues and generate necessary solutions. It encompasses the cognitive functions of design activities, necessitating a comprehensive understanding of physical objects, behaviors, and governing rules, and this knowledge is integral to devising intentional plans that fulfill diverse requirements [2, 3].

Creativity plays a pivotal role in design activities, and it is commonly evaluated based on two primary dimensions: novelty and usefulness [4]. The production of ideas that are both creative and successful is fundamental to effective problem-solving [5]. Much research in this area has traditionally employed ad hoc methods to assess creativity [6], for example, the co-valuation model [7], and protocol analysis employed to understand the design process [8]. However, semantic analysis offers an alternative approach by examining words through the computation of semantic metrics such as Polysemy, Abstraction, Information Content (IC), and Semantic Similarity. This methodology is considered valuable for quantifying and comparing different aspects of the design process and its outcomes [5].

Researchers have explored whether semantic metrics can accurately predict the generation of ideas [9], and this approach has been extended to analyze the semantic content of conversations [10]. For instance, Georgiev and Georgiev [9] utilized 49 semantic measures in a real-world conversation to facilitate problem-solving. Their findings suggested that a semantic similarity divergence, increased information content, and reduced polysemy could predict successful creative idea generation [5, 9]. Despite these advancements, the neural underpinnings of using semantic methods to enhance idea generation remain largely unexplored. Understanding this neural basis could enable researchers to develop more effective semantic-based methodologies to probe this phenomenon's underlying mechanisms.

The electroencephalogram (EEG) is an investigative technique that monitors brain activities by recording the electrical potentials generated by electrodes placed on the scalp [12]. Notably, EEG devices are characterized by a high sampling rate, providing them with an exceptionally high temporal resolution. This feature makes EEG particularly useful for examining temporal processes and brain activities involved in creativity [11-13]. However, EEG techniques face limitations in detecting brain activities from deeper cerebral sources [10]. Consequently, researchers employ EEG to measure the neurocognition and neurophysiological activations specific to design processes [14-16]. Spectral analysis is a fundamental technique utilized in the quantification of EEG data. The power spectral density (PSD) is particularly critical in this context as it represents the frequency composition of the EEG signal, detailing signal power distribution across various frequencies [19]. This measure allows researchers to assess the intensity of brain activity within specific frequency bands, providing insights into the changes of bran activities during different cognitive states or tasks. Researchers within the design field have broadly explored and contributed to understanding the relationship between design creativity and brain activities [18-20].

However, many design studies have traditionally neglected the role of semantic feedback in the ideation process, particularly regarding whether semantic feedback facilitates design ideation and how it influences brain activity during ideation. This research introduces a novel experimental paradigm designed to bridge this gap through a structured three-session approach. We performed the frequency-based analysis to explore the brain activities in different frequency bands and answer the research question:

RQ : How does semantic feedback affect brain activity during design ideation?

2 METHOD

2.1 Participants

Nine healthy participants (four females and five males) were recruited from the University of Oulu. The participants were all right-handed, had normal or corrected-to-normal vision, and were free of neurological disorders or illnesses. Two participants were excluded from a subsequent analysis due to their insufficient sketching results. Seven participants (three females and four males) were incorporated into the formal analysis. The study has been approved by the Ethics Committee of Human Sciences of the University of Oulu. The experimental-related information was disclosed to each participant in advance, and they were required to sign a consent form.

2.2 Experimental Design

In order to investigate the influence of semantic feedback on design ideation, an EEG experiment was divided into three distinct sessions. Participants participated in a design task for a period of ten minutes during the initial session. Subsequently, they were permitted a brief period of relaxation, following which they were obligated to communicate their design concepts to an instructor concisely. The second session lasted approximately five to six minutes, during which the instructor provided customized semantic feedback based on the participants' design outcomes. Participants completed the identical ideation task for an additional ten minutes after receiving feedback. In this session, they were given the choice to either refine their initial design or conceptualize a completely new product, taking into account the feedback they had received. Figure 1 illustrates the experimental procedure.

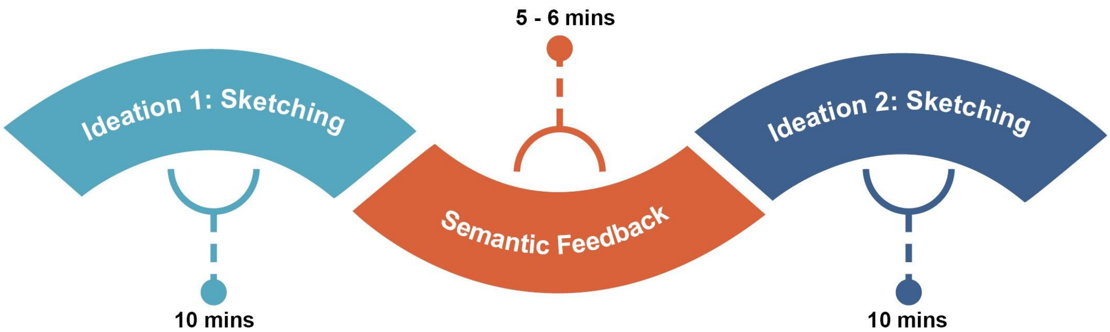

Figure 1. Experimental procedure

2.3 Design task

The design task is: "You are a designer. You are invited to design an amphibious bike. You can sketch and annotate as many ideas as you have. The vehicle can be any kind of bike, such as a bicycle or a motorbike. Amphibious vehicles are suited for both land and water. You can design several options for the product features and functions, such as the propulsion system and the number of allowed passengers."

2.4 EEG recordings

During the experimental period, participants were equipped with EEG devices to monitor their brain activity continuously. Brain Products, Germany (https://www.brainproducts.com/), supplied a 32-channel active electrode system with standard distribution to capture EEG signals (Figure 2). Utilizing sintered Ag/AgCl sensors that were integrally integrated into the cap, this system operated at a sampling rate of 1000 Hz. The impedance of all channels was maintained below 10 kΩ to guarantee signal clarity. The online reference and ground electrodes (GND) were strategically positioned at the FPz and FCz sites, respectively. In order to mitigate potential noise during the design ideation and feedback sessions, participants were advised to maintain a calm facial expression and minimize movement. The entire experiment was conducted in a chamber that was specifically designed to prevent external noise interferences, which was specialized for EEG.

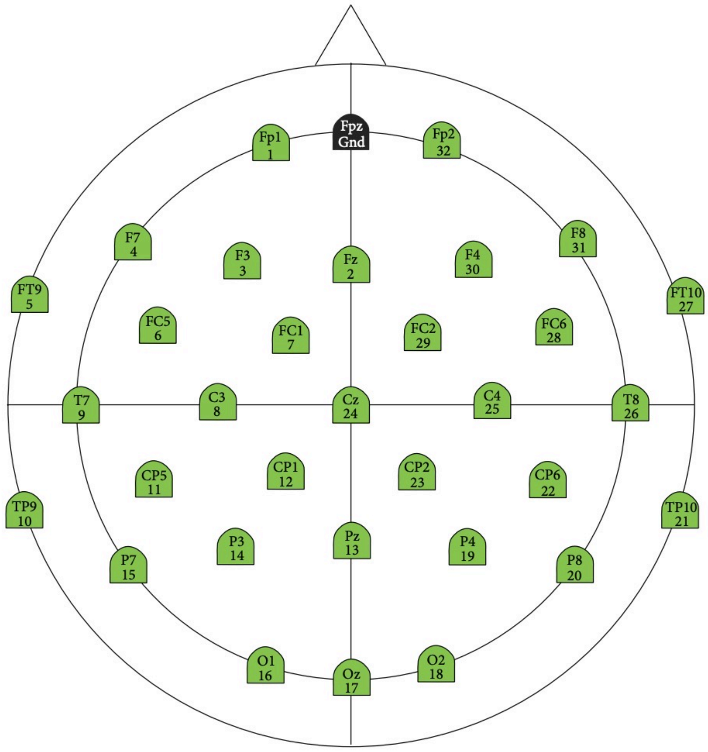

Figure 2. EEG channel distribution

2.5 EEG data analysis

2.5.1 EEG data preprocessing

All The Electroencephalogram (EEG) data collected during the study were processed and analyzed using MATLAB software (MATLAB 2022b, MathWorks, Inc.). The EEGLAB toolbox (EEGLAB v. 2023.0) [18], along with customized scripts, facilitated the preprocessing of the EEG data. During preprocessing, the continuous EEG recordings were filtered using a 1 to 40 Hz bandpass filter to enhance signal clarity by eliminating frequency components outside this range. Following filtering, the data were segmented into epochs of 2 seconds each to facilitate detailed analysis. Head motion artifacts were identified and manually removed to ensure the quality of the EEG data. Independent Component Analysis (ICA) was then applied to correct Electrooculogram (EOG) artifacts, which arise from eye movements and blinks, thereby preventing them from confounding the EEG signals. Additionally, an automatic detection method was employed to identify and remove EEG segments containing wavelet amplitudes greater than 100µV, indicative of aberrant electrical activity. Finally, the data were re-referenced to the average of all brain electrodes, excluding the FT9, FT10, TP9, and TP10 channels.

2.5.2 Power spectrum density analysis

The PSD (power spectrum density) was calculated for each data by periodogram MATLAB function with parameters with NFFT as 2048. The original unit of calculated PSD was in µV ^ / Hz, and then the index was multiplied by 10*log10 to transfer the unit to dB. Mean PSD was calculated for each interested frequency band by the definition of 1–4 Hz, 5–7 Hz, 8–13 Hz, 14–20 Hz, 21–30 Hz, and 31–40Hz as Delta, Theta, Alpha, Beta1, Beta2, Gamma band respectively [21, 22].

2.5.3 Statistics

The Paired-T test was implemented using MATLAB function *ttest* to compare the difference of PSD between Session 1 (Ideation 1) and Session 3 (Ideation 2) for 12 interested channels (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, O1, Oz, O2) in each frequency band defined above (Delta, Theta, Alpha, Beta1, Beta2, Gamma). The False Discovery Rate (FDR) multiple comparison corrections were performed using the MATLAB function made with the method of 'BHFDR' [25].

3 RESULTS

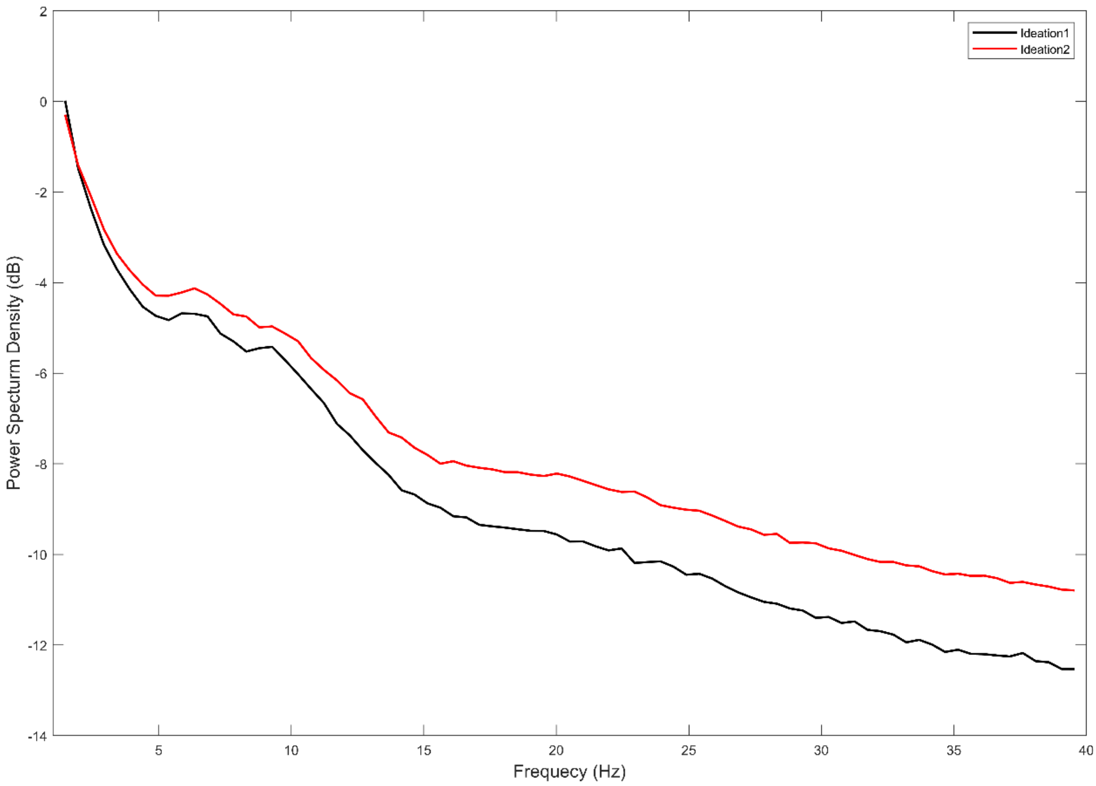

Figure 3. Group averaged PSD across 12 channels.

The group averaged PSD across all participants and interested channels (12 channels), calculated for all frequency points in the 1 to 40 sessions. As shown in Figure 3, the PSD was generally higher in Ideation 2 compared to Ideation 1.

Table 1 below shows the statistical results between two sessions: Ideation 1 vs. Ideation 2. Specifically, In the Delta frequency band, the PSD of C3, P3, and P4 in Ideation 2 was significantly higher than Ideation 1 (corrected $p < .05$).

In the Theta frequency band, the PSD of Fz, F3, C3, Pz, P3, P4, Cz. C4, F4 in Ideation 2 was significantly higher than Ideation 1 (corrected $p < .05$).

In the Alpha frequency band, the PSD of Fz, F3, C3, Pz, P3, O1, Oz, O2, P4, Cz, C4, and F4 in Ideation 2 was significantly higher than Ideation 1 (corrected $p < .05$).

In the Beta1, Beta2, and Gamma frequency bands, the PSD of all interested channels (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, O1, Oz, O2) in Ideation 2 was significantly higher than Ideation 1 (corrected $p < .05$).

Table 1. Statistic results

** Indicates FDR corrected p <.05*

	Delta	Theta	Alpha	Beta1	Beta2	Gamma
Fz	0.1029	0.0163*	0.0065*	0.0007*	0.0004*	0.0004*
F3	0.0521	0.0082*	0.0065*	0.0009*	0.0005*	0.0007*
C3	0.0161*	0.0029*	0.0031*	0.0003*	0.0001*	0.0004*
Pz	0.0521	0.0029*	0.0031*	0.0007*	0.0003*	0.0004*
P3	0.0161*	0.0008*	0.0021*	0.0005*	0.0003*	0.0004*
O1	0.9214	0.0584	0.0072*	0.0004*	0.0003*	0.0007*
Oz	0.2058	0.0813	0.0814	0.0007*	0.0017*	0.0049*
O2	0.0911	0.2610	0.0548	0.0004*	0.0006*	0.0022*
P4	0.0911	0.0039*	0.0180*	0.0020*	0.0006*	0.0013*
Cz	0.0911	0.0039*	0.0031*	0.0008*	0.0005*	0.0004*
C4	0.0088*	0.0029*	0.0041*	0.0007*	0.0003*	0.0004*
F4	0.0706	0.0039*	0.0031*	0.0007*	0.0003*	0.0004*

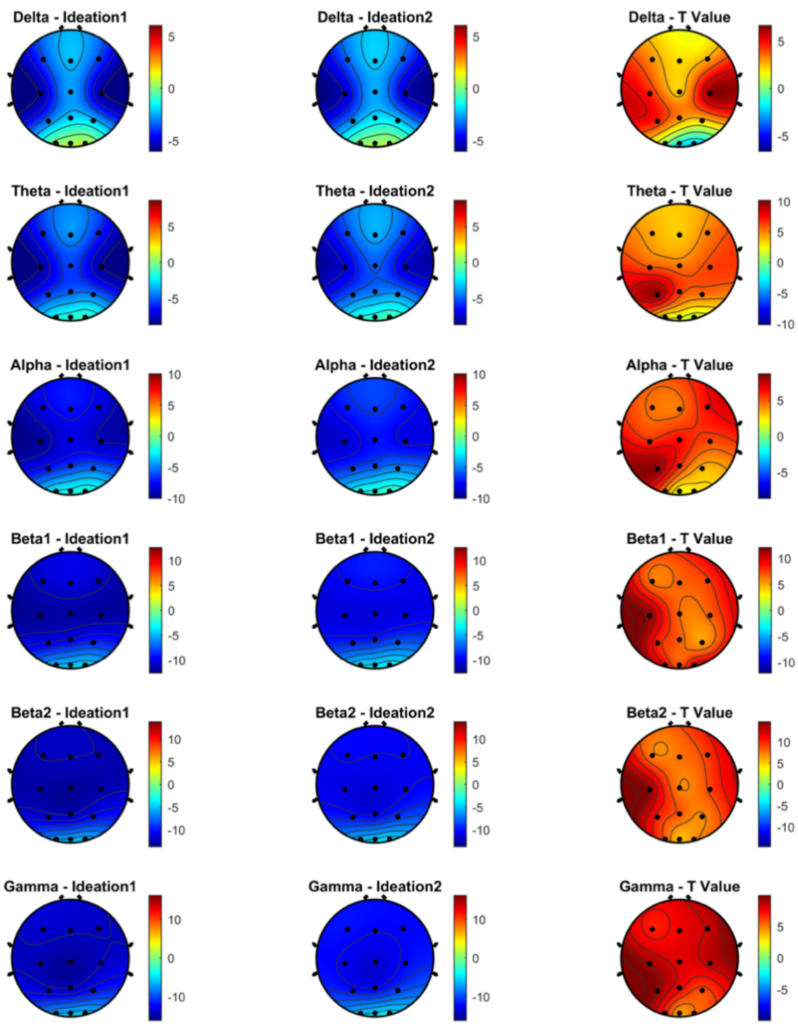

Figure 4. Topographic distribution of PSD

4 DISCUSSION

Power spectral density (PSD) is a neural index that reflects the intensity of brain activity across different frequency bands. Higher PSD values indicate stronger brain activity and different frequency bands are associated with distinct cognitive functions [26]. Figure 4 illustrates the PSD value for each frequency band of Ideation 1 and Ideation 2. The statistic T values reflect the difference between the two ideation sessions. In this study, we strategically selected 12 EEG channels to cover a comprehensive range of scalp locations, each corresponding to key brain regions involved in cognitive processing. The designations 'F', 'C', 'P', and 'O' represent the frontal, central, parietal, and occipital areas, respectively. Additionally, the numbers '3', 'z', and '4' indicate the positions on the brain's left, middle, and right sides. Based on the power spectral density (PSD) distribution observed on the topographic map, a more pronounced difference between Ideation 1 and Ideation 2 is evident from the alpha to gamma frequency bands, particularly in the central and parietal regions of the left hemisphere.

Additionally, our findings revealed that the power spectrum density (PSD) in the second ideation session (Ideation 2) was generally higher across all frequency bands when compared to the first session (Ideation 1). This increase in PSD indicates that the brain activities were more intense after participants received semantic feedback. Such an enhancement in brain activity suggests that the feedback made the participants more engaged and focused during the ideation process. This could be attributed to the cognitive integration and processing of the feedback, which may have stimulated more active and potentially creative thinking, thereby intensifying the overall brain activity observed in the second ideation session.

Furthermore, our research examined previous studies that predominantly focused on the theta and alpha frequency bands, where frontal alpha activity is associated with creative thinking, and theta activity increases during design tasks [22], [27-28].

Consistent with these findings, our study also observed significant activities in these bands within the non-occipital regions of the brain, thereby supporting the established correlation between these frequencies and creative cognition. Moreover, our investigation included the delta, beta, and gamma frequency bands, which are essential yet less frequently examined in the context of creativity and design. We found that delta activities were elevated, likely in response to the cognitive demands of the tasks [29]. Beta frequencies, known to be crucial in decision-making processes and design sketching, were prominently active [24], [30]. Additionally, gamma frequencies, which facilitate high-level cognitive functions such as information processing and memory, were also significantly engaged [31].

Finally, this research has implications for design education and extends beyond the comprehension of the cognitive processes that underlie creativity. We emphasize the potential benefits of integrating structured feedback into the design education process and the impact of semantic feedback on the enhancement of ideation-related brain activity.

5 LIMITATIONS AND CONCLUSION

This study uses EEG methodology to explore the impact of semantic feedback on brain activities during design ideation. We conducted frequency analysis and utilized Power Spectral Density (PSD) as a neural index to reflect the strength of brain activities from the delta to the gamma frequency bands. This investigation represents the initial exploration of the semantic influence on design ideation and marks our first attempt to analyze brain activities across all frequency bands comprehensively.

However, the study has several limitations that must be acknowledged. The experiment was conducted with only nine participants, and only seven were included in the formal data analysis, which may reduce the reliability and generalizability of the results. Additionally, the evaluation of design creativity itself was not incorporated, which is crucial to thoroughly examining the effects of semantic feedback on design outcomes. Furthermore, as this study was conducted in a laboratory setting, there were inherent limitations regarding the design problem and the time allotted for participants to complete the ideation process. We also face limitations in further analyzing the useful content provided by the semantic feedback, as it was customized based on the design outcomes.

Our findings indicate that brain activity increases after receiving semantic feedback in design ideation tasks, suggesting enhanced engagement and attention. These results offer new insights into the role of specific stimuli in design ideation and open possibilities for further studies on the impact of semantic feedback within design research. Future research should aim to recruit a larger sample size and include comprehensive evaluations of design creativity to more elaborately explore the effects of semantic feedback on both brain activities and creative outputs.

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PROCEEDINGS OF ASIA DESIGN AND INNOVATION CONFERENCE
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COGNITIVE EXERCISES FOR DESIGN THINKING

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ABSTRACT
Underlying design thinking process has been explained using visual thinking composed of seeing – imagining – drawing. In this way, interactive and iterative natures essential in design thinking can be better understood. The visual reasoning model that supports visual thinking with cognitive activities can be used to explain and guide cognitive processes in design thinking. It would be desirable to devise methods and tools to support design thinking using the visual reasoning model as a framework. This paper presents on-going research about cognitive exercises for design thinking with discussion on requirements in devising such exercises and future research issues.

Keywords: Design Thinking, Visual Reasoning Model, Activity Transformation, Design Cognition

1 INTRODUCTION

Design thinking is now recognized as a human-centered, possibility-focused and hypothesis-driven problem solving method [1, 2]. Design thinking process is often described with the process sequence of *Empathize – Define – Ideate – Prototype – Test* [3]. Many iterations of this design thinking process are conducted to solve a problem. Liedtka [4] described design thinking with four waves composed of *what is?*, *what if?*, *what wows?* and *what works?*, where what if? corresponding to Ideate is emphasized with the highest wave.

McKim (1972) described visual thinking process as iterative interactions of *seeing – imagining – drawing* [5]. The process would start from seeing as basic understanding of the design problem. Next the process moves to imagining where potential solution ideas are imagined while these are ambiguous. Drawing to help the imagination follows. Looking at the sketch, designers see if the imagination roughly sketched could be a solution to the problem understood with previous seeing processes. By seeing that some parts are OK but some other parts are deficient, improvements needed are identified in the next seeing. Imagining and drawing of solution improvements follow. Seeing the improvements are OK, understanding of the problem may be reinterpreted, then further imagining comes again. A simple prototype is built and the designers see the prototype to evaluate based on some evaluation criteria identified in previous seeing processes. Imagining continues with further improvements. Next improved prototypes are built. The next seeing process involving potential users for their feedback follows so that imagining of improved solutions can continue [6]. In this way, the design process makes progresses with visual thinking of seeing – imagining – drawing.

McKim [5] smoothly described the general designerly way of problem solving process through expressions easy and familiar to designers. This design process has been described later as seeing – moving – seeing [7]. Experienced designers smoothly combine the iterative process of seeing – imagining – drawing, and designers may seem to conduct imagining and drawing simultaneously. Designer capabilities in performing visual thinking smoothly and naturally with moving of imagining and drawing and reflection of seeing are critically important [8]. Visual reasoning capability has been identified as a critical element of design creativity [9]. A visual reasoning model [10] was developed to understand the cognitive process of design by describing the seeing – imagining – drawing visual thinking process with basic cognitive activities of *perception, analysis* and *interpretation* for seeing; *generation, transformation* and *maintenance* for imagining; and *internal* and *external representations* for drawing as shown in Figure 1. Interactions of these cognitive activities as well as designer's *knowledge* and *schema* on the object of designing constitute the visual reasoning process.

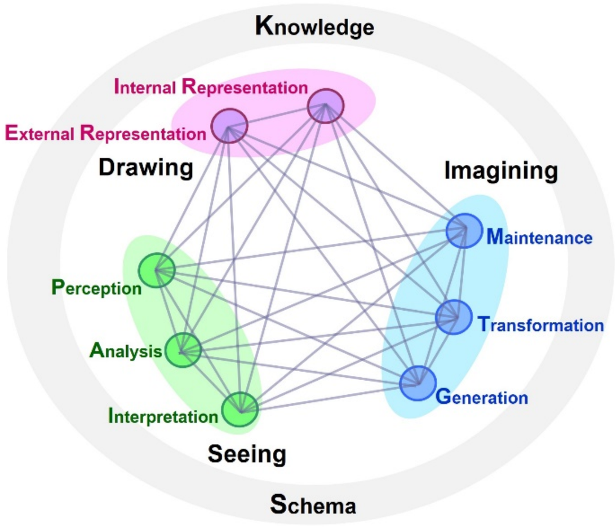

Figure 1. Visual Reasoning Model (from [10])

This reasoning model was developed to provide step by step guidances for visual reasoning processes for tasks like a missing view problem, where a third orthographic projection of a valid 3D solid object is to be sketched given two consistent orthographic projections [11]. Suwa and Tversky [12] proved that their *constructive perception* task, where many different interpretations are to be made for ambiguous drawings, was valuable in comparing visual reasoning ability between design experts and novices. Both capabilities on missing view problems and constructive perception tasks have been proven to be correlated with design capabilities [9].

Object of designing in service design is human activities as services are defined as activities done by human beings for others with some values [13]. Structured methods for imagining have been developed for service design and these methods have been characterized using the visual reasoning model [6]. Particularly, the structured *what if* method utilized the Context-Based Activity Modeling [14, 15] method of human activity description as the schema in associating the seeing part and the imagining part. It is critical to enhance the ability of imagining in close interaction with seeing and drawing in service design thinking. As CBAM would serve as a formal description language for human activities and would have an important potential to work as a framework for service design in the digital transformation era, exercises to enhance familiarities for CBAM would be desirable with the structured *what if* imagining method.

This paper presents on-going research about cognitive exercises for design thinking where interactive and iterative operations of those cognitive activities of the visual reasoning model are specifically orchestrated. The remainder of the paper is composed like the following. First, missing view problems and similar visual reasoning tasks are characterized with orthographic projection rules as schema. Constructive perception tasks are then discussed including the aspect of constructive perception that is not present in the missing view problem, which would be regarded as reframing or avoiding fixation. Thirdly, as a more comprehensive cognitive exercise for service design thinking, making stories exercises, that are newly developed, are explained so that exercises for cognitive elements of creativity [16] are combined with structured imagining method using CBAM. Finally, the paper will be concluded with discussions regarding potential frameworks for design thinking learning and education including future research issues.

2 COGNITIVE EXERCISES FOR SEEING – IMAGINING – DRAWING

Three cognitive exercises for design thinking process of seeing – imagining – drawing are now described as these can be used to address different level of difficulties and different emphases as well as interactivities. While the first two have been used before in some empirical research on design creativity, the third has been newly devised enhancing an existing exercise on cognitive elements of creativity.

2.1 Visual Reasoning Exercise

As the visual reasoning model was developed from the cognitive activities of the iterations of seeing – imagining – drawing, description of the cognitive process of a missing view problem like the one in Figure 2 would be straight forward. Note that a missing view problem is a typical visual reasoning so that a three dimensional solid is to be imagined by seeing the front view and top view projections through iterations of seeing – imagining – drawing. After *perceiving* top horizontal edge of the front view and the left rectangle of the top view and *analyzing* that these two entities match in their widths, it is hypothetically *interpreted* that these two would *generate* a long rectangular block based on the *schema* of orthographic projection. When this block is visually *represented internally*, it is confirmed that this block would be *analyzed* to satisfy the constraints imposed by the other entities. Then, that block may be sketched *externally*. For those who are good in their visual imaging, that block may not need to be externally represented. Next, the bottom edge of the front view and the big rectangle of the top view are *perceived* and their matching widths would be *analyzed*. Then the wider rectangle of the front view and the big rectangle of the top view would be hypothetically *interpreted* to *generate* a big bottom rectangular block in *internal representation* using the *schema* of orthographic projection. After confirming *analysis* that this block would satisfy the other constraints imposed by other entities, this base block can be visually *represented* or sketched. When these two blocks so far represented are considered together, the two rectangular faces matching the front co-linear edges of the top view can be *perceived* collectively. Then it can be *interpreted* that these two faces are co-planar. These in turn are *transformed* to be merged into a face in *internal representation*. Then the solid object is to be *perceived* and this would be *analyzed* to be inconsistent with the horizontal edge in the middle of the front view. Through further seeing, the horizontal top rectangular face of the upper block can be *transformed* to a slanted rectangular face with its front edge is lowered to the height of the middle horizontal edge of the front view using the *schema* of orthographic projection. Then finally the current 3-D solid object *represented* would satisfy both the front and top views. The solid is then *sketched externally*, ending the visual reasoning process. More of this kind of visual reasoning exercises are created with varying level of difficulties and different number of iterations required.

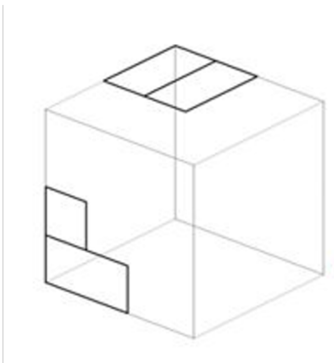

Figure 2. A Missing View Problem

2.2 Constructive Perception Exercise

In constructive perception, users are asked to give different interpretations as many as possible for a few ambiguous drawings shown in Figure 3. A typical process of constructive perception would start with *perception* of some visual features of the drawing. For example, round part in the bottom of Drawing 1 is *perceived* and round part in the upper portion is also *perceived*. Then these two round features are *analyzed* to be of the same width, making a matching bottom and top pair. Then what if hypothesis is made in *interpretation* like "what if these matching round features are hypothesized to be those of a hamburger" based on the *knowledge* of the user. Then, according to the hypothesized interpretation, some parts of the drawing would be *transformed*. For example, those small features at the right part of the upper round part could be removed in *imagining* with *internal* visual *representation*. With these transformed, further *analysis* with *knowledge* can be done and if this confirms the hypothesized hamburger what if, then the user would *say out externally* or *write down externally* "hamburger". This process can be depicted by visiting the basic cognitive activities of the visual reasoning model of Figure 1 and knowledge and schema if relevant as shown in Figure 4 with the reasoning sequence numbers.

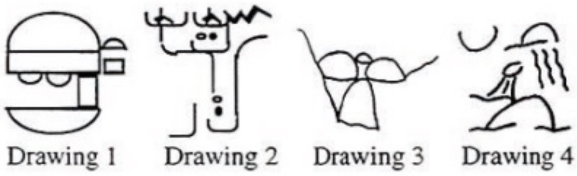

Figure 3. Ambiguous Drawings for Constructive Perception [12]

Perceiving and analyzing an ambiguous drawing, many different interpretations of the drawing are to be made. For this, a new interpretation is to be *imagined* hypothetically with support from previous *knowledge* of visual images, resisting fixation to previous interpretations. In *internal representation* of hypothesized *interpretation*, improved perception is to be confirmed by *analysis* with *knowledge* to result in the confirmed new *interpretation*. Then, the user would *represent* it *externally* by saying, for example, an espresso machine in this time. Note that, in this seeing – imagining – drawing iterations, the role of any specific *schema* is relatively weak unlike the missing view problems. On the other hand, *knowledge* plays an important role in making what if hypotheses repeatedly overcoming fixation.

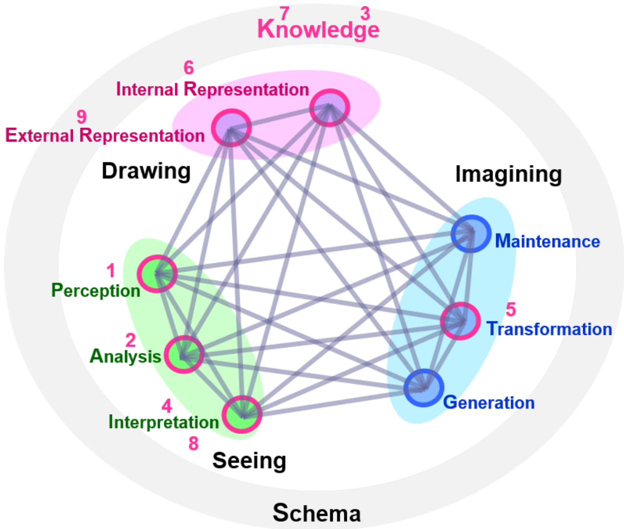

Figure 4. Visual Reasoning Model Process of a Constructive Perception Exercise
(1.perception – 2.analysis – 3.knowledge – 4.interpretation – 5.transformation –
6.internal representation – 7.knowledge – 8.interpretation – 9.external representation)

2.3 Structured Imagining (What If) Exercise

2.3.1 Making Stories

An exercise program for cognitive elements of creativity, such as *fluency*, *flexibility*, *originality*, *elaboration* and *problem sensitivity* [17, 18], has been devised to provide personalized support for creativity enhancement for design students [16]. The 'making stories' exercise asks the students to produce different stories using three different photos by changing the order of them. This exercise involves human characters appearing in the photos to form important parts of the stories so that originality and elaboration elements are exercised where different stories are generated flexibly reflecting changes in the sequences of photos. The 'making stories' exercise asks the students to produce different stories using three different pictures by changing the order of them. Therefore, this activity aims to improve the *flexibility*. The *elaboration* can also be developed through this activity by implying cause and effect of given pictures and specifying them. In addition, the *originality* can be enhanced through the effort to make unique and novel stories.

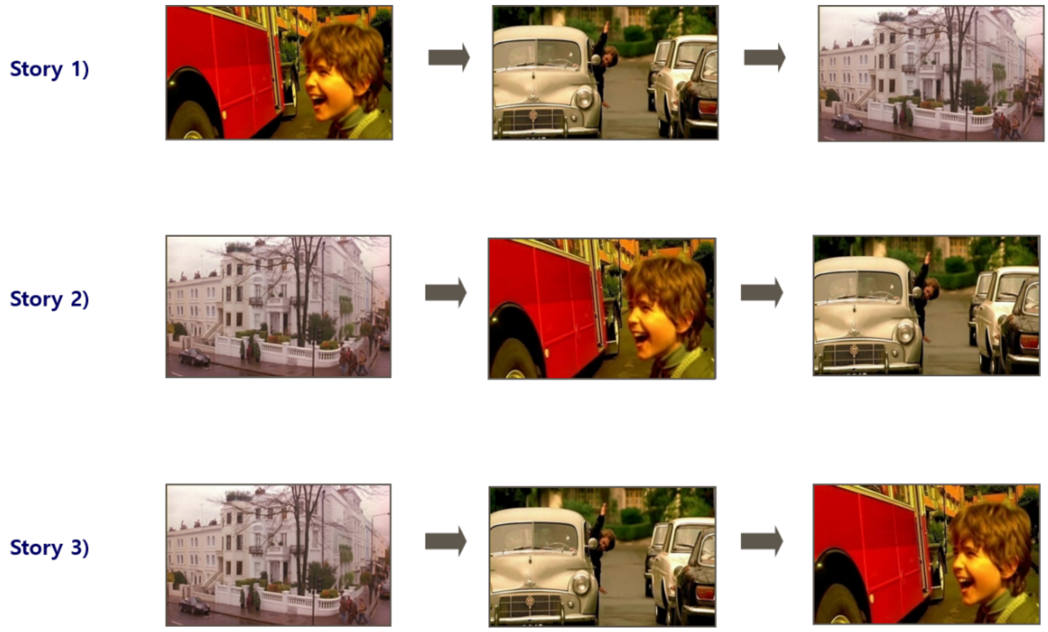

Figure 5. Make Stories Exercise [16]

As service design is all about human activity design, making stories exercise including photos of human characters have been enhanced to structured imagining exercises for service design thinking. As such exercises would require interactions and iterations of seeing – imagining – drawing together with schema and knowledge, the schema of CBAM would be used in describing human activities reflecting stories made from the photo sequences. Alternatively, human activity descriptions using CBAM can be first made from photos, and then stories can be constructed reflecting CBAM descriptions. Next in the section, CBAM is reviewed briefly and an exemplary exercise for structured imagining is to be explained.

2.3.2 Context-Based Activity Modeling

The activity description is centered around the *action verb*. The object of the action verb is specified as the *object* element of the activity. The *active actor* is the subject stakeholder of the activity who performs the action. In some cases, the *passive actor* and/or the *third-party actor* are specified as well. The *tool* of the activity is specified when a tool is used in the activity. Another element of the activity in CBAM is the *context*, which is in turn described by the following four context elements: The *goal context*, the *relevant structures*, the *physical context*, and the *psychological context*. The relevant structures are the entities associated with the object element in the action. The physical contexts such as location and time are specified. The psychological context such as emotional states and motivation level can be associated. In addition, whether the activity is public or private, and whether the activity is performed alone or with others can be specified as social context as a part of the psychological context. Through this rich description of activities as an underlying description, diverse experience issues can be addressed in human activity-centered experience design. That is, CBAM is regarded as a basic underlying schema in service activity design.

2.3.3 Structured Imagining Exercise

In the stories of the making stories exercise, activities of the main character should be modeled reflecting the photo scenes in describing the context based on the CBAM schema. Exercise tasks can be given as follows.

(1) For the photos given in the sequence of the story (1) in Figure 5, make a story where the main character is the boy of the first photo. Reflecting or seeing the story (1), make or generate a context-based activity modeling of an activity of the boy.

(2) For the photos given in the sequence of the story (2), make a story where the main character is the boy. Reflecting or seeing the story (2), transform the context-based activity modeling of the activity of the boy for story (1) to make a modified context-based activity modeling of an activity of the boy.

(3) For the photos given in the sequence of the story (3), transform the context-based activity modeling of the activity of the boy for story (1) or story (2) to make a modified context-based activity modeling of an activity of the boy. Reflecting the modified context-based activity modeling, make a story where the main character is the boy.

An example story (1) can be like the following: "The boy called the red bus to go home in a wide street near his school. He was happy as he finished today's school work and exciting as he was going home. The street was congested with a lot of cars until he reached his house". Reflecting this story, the boy's activity of *calling* the bus can be described using CBAM as shown in Figure 6 (a). The goal context is to go home. The relevant structures for the boy's activity of calling bus would be the wide street and other cars of various sizes in the street. The physical contexts are time and location of the street near school as well as the noisy and windy conditions of the street and clear weather condition. Exciting motivational state and happy emotional state of the boy actor are represented in the psychological contexts as well as social context of public activity and crowded occupant context.

Now the CBAM describing process of Figure 6 (a) is regarded using the visual reasoning model. The goal context would be coming from the story. The relevant structure of other cars of various sizes would be coming from the perception of a photo and the analysis that other cars would also be on the street as the bus is on. Then it can be hypothesized that calling, or waiving for, the bus would be influenced by other cars. Similarly, the wide street would be coming from the perception of a photo and from the knowledge that calling bus would be influenced by the width of the street. Some of the physical contexts are easily derived from perceiving on photos. The emotional and motivational state would be coming from the perceived image of the boy and the knowledge that students are on the streets on their way to school and on the way home. This emotional and motivational states were already constructed in story making. That is, the imagining of the story already utilized the interactive cognitive activities of perceiving, analyzing, interpreting, generating of happy emotion and exciting motivation, followed by confirmation using knowledge and the photo of the boy.

As asked in the task (3), a modified CBAM of the boy's activity can be made by transforming the object from Bus to Dad's Car as shown in Figure 6 (b). The action verb is also modified from *call* to *spot* (find among many cars). The activity of the boy in spotting Dad's car in spite of the big bus blocking his view can be modeled as shown in Figure 6 (b). Note that relevant structure has been modified to include the big Bus and Dad driving the car as the boy successfully spotted Dad's car in the context where a lot of cars of various sizes were in the street as well as a big Bus. Certainly, Daddy is relevant to the car he was driving. Physical contexts are directly copied, and so are psychological contexts. Then, from this new CBAM description, a new story can be made as the following; "The boy finally spotted dad's car and he was happy and exciting in spite of long waiting due to street congestion on dad's way from home to the school as daddy was making a big bodily gesture in the car so that the boy can easily spot his car".

This exercise is integrating making stories exercise of creativity and CBAM description exercise so that cognitive elements of creativity are mixed with cognitive activities of visual reasoning using CBAM as core schema.

3 DISCUSSIONS

In this section, future research tasks are discussed together with issues and requirements in devising cognitive exercises for design thinking and related design learning efforts. These discussions can be enhanced towards those of a framework for design thinking learning and education.

Visual reasoning exercises can be varied in a diverse manner. Usually the more faces in solution solid objects can make the exercise more demanding as exercises would need more reasoning steps if there are larger number of faces. The types of faces can be varied including faces parallel to viewing planes, faces perpendicular to viewing planes, slanted faces and skewed faces. If many skewed faces are involved, missing view problems would become more difficult requiring complicated reasoning steps. While missing view problems are more structured, it may be easier to make alternative exercises with different levels of difficulty. Such levels can be evaluated also empirically based on performance results by many exercise participants.

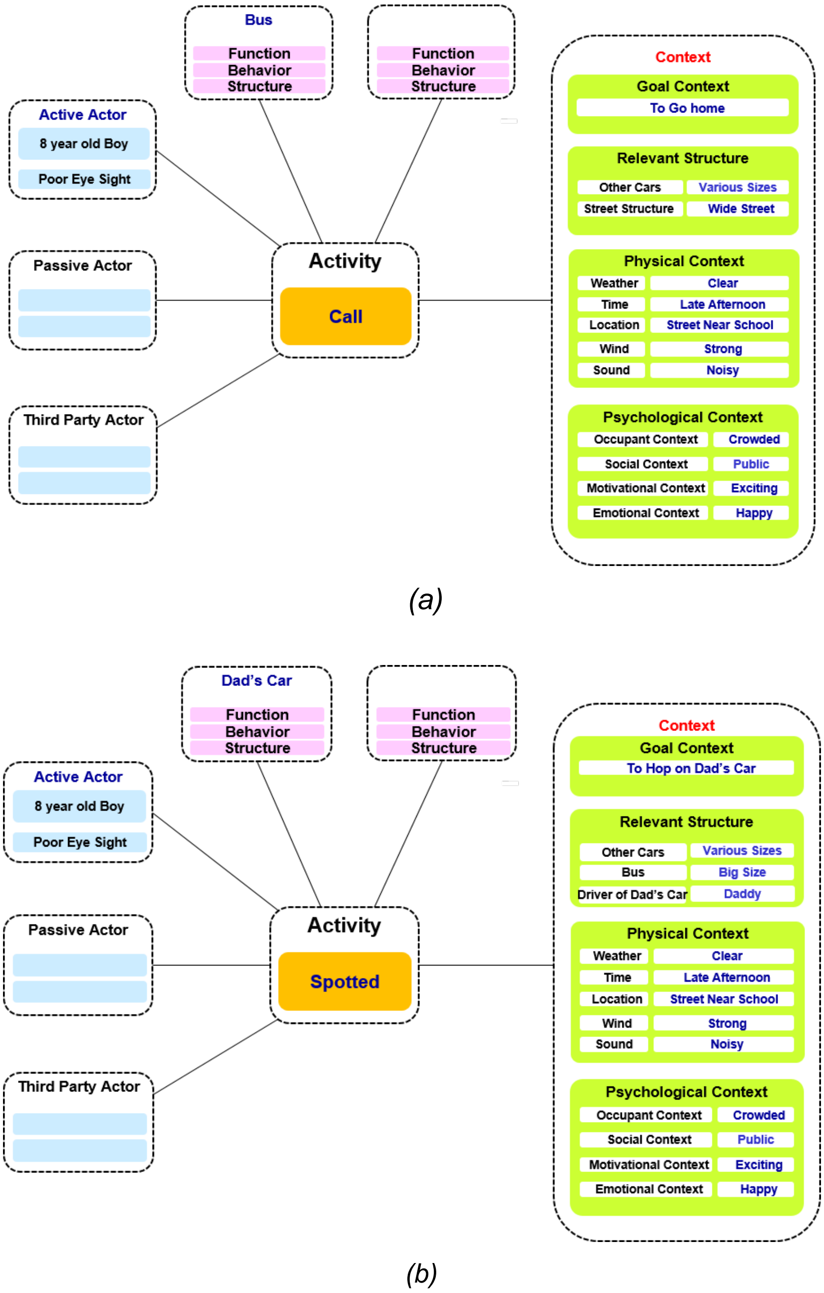

Figure 6. Context-Based Activity Modeling Used in Structured Imagining Exercises

As mentioned in descriptions on visual reasoning exercises, this kind of exercises has strong dependency of schema. On the other hand, constructive perception exercises show less dependency on schema. Maybe some exercises can require more involvements of knowledge while others may not. Some exercises could require deep involvements of both schema and knowledge. Based on the required involvement of knowledge and schema, respectively and collective, design thinking exercises can be differentiated. Regarding the basic cognitive activities of seeing, imagining and drawing, natures of exercises could also be distinguished by levels of involvements of these cognitive activities. In other words, some exercises may require more analyses while other exercise may demand more critical interpretations. Some exercises may require more of internal representations, others need more of external representations while these could be also differently involved reflecting personal visualization ability differences. Maybe some problems may require more iterations in outer iterations of seeing – imagining – drawing, some others may require many of local level, or inner iterations of seeing – imagining – drawing.

As in the case of structured imagining exercise, cognitive exercises can be more complex requiring cognitive activities of seeing, imagining and drawing, and cognitive elements of creativity. Also exercises may require nice handling of transformations between different elements of exercises. As discussed, some dimensions of cognitive exercises of design thinking could be identified so that these will form the foundation for the framework of design thinking cognitive exercises. This is certainly an important future research task. In such a framework, various different design thinking exercises can be compared and classified, and such dimensions could guide how new exercises can be devised.

Future research tasks for design thinking exercises can include both prescriptive research and empirical research. Empirical research may involve novice design thinkers and more experienced design thinkers. Such research also includes identifying potential inter-relations among different cognitive aspects, for example, such as personal creativity modes [19] and learning styles [20]. Many future research tasks could be identified addressing these issues. As critical in design learning in general, more opportunities of learner reflection could be provided utilizing various tools [21]. As digital tools such as experience evaluation and experience engagement are being devised to support users to make their experience iterations of experience – evaluation – engagement in an accumulative and improving manner [22], research on design thinking learning and education should also address devising of similar tools. As more immediate future research task, some initial empirical research dealing with the three design thinking exercises explained in this paper, that is, visual reasoning, constrictive perception and structure imagining exercises, will be conducted.

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A BIBLIOMETRIC REVIEW OF RESEARCH ON GAMIFICATION USED IN ENVIRONMENTAL PROTECTION, 2014-2024

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ABSTRACT
This study presents a bibliometric analysis of the research trends and applications of gamification technology in the field of environmental protection between 2014 and 2024. Addressing critical environmental challenges such as climate change, resource depletion, and biodiversity loss, gamification has emerged as an innovative approach to enhance public engagement in sustainability. By incorporating game-like motivational mechanisms into non-game contexts, gamification has proven effective in fostering behavioral changes in areas like energy conservation, water management, and ecological restoration. Utilizing tools such as VOSviewer and CiteSpace, this study analyzes collaboration networks, citation patterns, and emerging trends, with a particular focus on the integration of immersive technologies like virtual and augmented reality. The findings highlight key applications of gamification in environmental protection and suggest practical implications for policymakers and practitioners seeking to design more engaging environmental initiatives. Furthermore, the study identifies the potential for immersive technologies to enhance environmental awareness and action. Despite these advancements, challenges remain, particularly in adapting gamification strategies to diverse demographic groups and sustaining long-term behavioral changes. The study concludes with recommendations for future research, including the need for large-scale evaluations and the exploration of the synergy between gamification and emerging technologies to maximize the impact on public engagement in environmental sustainability.

Keywords: *Gamification, Environmental Protection, Bibliometric Analysis,Serious Games, Energy Conservation*

1 INTRODUCTION

The increasingly severe environmental challenges, such as climate change and biodiversity loss, necessitate innovative approaches to engage the public in sustainable practices. Traditional environmental education methods often fail to sustain long-term public interest and action, highlighting the need for interactive technological solutions. For instance, mobile augmented reality and gamification have been shown to improve students' environmental knowledge and awareness, encouraging greater involvement in environmental issues [1]. Furthermore, public sector innovation aimed at addressing environmental challenges often faces obstacles such as limited resources and governance issues, which may hinder effective implementation [2]. The role of community initiatives and environmental NGOs is also critical in promoting public engagement and raising awareness [3]. Integrating technology into environmental education can significantly enhance public participation, foster a deeper understanding of sustainability issues, and ultimately lead to more proactive environmental behavior [4]. Thus, employing innovative educational technologies and promoting community involvement are essential strategies for maintaining public interest in environmental protection efforts.

Gamification, by integrating game elements such as points, rewards, and leaderboards into non-game environments, has become a powerful tool for enhancing public environmental awareness and behavior. This approach has demonstrated its effectiveness in various fields, including energy management and water conservation, successfully motivating individuals to adopt sustainable practices [5][6]. For example, Madani et al. illustrated how serious games can significantly improve public understanding of environmental management, leading to tangible pro-environmental behaviors[7]. Empirical studies further support the effectiveness of gamification in fostering both intrinsic and extrinsic motivation. The Self-Determination Theory (SDT) explains how gamification fulfills individuals' needs for autonomy, competence, and relatedness, thereby enhancing intrinsic motivation and sustaining long-term engagement with environmental initiatives [8][9]. Overall, gamification represents a promising strategy for encouraging public participation in environmental protection efforts.

Despite the extensive exploration of gamification technology in existing studies, several challenges and limitations remain. First, further research is needed to understand how current gamification designs can be adapted to meet the needs of diverse groups, ensuring they effectively stimulate user engagement across different demographics. Variations in age, cultural background, and educational levels affect how individuals respond to gamification mechanisms, necessitating the design of more targeted and flexible gamification strategies. Second, most research to date has focused on small-scale or short-term experiments, with a lack of systematic evaluations on large-scale, long-term behavior change. Thus, exploring how gamification can sustain public participation in environmental actions and foster lasting behavior change in real life is a critical direction for future research. Additionally, with the rise of emerging technologies such as virtual reality (VR) and augmented reality (AR), investigating how these technologies can be integrated with gamification to enhance public engagement and behavior change has become a growing area of interest.

Based on these challenges, the primary objective of this study is to systematically review the application of gamification in the field of environmental protection over the past decade (2014-2024) using bibliometric methods, to identify research hotspots and future trends, and to explore how gamification can encourage public participation in environmental behaviors and sustainable development actions. Specifically, this study will address the following research questions:

1. What are the main application scenarios and research hotspots of gamification in the field of environmental protection?
2. How does gamification technology promote public engagement in environmental protection and associated behavior change?
3. How have citation patterns and research trends in the literature evolved, particularly regarding the integration of emerging technologies such as virtual reality and augmented reality with gamification?

This paper will employ bibliometric analysis tools, such as VOSviewer and CiteSpace, to systematically review relevant research from 2014 to 2024, identifying current research hotspots and trends, and proposing directions for future research. Through a comprehensive analysis of the role of gamification in environmental protection, this study aims to provide new insights into promoting long-term public engagement in environmental actions and advancing sustainable development.

2 METHOD

This study adopts bibliometric analysis in order to reveal the current status and future development trend of gamification technology application in the field of environmental protection. To ensure the breadth and academic authority of the data, Web of Science and Google Scholar were chosen as the main data sources for this study, and the bibliometric tools VOSviewer and CiteSpace were applied to visualise and analyse the data. Three key visualisation data were included in the study: (1)keyword co-occurrence analysis, (2)citation emergence detection, (3)time-evolving pattern recognition. The study aims to systematically reveal the research hotspots in the field as well as the analysis of future trends. The results of the study provide a comprehensive academic overview of gamification applications in environmental protection, as well as an important reference value for future research directions.

Based on bibliometric analysis, this study aims to systematically sort out and summarise the current status and future development trend of the application of gamification technology in the field of environmental protection. The advantage of the bibliometric method is that it can reveal research areas that have not been fully explored through objective data, and provide scientific direction guidance for future research. This method is particularly effective in interdisciplinary research, which can avoid the bias of subjective assessment by researchers and provide a more comprehensive analysis perspective(see Figure 1).

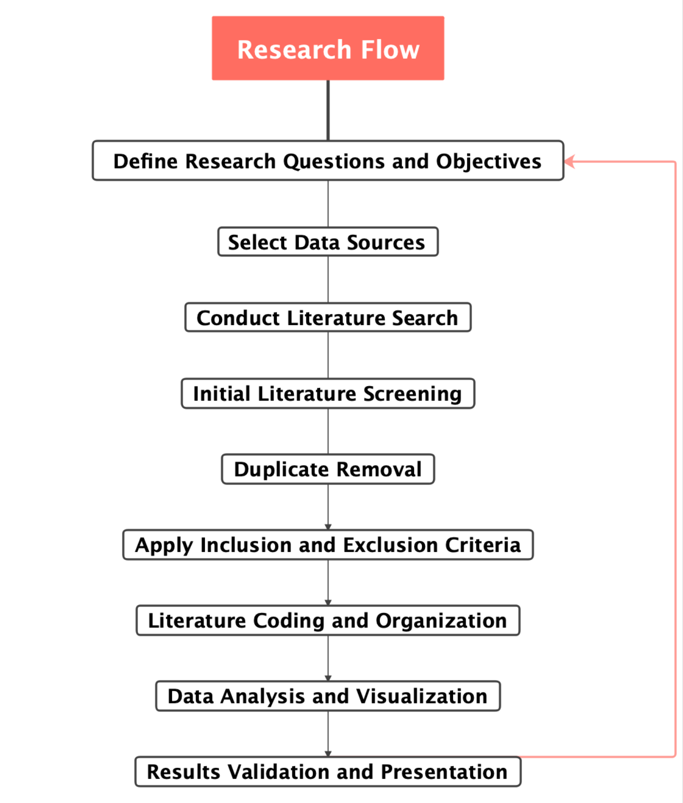

Figure 1. Research Flow

2.1 Search Strategy

During the data collection process, a detailed literature search strategy was designed to ensure that all key literature related to gamification technology and environmental protection was covered. Web of Science and Google Scholar were chosen as the data sources, which not only cover a wide range of topics, but also provide a large amount of peer-reviewed, high-quality literature, providing a solid data base for the study and ensuring that the data are academically rigorous and comprehensive. we set a timeframe of 2014 to 2024, aiming to capture the trend of gamification technology in the field of environmental protection over the past decade. To ensure the academic rigour and empirical validity of the data, the types of literature screened for inclusion were limited to journal articles, review papers, and conference papers, with a focus on empirical analysis studies of academic value.

In the literature search, multiple keyword combinations were used to cover gamification-related topics (e.g., 'gamification', 'serious games', ' interactive games', "game-based learning") and environmental protection related topics (e.g., ' environmental protection ', 'sustainability', 'climate change', 'energy conservation', 'pollution control'). In the Web of Science database, the specific search formula is:

TS=('gamification' OR 'serious games' OR 'interactive games' OR 'game-based learning') AND TS=('environmental protection' OR 'sustainability' OR ' climate change ' OR "energy conservation" OR "pollution control") AND PY=(2009-2024) AND DT=(' Article' OR "Conference Paper").

This search formula resulted in an initial 570 documents. Then, after subject relevance filtering, the filtering result was 299 articles. In Google Scholar, using a similar advanced search strategy, 502 articles were obtained and 202 articles were retained after further screening. Subsequently, an initial screening based on the titles and abstracts of the literature excluded literature that was not relevant to the study topic, especially those that only explored education or business management but did not address environmental protection. Eventually, after further screening, 299 documents were retained in Web of Science and 202 in Google Scholar.

To ensure the uniqueness of the literature, the screened literature was de-weighted using the literature management tool Zotero. After de-weighting, the final included dataset contained 457 documents. Next, the literature was further screened and processed based on explicit inclusion and exclusion criteria. The inclusion criteria included that the literature should be related to the application of gamification in the fields of environmental protection, sustainable development, climate change, energy saving or pollution control, and only journal articles, conference papers and review papers published between 2014 and 2024 were included to ensure that the literature had internationalisation and academic impact. At the same time, literature with inconsistent themes, non-academic literature, short literature with abstracts only, and literature that is biased towards medicine, chemistry, and other literature that is not directly related to the cross-cutting applications of gamification and environmental protection were excluded.

- Inclusion Criteria
  – The literature should discuss the application of gamification technology or interaction design in environmental protection, sustainable development, or climate change.
  – The literature should include empirical research, such as the application of gamification technology in specific environmental protection projects or empirical analysis of user behavior.
  – The literature should be academic journal articles or conference papers to ensure academic rigor and scientific quality.
- Exclusion Criteria
  – Studies that focus solely on energy-saving education without directly addressing the broader application of environmental protection.
  – Research that mainly discusses workplace gamification for efficiency improvement, which does not focus on environmental protection.
  – Literature that concentrates on climate change risk management or digital transformation without in-depth exploration of gamification applications.
  – Studies related to traffic management or food systems, which do not focus on the direct impact of gamification on environmental protection
  ....

After rigorous screening, a total of 213 literatures were finally included in the data analysis. In order to systematically process and analyse these documents, we coded the documents using Excel and Zotero, and the coding fields included information such as document title, author, year of publication, keywords, DOI, number of citations, and the name of the journal or conference in which the document was published. These literature organisation and coding laid a solid data foundation for the subsequent analysis.

2.2 Data Analysis

After completing the literature de-duplication and screening process, the study entered the literature network analysis phase. With the help of bibliometric analysis tools such as VOSviewer and CiteSpace, key hotspots and trends in the field were systematically revealed. This phase began with a keyword co-occurrence analysis using VOSviewer to identify high-frequency keywords and their co-occurrence relationships, helping to identify important topics and concerns in the study. In this way, high-frequency co-occurrences of certain concepts can be clearly identified, revealing key themes in the field of gamification and environmental protection. For example, “environmental sustainability”, “user engagement”, “behavioral change”, and “incentives” may be high-frequency keywords.

The keyword co-occurrence analysis not only demonstrates the core issues that researchers are concerned with in this field, but also reflects the intersection and collaboration of different disciplinary fields, showing how gamification technology can be combined with behavioral science, psychology, pedagogy, and other disciplines to provide innovative solutions for environmental protection. By analyzing the co-occurrence relationships between keywords, researchers can better understand the intrinsic connections between different concepts, reveal the importance of interdisciplinary collaboration, and help identify future research directions.

In addition, a citation emergence analysis was conducted through CiteSpace in order to further explore the academic frontier. This analysis identifies key documents with a significant increase in citation frequency within a specific time period, revealing important research breakthroughs and hot topics in the field. By analyzing citation bursts, researchers are able to identify certain studies that have gained a high level of academic attention within a short period of time, indicating that these literatures have made significant contributions to advancing the field. For example, within certain time frames, there may be prominent studies that explore how gamification can motivate users to adopt more environmentally friendly behaviors in their daily lives, or how interactive systems can be designed to drive public awareness of sustainability. This analysis provides a dynamic perspective on research that can help understand how academic hotspots evolve in response to technological developments and changing societal needs.

In addition to keyword co-occurrence analysis and citation emergence analysis, time evolution analysis was also used. This analysis reveals changes in research focus over time by generating a timeline showing the evolution of gamification technologies in environmental protection. For example, early research may have focused more on basic interaction design and user behavioral changes, while over time, research has gradually evolved toward how to more effectively promote environmental protection actions through the application of refined game mechanics, and smart devices. This time-dimensional analysis helps researchers better understand the development trajectory of the field and possible future research directions, providing a reference basis for the next academic work.

In order to verify the accuracy and consistency of the analysis results, the keyword co-occurrence and citation emergence analyses were repeated at various stages, and cross-validation was performed to ensure the reliability of the data. Intuitive visualization diagrams were generated using tools such as VOSviewer and CiteSpace, which provide a clear picture of the key issues in the research area as well as an analysis of trends in future research.

3 RESULTS

Through a comprehensive bibliometric analysis of literature from 2014 to 2024, this study identifies major trends and research hotspots in the application of gamification within the field of environmental protection. Using tools such as VOSviewer and CiteSpace, the study conducted keyword co-occurrence, citation burst, and timeline analyses.

3.1 Keywords Co-occurrence Analysis

The analysis highlights the prominence of keywords such as gamification, serious games, and sustainability within the research network (see Figure 2). These terms frequently co-occur with concepts like **behavior change**, **social interaction**, and **pro-environmental behavior**, demonstrating the focus on utilizing gamification to foster public engagement and modify environmental behaviors. For instance, gamified applications incorporating **point systems**, **rewards**, and **interactive tasks** have been shown to enhance user motivation in adopting environmentally responsible actions. Moreover, the strong association between **sustainability** and **pro-environmental behavior** further underscores the potential of gamification in promoting sustainable practices at both individual and community levels. The significant co-occurrence of **education** with these key terms also points to the widespread use of gamification in **environmental education**, where **serious games** provide simulated environments for users to learn and apply environmental knowledge in real-world contexts.

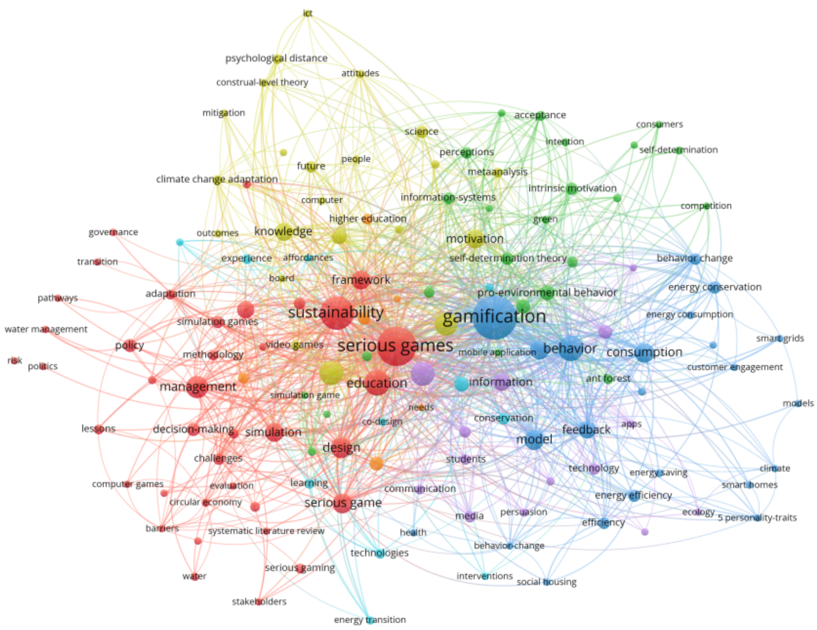

Figure 2. Keywords Co-occurrence

3.2 Citation Burst Analysis

The citation burst analysis identifies pivotal studies that have significantly influenced research on gamification and serious games since 2014. Notable publications, such as Hamari (2014) and Connolly (2012), have been instrumental in shaping the application of gamification in both education and environmental protection (see Figure 3). Hamari's (2014) work investigates the impact of gamification on user behavior, providing empirical evidence that highlights gamification's potential to drive environmental behavior change by enhancing user engagement and motivation. Similarly, Orland et al. (2014) explore the role of gamification in promoting energy conservation within buildings, demonstrating how virtual environments can educate users on energy-saving practices. These citation bursts underscore the expanding application of gamification, emphasizing its broader social and environmental implications beyond conventional domains like entertainment and education.

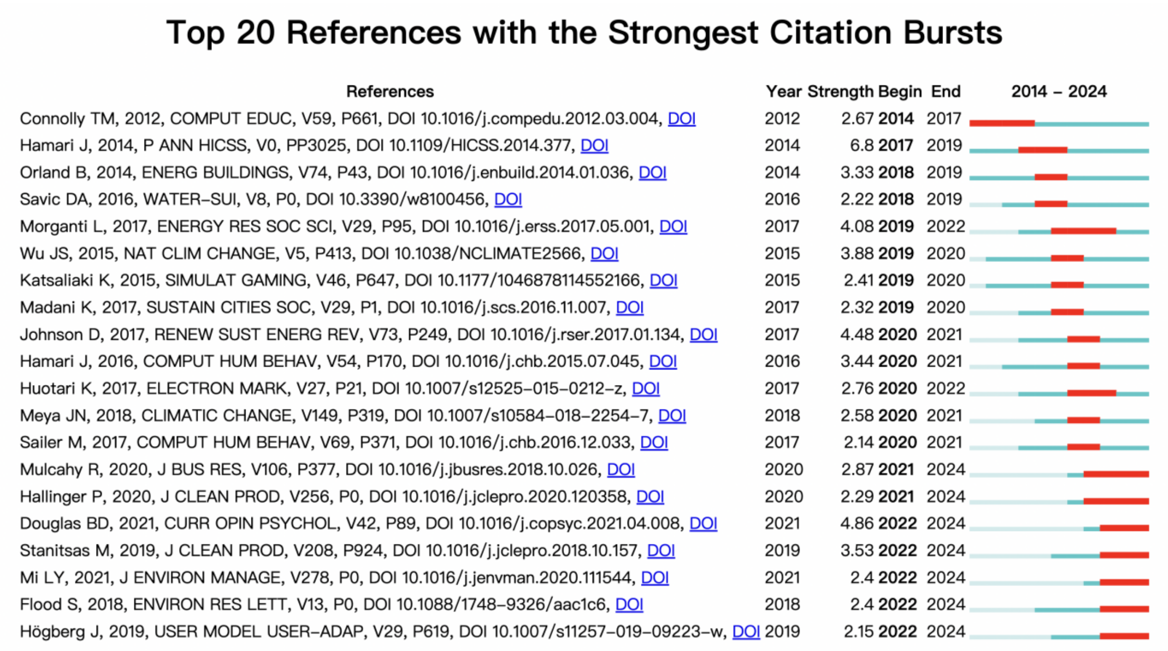

Figure 3. Citation Bursts

3.3 Timeline Analysis

The timeline analysis reveals that since 2017, the integration of energy conservation and virtual reality technologies has emerged as a significant research trend in the field of environmental protection (see Figure 4). The increasing occurrence of keywords like energy conservation and virtual reality reflects growing interest in utilizing these technologies together. The prominence of energy conservation suggests a focus on leveraging gamification to improve energy management practices. Virtual reality, as an emerging technology, enhances the immersive experience, allowing users to visualize the consequences of energy wastage, thus encouraging behavioral change. Additionally, the rising frequency of augmented reality points to its recognized potential in environmental education and behavior modification, where users can simulate real-world environmental challenges in virtual environments.

3.4 Multidisciplinary Applications of Gamification in Environmental Protection

The experimental data underscore the broad application of gamification across various environmental protection domains, particularly in energy conservation, ecological restoration, and water resource management. Keywords such as energy conservation and energy efficiency frequently appear in the literature, signaling the significant role of gamification in these areas.

The strong association between gamification and behavior change in the context of energy conservation suggests that researchers are focusing on how gamified systems can foster sustainable energy behaviors in daily life. For example, platforms like Smartege simulate energy-saving activities within virtual environments, educating users on efficient energy use. Gamification systems also support community-level initiatives, such as promoting the adoption of renewable energy.

In the area of water management, keywords like water conservation highlight gamification's potential in encouraging the efficient use and management of water resources. Although less frequently discussed, the combination of ecological restoration and gamification presents opportunities for public engagement in virtual ecological restoration tasks, offering interactive learning experiences and practical skills that can be applied to real-life conservation efforts.

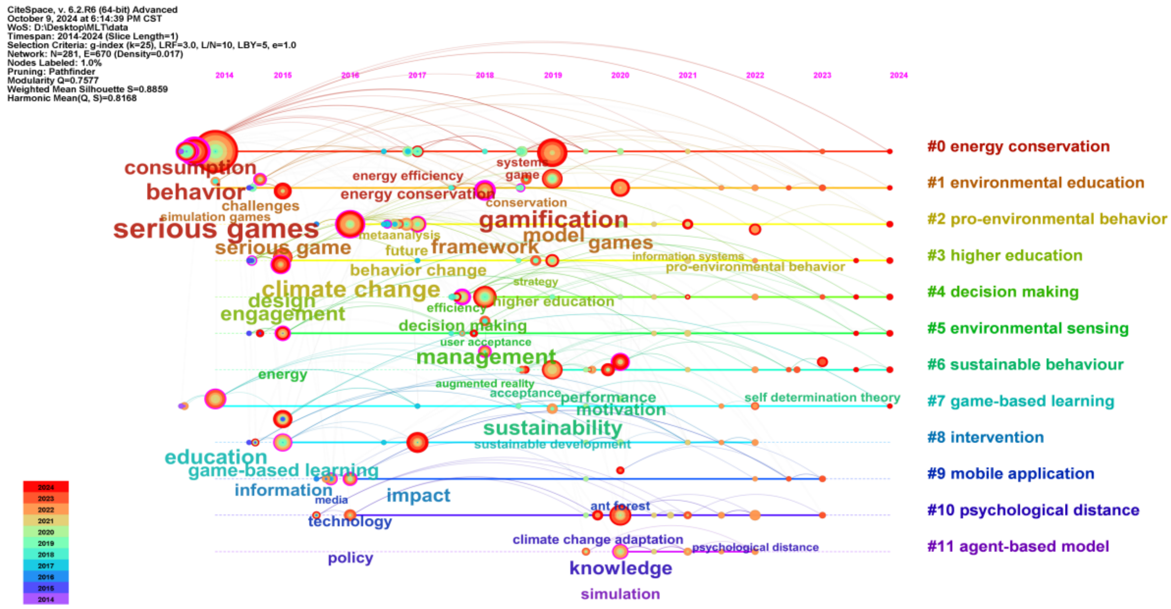

Figure 4. Timeline

3.5 Public Engagement and Social Impact

Gamification has proven to be an effective tool for enhancing public engagement and generating social impact in environmental actions. The high frequency of engagement in the keyword co-occurrence analysis highlights public participation as a key objective of gamified applications. By increasing users' sense of involvement, gamified platforms, such as community-based energy conservation apps, have significantly boosted participation in energy-saving behaviors through competitive elements like leaderboards and rewards.

Furthermore, the strong association between social interaction and engagement indicates that gamification frequently integrates social features such as progress sharing, team collaboration, and community challenges. These elements further enhance public participation, particularly in collective environmental initiatives, by fostering a sense of community and shared responsibility.

3.6 Emerging Trends: Virtual Reality and Augmented Reality

The integration of virtual and augmented reality with gamification has seen significant growth since 2018, as indicated by the increasing frequency of these keywords in the literature. Immersive technologies, such as virtual reality, when combined with gamified environments, allow users to directly experience environmental challenges, such as ecosystem degradation. This immersive experience fosters a stronger sense of environmental responsibility and promotes behavior change.

The expanding application of augmented reality further enhances user interaction with real-world environmental challenges by superimposing virtual information onto physical surroundings. This approach provides innovative ways to engage users in sustainability actions, enabling them to interact with environmental data in real time and encouraging more effective environmental behaviors.

4 CONCLUSION

This study provides a comprehensive bibliometric analysis of the application of gamification in the field of environmental protection, focusing on the evolving research trends, key areas of impact, and future directions. The findings demonstrate that gamification, through its interactive and motivational

mechanisms, has proven effective in enhancing public engagement with environmental issues, particularly in areas like energy conservation, water management, and ecological restoration.
The study identified gamification, serious games, and sustainability as central concepts, with an increasing focus on behavior change and social interaction. These elements are vital in driving public participation and fostering long-term commitment to sustainable practices. Moreover, the integration of virtual reality (VR) and augmented reality (AR) with gamification has emerged as a significant trend since 2017, offering immersive experiences that can enhance the effectiveness of environmental education and behavior change initiatives.
While the application of gamification has gained traction, there are several areas for future exploration. First, the long-term impact of gamification on sustained behavior change, particularly in large-scale initiatives, requires more comprehensive evaluation. Second, adapting gamification strategies to suit diverse demographic groups is essential, as cultural and educational differences influence the effectiveness of these interventions. Finally, the growing synergy between gamification and emerging technologies like VR and AR presents a promising avenue for creating more engaging and impactful environmental solutions.
In conclusion, gamification holds significant potential in addressing environmental challenges by promoting public engagement and facilitating sustainable behavior change. Future research should focus on optimizing these technologies, exploring their broader applications, and investigating their long-term effects on public involvement in environmental protection.

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PROCEEDINGS OF ASIA DESIGN AND INNOVATION CONFERENCE
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AN OPTIMAL DESIGN METHOD FOR PRODUCT-SERVICE SYSTEMS USING AN INVENTIVE DESIGN APPROACH

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ABSTRACT
In the context of rising market competition, diverse customer needs, and increasing environmental concerns, product-service systems (PSS) are gaining attention for achieving financial benefits and resource efficiency. Existing research on PSS design has applied multi-objective optimization methods to derive solutions that meet the requirements of multiple stakeholders. However, when strict constraints exist among PSS design requirements and their realization, simple optimization often fails to satisfy all stakeholders. To address this, the paper focuses on the inventive design approach, which facilitates creative solutions for problems that are difficult to solve through optimization. This study proposes a method to support the optimal design of PSS by integrating TRIZ, an inventive design approach. The proposed method is demonstrated in a PSS design case for automated valet parking. Application results demonstrate that the method enables designers to resolve physical contradictions through a comprehensive, top-down design approach.

Keywords: Product-service systems, Design optimization, Multi-objective optimization, Inventive design, TRIZ

1 INTRODUCTION

Amid intensifying market competition, diverse customer needs, and growing environmental concerns, product-service systems (PSS) [1] are gaining attention as a means of achieving financial benefit and resource efficiency. PSS addresses these issues by integrating products and services and involves collaboration among stakeholders with different requirements [2]. Enhancing stakeholder satisfaction is crucial while considering trade-offs from the conceptual design stage to define the PSS concept and construct a solution that optimizes various stakeholders' requirements. However, the diverse requirements and resulting trade-offs make it challenging to derive a PSS design that satisfies all requirements simultaneously.

In engineering design, multi-objective optimization is considered an effective approach for optimizing multiple objective functions, which quantify requirements, under constrained conditions during the conceptual design phase [3]. However, in PSS design involving multiple stakeholders, value ranges may not simultaneously satisfy all requirements, and the objective functions and parameter conditions required for components (functions and attributes) may be unknown. Therefore, optimization that merely searches under constraints is not viable. Design solutions must be derived by compromising initial requirements, expanding the search space, and relaxing constraints. These solutions do not fully satisfy each requirement and deviate from the original optimization goal. To address this issue, this study focuses on the inventive design approach, which enables creative solutions for problems difficult to solve through optimization. Specifically, we propose a method to support PSS design by integrating TRIZ [4], an inventive design approach for solution generation.

2 RELATED STUDIES

2.1 Routine and inventive design in solution search

There are two types of problems in design solution search: those solvable by optimization and those challenging to solve with optimization [5]. The former, known as "routine design," involves a minimum of one solution within the search space, enabling an efficient search using established optimization methods. The latter, termed "inventive design," is difficult to address with existing methods and requires a novel, creative approach involving trial and error to find a solution. While routine design efficiently optimizes, it often results in a compromise when no suitable framework exists. By contrast, inventive design, unconstrained by existing frameworks, may avoid compromise by generating innovative solutions. The comparison between two design approaches is presented in Table 1.

Table 1. Comparison between routine design and inventive design [6]

Routine design	Inventive design
Manage what is known	Discover what is unknown
Optimization of existing data for best result	Moving further ahead from the optimized result of existing data
Incremental improvement	Radical innovation
Accept compromise as a potential solution	Refuse compromise as a potential solution

2.2 TRIZ and PSS design

TRIZ is an innovative problem-solving methodology, developed by Altshuller and Altov (1996) through the statistical analysis of a vast amount of patent literature in various technical fields [4]. It represents a representative approach to the original design. In TRIZ, contradictions are classified into three levels according to the level of abstraction. In TRIZ, several tools have been proposed to detect contradictions in the design and to eliminate or mitigate the relationship between the contradictions according to the levels of contradiction. Contradictions are classified according to their level of abstraction into the following three levels.

- Administrative Contradictions: The situations where improvement is required, but the solution remains unknown.
- Technical contradictions: The classical engineering trade-offs, where you cannot reach the desired state because something else in the system prevents it.
- Physical contradictions: The situations in which an object or system suffers contradictory, opposite requirements.

The 40 Inventive Principles provide a framework for addressing contradiction problems, offering a set of ideas based on the 40 inventive principles for technical contradictions and the principle of separation for physical contradictions. The former comprises a set of 40 general-purpose abstract solution ideas, including such concepts as "division" and "asymmetry," which are employed to obtain conceptual solutions for technical and physical contradictions. The contradiction matrix, a tool provided by TRIZ, can be employed to identify inventive principles that resolve contradictions. The principle of separation is a technique for deriving solutions to physical contradictions, which consists of four fundamental separations: (1) separation in space, (2) separation in time, (3) separation between part and whole, and (4) separation between conditions.

In the field of PSS design, a range of TRIZ-based design support methodologies have been investigated [7]. Initially, researchers verified the effectiveness of TRIZ adoption for a new and inventive PSS concept-generation [8,9]. Several studies suggested an approach to generating a new PSS concept by providing 40 inventive principles of TRIZ for PSS [10,11]. Furthermore, the innovative design support for PSS has been addressed by combining TRIZ with several methods such as quality-function deployment (QFD) [10] and case-based reasoning [12]. The intricate nature of PSS structures and their interdependencies frequently gives rise to trade-offs, necessitating the application of inventive design approaches such as TRIZ in PSS designs. However, identifying the optimal solution in such PSS designs solely through inventive approaches, which often entail trial and error, is a challenging endeavor. TRIZ is a qualitative method, and it is not feasible to confirm whether a solution was truly generated within the search space through its application to PSS design.

2.3 Optimal design support for PSS

Some studies have proposed PSS design methods using optimal design approaches. Song et al. (2015) examined the trade-offs among stakeholders in designing elevator services, focusing on optimizing service performance, minimizing service costs, and reducing response time [13]. Similarly, Bal et al.

(2020) developed a model to determine the optimal placement of recycling facilities. Their approach balanced "efficiency of product collection from customers" and "transportation costs" with social benefits such as improved access to medical facilities and public safety for employees at each facility [14]. Although these studies proposed multi-objective optimization methods for specific PSS cases, these models are only applicable to individual scenarios. Applying them to various PSS designs with differing requirements is difficult. Specifically, the design variables required to express the objective function, the determination of constraints, and the formulation process using these variables have not been formalized. Additionally, no general guidelines exist for PSS designers to optimize their solutions. To address this, Tsuji et al. (2022) proposed a general-purpose multi-objective optimization method for PSS design. This method formulates the objective function by setting and evaluating parameters based on stakeholder requirements [15].

2.4 Approach of this study

Due to the complexity of PSS requirements, driven by diverse stakeholders, an inventive design approach is essential. However, finding an optimal solution in PSS design using this approach (i.e., TRIZ) alone is challenging and involves trial and error. This paper proposes a methodology to support PSS design optimization by applying TRIZ to specific elements of the PSS structure, identifying factors that hinder optimization. The study focuses on the "physical contradictions among requirements and functions related to the same attribute," a key factor in trade-offs. Using TRIZ's "Separation principle," physical contradictions are separated from constraint conditions, as shown in Figure 1 (I). This approach resolves trade-offs by eliminating the overlap between constraints and requirements, enabling PSS design optimization. The key principles of the proposed method are outlined below.

Identification of physical contradictions

First, the physical contradictions within the PSS structure must be identified. Given the complexity of PSS requirements, the initial step involves identifying the components to be designed and their interdependencies. Next, the components that cause physical contradictions—trade-off factors—are identified.

Resolving physical contradictions through separation

Once the attributes causing the physical contradictions have been identified, the overlap between the constraints of the requirements is examined. This involves determining whether a value range exists that can simultaneously satisfy all requirements. When the constraints do not overlap and standard optimization is not applicable (Figure 1 (I)), the separation principle is employed to resolve the physical contradiction. For instance, as illustrated in Figure 1 (II), the value ranges of the attribute related to requirement A (α) and the attribute related to requirement B (β) are established independently to differentiate the constraint conditions. When individualizing constraint conditions for a specific attribute, appropriate value ranges must be set for related attributes that depend on it. Based on the identified dependencies in (I), clustering is performed to determine which attributes should be considered together when applying separation. This outcome is then incorporated into the entire PSS structure, allowing for the individualization of constraint conditions for specific attributes.

Confirmation of design solution appearance

As previously mentioned, the inventive design approach is employed when solutions are not readily apparent through routine design methods. Specifically, a solution may not exist within the search space following the separation process. Therefore, the suitability of the separation is assessed by determining whether a solution is present within the search space through a solution search conducted under the individualized constraints resulting from the separation. During this process, it is essential to formulate each requirement into an objective function and incorporate the outcomes of the separation into this formulation. This study employs a proposed formulation support method for PSS optimization design [15] to convert each requirement into an objective function. This approach enables the reflection of the separation results in the design problem formulation, as detailed below.

- In the case of a design variable x representing a separated attribute, the upper and lower bounds of each constraint condition are set as threshold values (x_{α}, x_{β}), as illustrated in Figure 1 (II).
- While maintaining the objective function targets (f_1, f_2) at the threshold, they are formulated separately as ($f_{1\alpha}$, $f_{2\alpha}$) and ($f_{1\beta}$, $f_{2\beta}$) according to the circumstances under each constraint

condition.
- Optimization is performed for each combination.

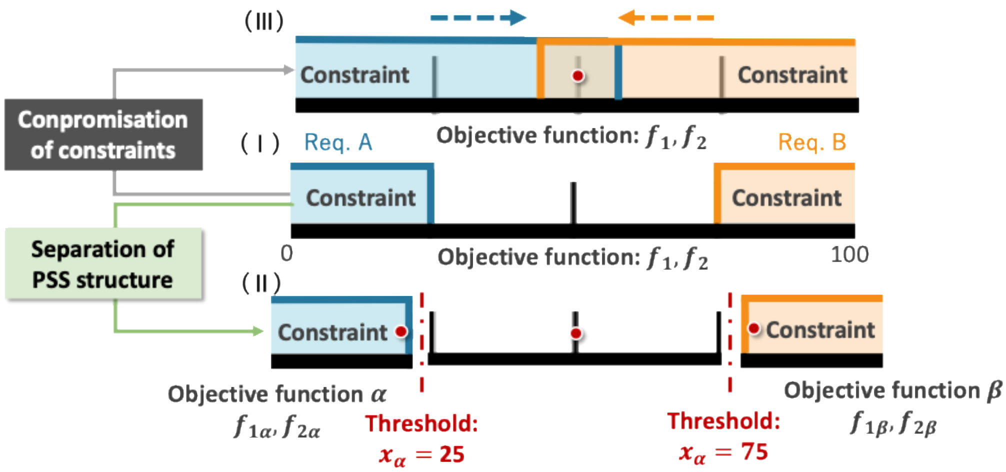


Figure 1. Separation approach of this study

3 PROPOSAL

The proposed method comprises five steps based on the approach described in Section 2.3. The following subsections detail each step, and the overall procedure is illustrated in Figure 2.

3.1 Step 1: Identification of components of PSS

To identify the components of the PSS, a functional deployment based on the view model [16] is first conducted to clarify the functions and attributes that fulfill the requirements of each stakeholder. The view model serves as a tool that represents the quality elements provided to customers as requirements and expresses the structure of the PSS in terms of requirements, functions, and entities. By constructing a view model for multiple requirements, the components of the PSS are clarified.

3.2 Step 2: Identification of dependencies and physical contradictions between components

To investigate dependencies among the components identified in Step 1, a multiple domain matrix (MDM) [17] is constructed by integrating the design structure matrix (DSM), which describes dependencies between elements in the same domain, and the domain mapping matrix (DMM), which describes dependencies between elements in different domains. To assess the impact of changes in a specific element on others, the relationships between elements in the same domain—such as requirements, functions, and attributes in the DSM—and between elements in different domains, such as requirements and functions or functions and attributes in the DMM, are evaluated based on the criteria shown in Table 2. When functions marked as "-2: inhibit" in the function DSM are analyzed in the function-attribute DMM as being caused by competing values of the same attribute, they are identified as physical contradictions.

Table 2. Evaluation criteria of MDM

Matrix		Evaluation criteria
DSM	Requirement	0：No influence，-1：Trade-off
	Function	2: Necessary，1: Preferable, 0：No influence, -1: Not- Preferable，-2: inhibition
	Attribute	1：Influential, 0：No influence
DMM	Requirement-Function	1：Influential, 0：No influence
	Function-Attribute	1：Influential, 0：No influence

3.3 Step 3: Clustering of PSS components

To comprehend the elements considered during separation in TRIZ, it is necessary to cluster elements with positive dependencies (2: necessary/1: preferable) in the function DSM and dependencies (1: influential) in the attribute DSM, based on the matrices constructed in Step 2. This creates functional and attribute clusters that are essential for realizing PSS.

3.4 Step 4: Separation of PSS structure

If the physical contradiction identified in Step 2 is deemed inapplicable by conventional optimization procedures after assessing constraint conditions, the contradiction is resolved through separation. Specifically, based on the TRIZ separation principle, attributes are separated to ensure the satisfaction of each function and requirement. The value range of attribute A1 for requirement R1(α) and the value range of attribute A1 for requirement R2 (β) are established as discrete entities to differentiate the constraints (Figure 3). Accordingly, when individualizing the constraint conditions for attribute A1, appropriate value ranges must be set for surrounding attributes that are dependent on or function in contradiction with it. The outcomes of the separation are then reflected in other attributes, A2 and A3, which belong to the same cluster AC1, as identified in Steps 2 and 3. This allows the specific constraints associated with attribute A1 to be integrated across the entire PSS structure, facilitating the formulation of the objective function under individualized constraints based on the effects of separating specific attributes across multiple attributes.

3.5 Step 5: Multi-objective optimization of PSS design

Step 5-1：Setting objective parameters

In cases where a requirement directly conflicts with another, a quantitative and objective parameter is established as the objective parameter (OP) to be optimized. For instance, if the requirement is to “reduce environmental load,” it is preferable to define parameters such as “CO_2 emissions” or “water consumption” rather than vague terms such as “size of environmental load,” which are challenging to quantify. It is essential to ascertain whether the optimization of the OP is being achieved, specifically whether the OP is being minimized or maximized.

Step 5-2：Setting design variables and constant parameters

In this step, the attributes from the view model created in Step 1 are considered potential design variables. The designer subsequently classifies the variables based on two criteria: first, whether their values can be manipulated for each attribute; and second, whether their effects on the satisfaction of each OP should be considered. Even for attributes that can be manipulated, if they do not impact the fulfillment of the OP, they can be excluded from the formulation.

Step 5-3：Formulation of requirements

As illustrated in Step 4, each OP is expressed using design variables and constant parameters to formulate an objective function. As demonstrated in Section 2.3, the upper and lower limits of each constraint condition are defined as threshold values (x_α, x_β) for the design variable x, representing the separated attributes. The objective function (f_1, f_2) is maintained at these values but is formulated independently according to the constraint conditions as ($f_{1\alpha}$, $f_{2\alpha}$) and ($f_{1\beta}$, $f_{1\beta}$).

Step 5-4：Implementation of optimization

Finally, optimization is performed for each combination, and the occurrence of solutions in both search spaces is mathematically evaluated to ascertain the efficacy of the separation. If the solution obtained fails to satisfy the requirements, it may be difficult to determine the underlying cause based solely on the output results. In such cases, designers should return to each step and systematically examine the attributes to be separated, the separation methods employed, and the formulation itself to derive a solution that satisfies both requirements.

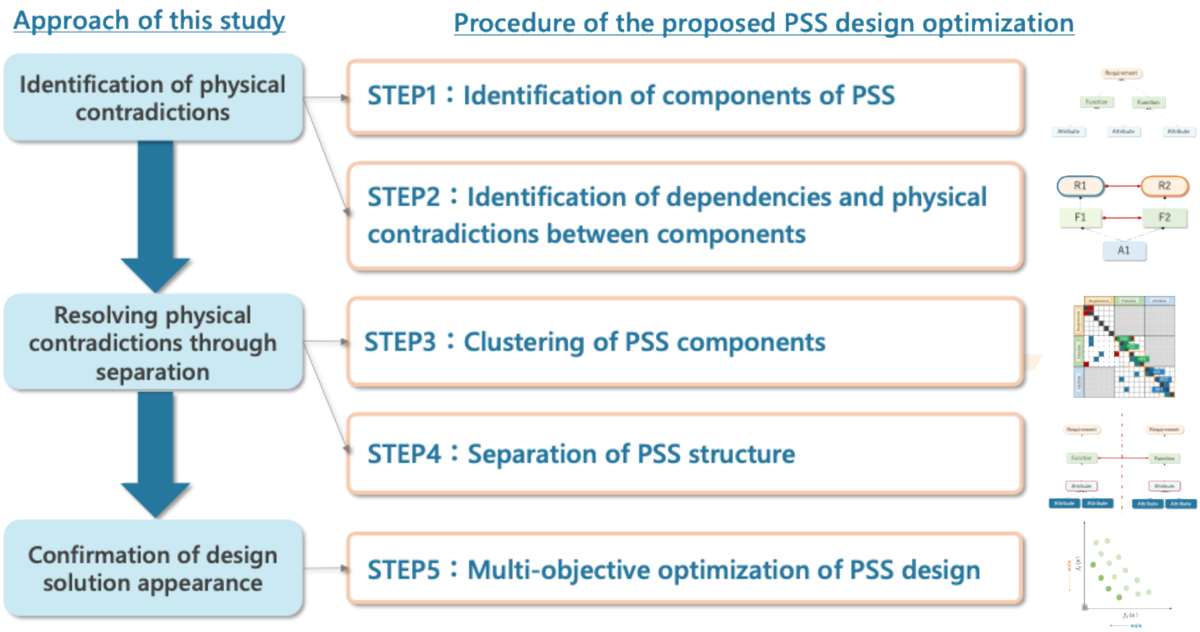


Figure 2. Overview of the proposed method

4 CASE STUDY

4.1 Description of the target case

To verify the usefulness of the proposed method, it was applied to a case involving the introduction of automated valet parking (AVP) at Lyon Airport in France [18]. This service utilizes automated driving technology to park vehicles automatically in a parking lot. Once the driver has entered and exited the designated area, the automatic guided vehicle (AGV) performs a series of operations on their behalf, including entry, transportation, and exit. In this case study, the various stakeholders involved in this PSS were identified, including airport customers, system integrators, parking lot operators, and other relevant parties. Their requirements were extracted and are shown in Table 3.

Table 3. Stakeholders and their requirements

Stakeholder	Role	Requirements
Airport user	Visit the airport for boarding and shopping	R1: Reduce parking fee
		R2: Reduce waiting time
		R3: Ease of retrieving luggage
Equipment provider	Provision of AGV equipment that is part of an AVP system	R4: Increase customer satisfaction
System integrator	Introduction and operation of AVP system	R2: Reduce customer waiting times
Parking operator	Lease land from airport to operate parking lot	R5: Improve operational efficiency
		R6: Ensure safety in the parking lot

4.2 Step 1: Identification of components of PSS

The components of the PSS involved in realizing each stakeholder's requirement were identified using the view model. For instance, the view model for the customer's requirement "R1: Reduce parking fee" identified "discount based on conditions" as a function to meet this requirement and "parking location from the boarding/exiting area" as an attribute related to this function.

4.3 Step 2: Identification of dependencies and physical contradictions between components

Figure 3 shows the result of constructing the MDM based on the components identified in Step 1. For instance, "F1: discount if parking position is far away" and "F12: move parking position closer to the boarding/exiting area" were identified as exhibiting a value of inhibition (-2) toward each other. This is due to their classification as physical contradictions stemming from the same attribute, “A1: Parking position from boarding/exiting area,” in the function-attribute DMM. Furthermore, the requirement-function DMM corroborates that the inconsistency between the two functions represents a trade-off between the requirements “R1: Reduce parking fee” and “R2: Reduce waiting time.”

4.4 Step 3: Clustering of PSS components

Figure 3 shows the outcomes of the clustering process conducted in MATLAB, based on the dependencies identified in Step 2. For instance, the attribute clusters “AC1: Exit time” and “AC3: Parking fee” were identified as being associated with the function “F1: Reduction in the parking fee if the parking position is situated at a distance.”

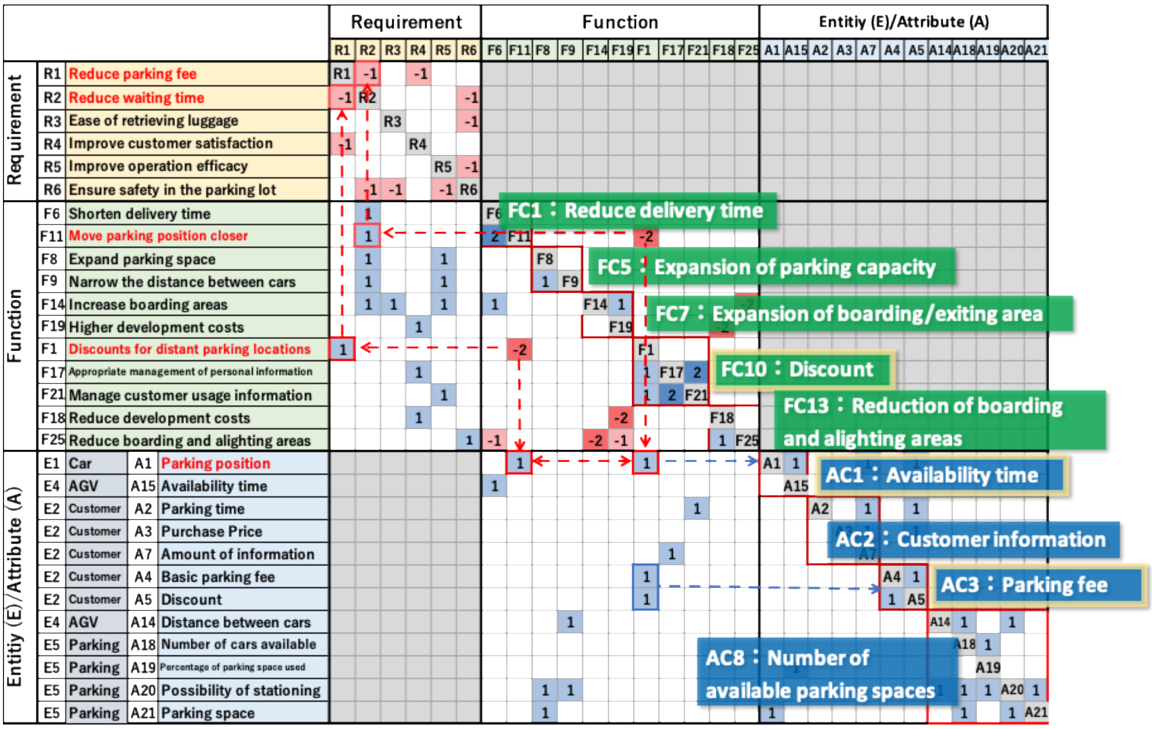


Figure 3. Part of the structured MDM

4.5 Step 4: Separation of PSS structure

A review of the constraint conditions for the same attribute, “A1: Parking position from boarding/exiting area,” revealed a physical contradiction between the functions “F1: analysis of the discount if parking position is far away” and “F11: parking position closer to boarding/exiting area” (Table 4). No overlapping range was found between the constraint conditions, resulting in no solution that can satisfy both requirements simultaneously. Thus, the factor impeding the realization of both functions is the physical contradiction of the spatial attribute of the parking location. To address this, we separated this contradiction from a spatial perspective. This separation was also reflected in the attributes “A6: Exit time” and “A4: Discount rate,” which should be considered concurrently.

Table 4. Result of separation

		Perspective of separation: space	Elements should be considered concurrently		
Target of separation		A1: Parking position from boarding/exiting area (AC1)	A6: Availability time (AC1)	A5: Basic parking fee (AC3)	A4: Discount fee (AC3)
Separation result	α	Close	Short	Fixation	No discount
	β	Far	Long	Fixation	Discount

4.6 Step 5: Multi-objective optimization of PSS design

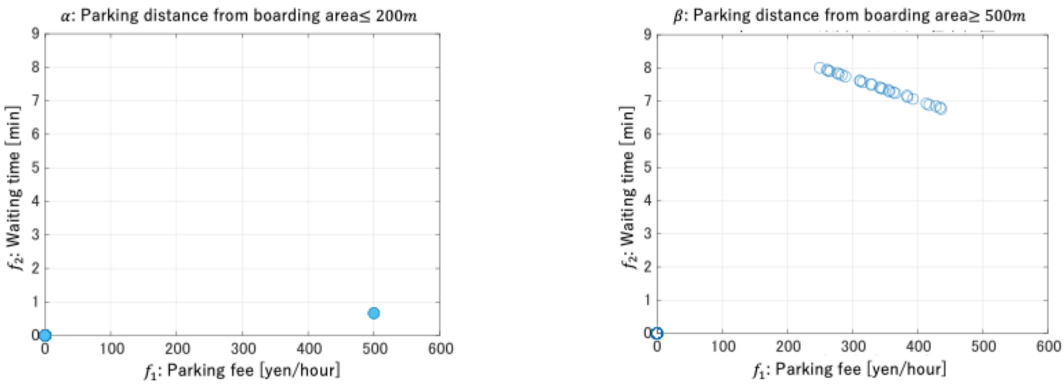
Based on the separation results, the upper limit of the constraint condition for requirement R2 was set for α, while the lower limit of the constraint condition for requirement R1 was set for β as threshold values. In light of the data presented in Table 5, the objective function was formulated in a simplified manner as Equations (1) and (2).

Table 5. Formulation of the PSS design

Parameter	Definition		Constraints/numbers
Objective parameters	f_1	Parking fee [yen/hour]	$f_1 < 500$
	f_2	Waiting time [min]	$f_2 < 1.5$
Design parameters	x_1	Basic parking fee [yen/hour]	$500 \le x_1 \le 600$
	x_2	Parking position from boarding area [m]	$(R2) 50 \le x_2 \le 200$, $(R1) 500 \le x_2 \le 1000$ $(x_\alpha, x_\beta) = (200{,}500)$
Constant parameters	V_{AGV}	AGV travel speed [m/min].	150

$$f_1(x) = \begin{cases} x_1 & , \quad x_2 \le 200 \\ x_1 - \min\,(50 + (x_2 - D_{th})/5) \times 10, x_1 \times 0.50), & x_2 \ge 500 \end{cases} \tag{1}$$

$$f_2(x) = 2x_2 / V_{AGV} \tag{2}$$



(i) $\boldsymbol{\alpha}$: Parking position from boarding/exiting area $\le \mathbf{200}[\boldsymbol{m}]$

(ii) β : Parking position from boarding/exiting area $\ge 500[m]$

Figure 4. Results of plots by multi-objective optimization

Figure 4 shows the results of the multi-objective optimization plots. An examination of the solutions for α in Table 4 yielded two options for the parking position x_2 at a distance of 50 m from the boarding area. One solution was derived with a non-discounted rate (500 yen per hour), while the other was calculated with a waiting time of 0.667 min, or approximately 40 seconds. These solutions satisfy the constraint condition of "waiting time f_2," which stipulates a maximum waiting time of less than 1.5 min. By contrast, under condition β, the parking position x_2 from the boarding/exiting area is over 500 m, resulting in a waiting time ranging from 6.5 to 8 min. However, several values were derived that offer discounts of up to approximately half the price, depending on the additional distance. Both solutions satisfied the constraint condition of "parking fee f_2." This indicates that a solution exists under both constraint conditions as a result of the separation.

5 DISCUSSION AND CONCLUSIONS

PSS designs that involve multiple stakeholders often fail into compromise initial requirements and constraints because value ranges may not simultaneously satisfy all requirements of stakeholders. To address this issue, this paper proposed a method to support PSS design by integrating TRIZ to the multi-objective optimization process. The application result revealed several practical implications of the method. The view model and MDM are utilized to identify not only the physical contradictions inherent in the PSS structure but also the individual components and their respective dependencies. Additionally, Step 3 aids in understanding the elements that should be considered simultaneously when applying separation. This approach allows for both the partial resolution of physical contradictions and the separation of other attributes potentially affected by the attribute values in question. This capability enables designers to anticipate that fundamental resolution of physical contradictions can be achieved through a comprehensive, top-down design approach for the PSS. Furthermore, by reflecting the results of the separation in the formulation of the objective function according to each constraint condition, we confirmed design solutions that were previously inaccessible. For instance, in Step 5, the separation results informed an optimization process to verify the presence of solutions within the search space. Unlike TRIZ, which is limited to qualitative solution searches, this study facilitates efficient solution searches and the potential for solutions was confirmed by applying an optimization method.

Despite these advantages, some limitations remain. First, the suitability of the separation in Step 4 relies on the designer's perspective and expertise, making it challenging to resolve issues with certainty. Therefore, converting the physical contradiction between functions into a trade-off between requirements or a technical contradiction in the requirement-function DMM can be effective. This allows for the application of the 40 inventive principles to resolve the trade-off from a different perspective. Second, the formulation presented in this paper is simplified. To identify more feasible design solutions, it is essential to further refine the formulation by incorporating more specialized information and optimizing the entire PSS structure, considering its relationship with the objective functions for other requirements. Lastly, the proposed method does not prioritize selecting the solution that maximizes the sum of each required value among those obtained through optimization. Therefore, applying the weighted percent of deviation (WPD) [19], which facilitates the weighting of each objective function in selecting Pareto solutions, may effectively address this issue.

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THE NECESSITY OF DEVELOPING AN EVALUATION SCALE FOR ASSESSING LEARNING EXPERIENCES IN DESIGN-ORIENTED CREATIVITY COURSE FOR KOREAN UNDERGRADUATES

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ABSTRACT
This research is part of a comprehensive study exploring the experiences of learners enrolled in a Design-Oriented Creativity Course for undergraduates. Previous research employed qualitative methods, specifically Grounded Theory, to investigate the formation processes of learning experiences from the learners' perspectives. This initiative aims to advance beyond existing research trends in Korea that evaluate learners from the perspectives of educators and researchers, seeking to establish a new theoretical model based on the learner's viewpoints. Additionally, the study intends to develop a scale that facilitates quantitative research by utilizing the theoretical model established through qualitative research. The scale's development will facilitate the assessment of the current Design-Oriented Creativity Course through our theoretical model, providing valuable insights and inspiration for educators and researchers. This research distinguishes itself by attempting to create a quantitatively verifiable scale using a localized theoretical model developed through qualitative research, diverging from existing research trends. The results of future research are expected to provide essential data for establishing new creativity education models from a design perspective.

Keywords: Learner Experience, Evaluation Scale, Scale Development, Grounded Theory

1 INTRODUCTION

Modern society is increasingly complex, and the problems surrounding human life are becoming increasingly intricate. As a result, the emphasis on individual's creative abilities to adapt to new situations and effectively solve problems is growing [1]. In this context, design educators and researchers in South Korea have also acknowledged the importance of creativity and explored its connection to design [2]. They have conducted numerous studies aimed at enhancing creativity through design education. However, most of these studies focus on how to train students from the perspectives of educators and researchers, often neglecting the learner's viewpoint as a primary variable. Additionally, research on creativity in the design field has predominantly involved borrowing Western theories of creativity and utilizing design thinking [3].

As the world transitions into a glocal era, the significance of local characteristics alongside universality is becoming increasingly important. Since the mid-20th century, Korea has rapidly developed, leading to increased social complexity and raising the issue of localization of theories across various academic fields. We aimed to conduct research that responds to these contextual and temporal demands. In previous studies, we conducted an in-depth exploration of learner's experiences in design-oriented creativity education in South Korea, focusing on perspectives that had not been thoroughly examined in prior research [3].

We employed Grounded Theory in our earlier research, which is one of the representative qualitative methodologies aimed at forming new theories based on contextual experiences. Grounded Theory is particularly useful when existing theoretical frameworks are limited in explaining certain phenomena or when no theory exists to account for a specific phenomenon. Most current research on creativity in Korea's design field is centered on external theories, with limited attempts to explore theories relevant to the Korean context. Consequently, we investigated the process of forming learning experiences among undergraduates enrolled in a Design-Oriented Creativity Course using Grounded Theory, resulting in a theoretical model based on field experiences.

However, while the theories developed through qualitative research are well-suited for explaining specific phenomena, they may lack generalizability [4][5]. Therefore, we aim to develop a quantitative tool to evaluate learning experiences in design-oriented creativity education based on the theories established through Grounded Theory.

This paper is part of the overall research project and intends to introduce the theoretical model developed through qualitative research and outline the study aimed at creating a scale for quantitative research. Our research, as a foundational study, ultimately aims to achieve two primary objectives. First, to establish a localized theory of design creativity tailored to the Korean educational context. Second, to enhance the quality of design-oriented creativity education, thereby improving learner's experiences and increasing the learning efficiency of creativity education. To this end, we have initially employed qualitative research methods to inductively analyze the experiential context of the currently implemented course and develop a theoretical framework. The scale developed in future research is expected to validly assess the creativity education experiences of learners, and the resulting data could be utilized in various ways, including improving existing curricula, exploring new research directions, and developing innovative educational models. Furthermore, we aim to continuously refine and strengthen our theoretical framework by integrating the data accumulated through future research with educational experiences from the field.

2 DEVELOPMENT OF A THEORETICAL MODEL

2.1 Grounded Theory

To develop a model of the process by which undergraduates form their experiences in a Design-Oriented Creativity Course, we adopted the Grounded Theory approach. Grounded Theory is a powerful tool for theory development when no existing theories explain specific phenomena, or when current theories are limited in doing so. It forms new theories based on the experiences, emotions, thoughts, and contexts of individuals who share certain experiences [6]. Grounded Theory is widely used in various research fields in Korea, including sociology, political science, public administration, social welfare, and education. This is because many theories introduced from the West often conflict with local contexts. Grounded Theory provides an explanation for phenomena that are difficult to explain with foreign theories, helping to understand them more deeply and contextually through localized theories [7][8].

This is because Grounded Theory adopts an approach that generates theories through an inductive process based on empirical data from the field. Grounded Theory researchers, adhering to the norms of qualitative research, exclude personal biases, preconceived notions, and assumptions about specific phenomena, to reconstruct the field experience according to the cultural context. Thus, rather than interpreting phenomena through existing theories, concepts, conventions, or preconceptions, they begin with the phenomena themselves, proposing new theoretical frameworks. Through this process, it becomes possible to produce reflections on new perspectives and processes grounded in local culture, effectively utilizing the Western methodology of Grounded Theory as a powerful tool for systematically organizing non-Western contexts [7][9].

Grounded Theory was jointly developed by Glaser and Strauss in 1967, and since then, various research traditions and norms have been established by numerous scholars. Currently, the most commonly used approaches are the systematic procedural approach developed by Strauss and Corbin, known as Straussian Grounded Theory, and Charmaz's constructivist approach [6][10].

Constructivist Grounded Theory is based on the idea that the researcher plays a central role in the flexible interpretation of data and the theory-generation process. This approach adopts an interpretive format, emphasizing flexibility in interpreting internal ideas at an individual level rather than adhering strictly to systematic research procedures [6][11].

In contrast, the systematic procedural approach relies on key concepts such as saturation and constant comparison. It involves collecting data until no new concepts or categories emerge concerning a particular phenomenon. This approach also outlines a structured process involving open coding, axial coding, and selective coding [10].

For our study, we adopted Straussian Grounded Theory among the various traditions of Grounded Theory. This choice was driven by our research aim to explore learners' experiences and meanings in the learning process based on data collected from research participants, ultimately seeking to enhance educational experiences and generate new theories. Consequently, we prioritized deriving theories through rigorous analytical processes rather than focusing on individual-level internal inquiry and interpretation. [9][12].

2.2 Structure of the Research and Overview of the Target Course

Our participants were students from the Department of Design at D University in Korea, who had taken the Design-Oriented Creativity Course. We recruited seven students and conducted in-depth interviews for coding procedures in Grounded Theory. Prior to the interviews, we obtained Institutional Review Board (IRB) approval to ensure the protection of participant's rights. Semi-structured interviews were employed to broadly understand the participant's experiences and contexts. Using semi-structured interviews, we provided a general guideline to facilitate participants' statements about various aspects, including their impressions of the course, experiences during the progression of the curriculum, and the connection between the knowledge gained from the course and their major. Additionally, new questions were generated based on participants' responses to explore both superficial events and deeper internal perspectives.

All interviews were recorded and transcribed by the researchers. Qualitative coding was then performed while interpreting the context of the transcribed data. Through the arrangement of meaning-based codes, we aimed to reconstruct the context that shapes participants' experiences. Each participant was interviewed at least three times at different times and locations to ensure consistency and context in their statements. The coding process involved three researchers with experience in qualitative research, and a triangulation process was conducted to cross-verify the coding results.

Table 1. Research Structure [13]

Stages	Construction of Research Methodology	
1: Philosophies	Interpretation of human social behaviour from an interpretivist perspective.	
2: Approaches	Data analysis and review through an inductive approach.	Inference and theory generation through an abductive approach.
3: Methodological Choice	Single-method qualitative research.	
4: Strategies	Grounded Theory (Strauss & Corbin, 1990, 1998).	
5: Time Horizons	Longitudinal study: Investigating the process of forming learning experiences over time.	
6: Techniques and Procedures	Data collection on learning experiences through in-depth interviews.	Ensuring validity and reliability through triangulation.

The Design-Oriented Creativity Course targeted in this study was developed in 2015 and has been implemented since 2019. From 2019 to the present, a total of 485 classes has been offered, with 17,022 students enrolled. Currently, over 400 students take the course each semester. The primary objectives of the course are to enhance design literacy and promote experiential education through a Learning by Doing approach, moving away from theory-centered learning. Specifically, the course aims to improve both individual and collective creativity by applying design thinking and processes. The course is designed as a flipped learning program. During the first seven weeks, students acquire foundational knowledge through online lectures, completing their theoretical preparation. The subsequent eight weeks focus intensively on mastering the design process [14].

This curriculum consists of individual and team assignments and is structured as an intensive program that covers both the theory of creativity and practical exercises through the design process. We selected this course, with its accumulated educational experience and numerous learners, as the subject of our study, collecting and analyzing experiences from those who have participated in it.

2.3 Results

Open Coding and Axial Coding

We conducted at least three in-depth interviews with each participant, collecting a total of 1,072 minutes of audio data and 175 pages of A4 text data. Using the three stages of Grounded Theory coding—open coding, axial coding, and selective coding—we conceptualized 100 codes from the participant's experiences and identified 84 codes related to educational experience formation. These conceptual codes were then grouped into 30 subcategories and 18 categories. The concepts and categories developed through this Grounded Theory research are presented in Table 2 [4].

Table 2. Results of the Conceptualization and Categorization of Learning Experiences in the Design-Oriented Creativity Course

Concept	Subcategory	Category	Paradigm
Mandatory Course	Lack of motivation for learning	Absence of learning motivation	Causal Conditions
Lack of Motivation for Learning			
Low Level of Interest			
Perceived Lack of Importance of the Course			
Shared Reputation of the Instructor	Lack of information about the instructor and the course	Lack of information	
Sense of Distance from the Instructor			
Unique Characteristics of the First-Year Experience at D University	Temporal characteristics		
Course Content Different from Expectations	Loss of anticipation for the course	Formation of negative impression of the course	Phenomena
Loss of Anticipation			
Uncreative Course Content			
Content Unrelated to the Course Title			
Low-Quality Course Content	Difficulty taking the course seriously		
Lack of Course Structure			
Low Level of Classroom Engagement			
Challenges in Receiving Real-Time Feedback	Discomfort in conducting online classes	Discomfort with the unfamiliar learning environment	
Decreased Focus in Class			
Increased Learning Burden			
High Proportion of Theoretical Content	Course heavily focused on theory	Content and teaching methods that increase fatigue in the course	Contextual Conditions
High Difficulty of Course Materials			
Ephemeral Knowledge			
Desire for Practical Knowledge			
Excessive Workload	Unreasonable weight of assignments		
High Degree of Freedom in Assignments			
Unfair Presentation Methods			
Insufficient Presentation Time			
High Level of Fatigue			
Instructor's Disregard for General Education Courses	Impression that the instructor undervalues general education courses	Factors contributing to distrust and rejection of the instructor	
Perception of a Relaxed Teaching Approach			
Instructor's Focus on Their Own Specialization			
Unreasonable Changes to Lecture Times	Instructor's authoritative course management		
Excessive Control			
Instructor's Ambiguous Language Habits	Feeling anxious about the instructor's		

Instructor's Negative Feedback	attitude		
Instructor's Passive Attitude			
Low Digital Literacy	Low digital literacy	Environmental factors causing discomfort in online settings	
Sense of Distance Among Peers	Communication challenges in an online environment		
Lack of Interaction			
Difficulty in Communication			
Decreased Proactiveness			
Decline in Collaborative Skills			
Follower Tendencies	Learner's passive tendencies	Need for support from instructors or peers during the learning process	
Pressure from Excessive Attention			
Difficulty in Asking Questions or Engaging in Discussions			
Leadership Tendencies	Learner's active tendencies	Clear sense of goal	Intervening Conditions
High Interest in Grades			
Stimulation of Learning Motivation	Stimulation and support from peers during group activities	Receiving support from instructors and peers during the learning process	
Experience of Multidisciplinary Collaboration			
Recognition of the Importance of Discussion			
Creation of a Free Classroom Atmosphere	Factors contributing to the formation of trust in the instructor and the course		
Unique Teaching Methods			
Active Feedback from the Instructor			
Motivation Provided by the Instructor			
Confusion Due to Free Group Formation	Factors that increase uncertainty during group activities	Factors causing unpleasant group activity experiences	
Grades Determined by Group Luck			
Dissatisfaction with Shared Responsibility			
Emotional Conflict			
Imbalance in Group Roles	Unfair group activity evaluation system		
Need for Fair Group Member Evaluation			
Experience of Anxiety	Negative emotional experiences during the course	Emotional harm caused by instructors and peers	
Experience of Depression			
Experience of Frustration			
Experience of Low Self-Esteem			
High Degree of Personal Freedom	Positive aspects of the online learning format	Leveraging the benefits of the online environment	
High Digital Literacy			
Ability to Repeatedly Review Course Content			
Active Group Participation	Active participation in the course	Independent exploration of the course's meaning	Action /Interaction
Valuing Diverse Experiences			
Exploring Rich and Diverse Reference Materials			
Disregard for the Course Process	Passive withdrawal	Neglecting the course's progression	
Abandonment of Course Participation	Active withdrawal		
Abandonment of Grades			
Understanding the Process of Ideation	Understanding the process of creative ideation	Forming positive experiences with creativity education	Consequences
Experiencing Creativity			

Enhancement Through Training			
Experiencing Diversity in Expression			
Increased Confidence	Improved self-confidence		
Acquisition of In-Depth Knowledge			
Problem-Solving Through Design	Experience in problem-solving through design		
Recognition of the Importance of Research			
Difficulty in Perceiving Educational Effectiveness	Experience of disappointment	Forming negative experiences with creativity education	
Doubt Regarding the Course's Effectiveness			
Unmemorable Course			
Regret Over Class Selection	Regret due to lack of information		
Feeling of Weak Relevance to Major	Perception of low relevance to their major	Demand for advanced content	

The paradigm model proposed in Grounded Theory was utilized to organize the conceptual relationships between the categories derived, as shown in Table 2. Figure 1 presents the paradigm model, illustrating the contextual flow of conditions, actions/interactions, and consequences centered around the phenomenon [4].

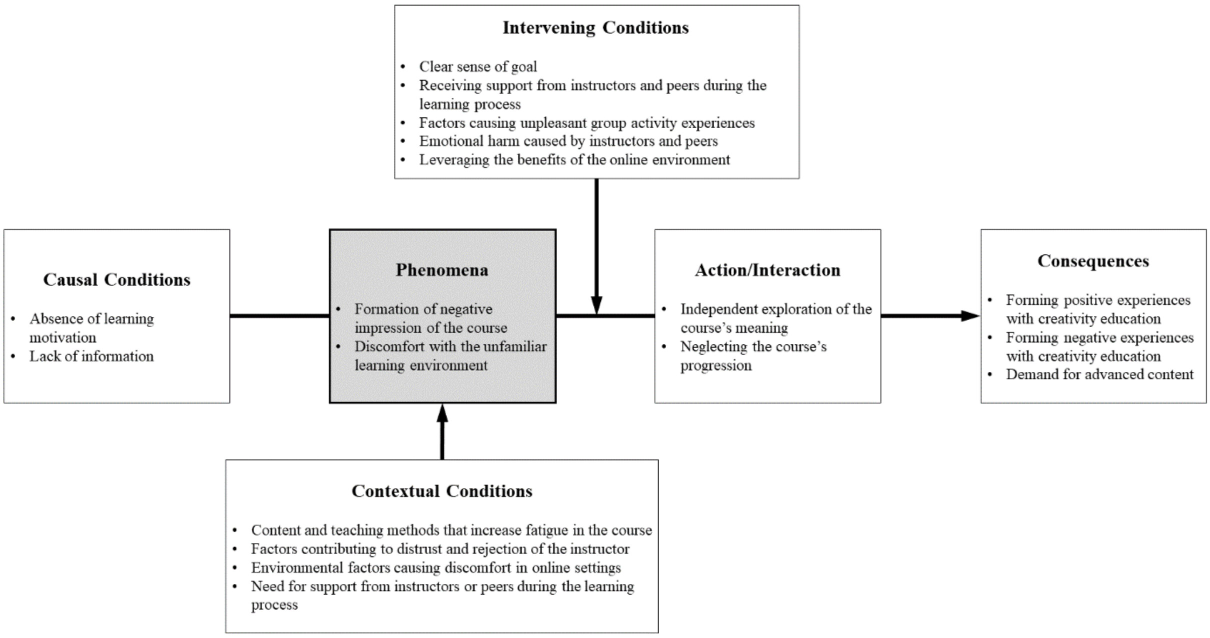

Figure 1. The Paradigm Model of Learning Experiences in the Design-Oriented Creativity Course

Core Category

We conducted selective coding based on the results of the open and axial coding previously performed. Selective coding is the process of developing a core category that encapsulates all the categories created through Grounded Theory. Through this process, we aimed to present a single sentence that intuitively captures the entire phenomenon. We derived the core category as: *"Efforts to overcome situations without choice and negative variables and factors in the learning process, striving to achieve personal motives through active exploration of meaning."* This is summarized in Table 3 [5][13].

Table 3. Core Category and Its Attributes and Dimensions

Core Category	Attributes	Dimensions
Efforts to overcome situations without choice and negative variables and factors in the learning process, striving to achieve personal motives through active exploration of meaning	attitude	Active/Passive
	personal motivation	Strong/Weak
	Negative contextual factors	Many/Few

The properties of our core category are attitude, personal motivation, and negative factors. Each property was dimensionally set as follows: attitude as 'active' or 'passive'; personal motivation as 'strong' or 'weak'; and negative factors as 'many' or 'few'. The extraction of core categories is an effort to simplify the key content of the theory by integrating complex conceptual terms and abstractly representing the process of experience formation.

Based on data collected from interview participants, we closely examined the semantic relationships between categories and concepts to refine and reorganize their experience formation process. As a result of reviewing and arranging the main categories that shape our theory, we simplified the process of experience formation into four stages: 'feel confusion', 'feel disappointment', 'attempts to adapt', and 'learning experience is formed'. This simplified process, along with the core categories, is summarized in Figure 2 [13].

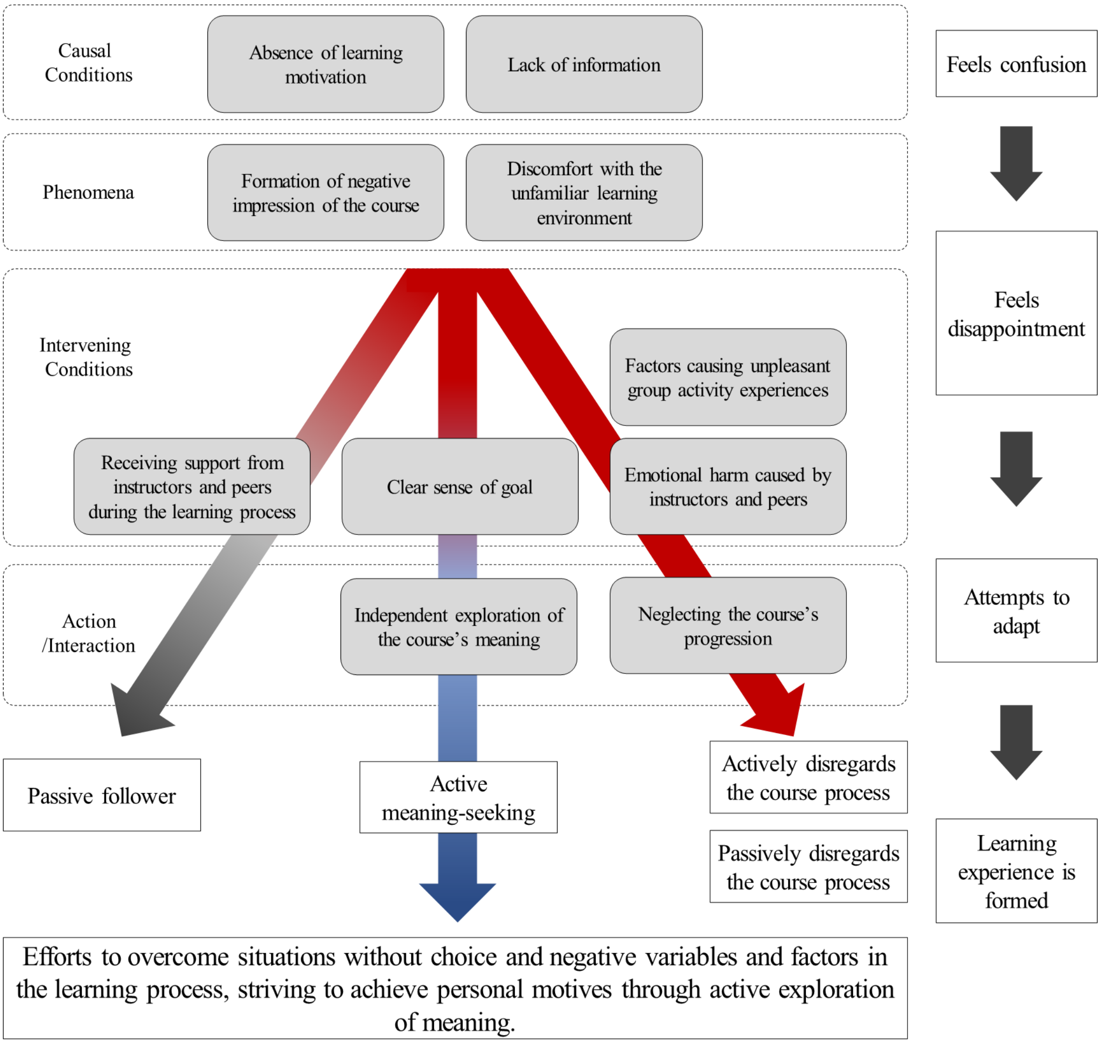

Figure 2. Conditional Matrix of Learning Experience Formation

We constructed a conditional matrix to visualize the process through which learners form their learning experiences by reorganizing the meaning-based codes and contexts we derived. The conditional matrix serves as a systematic tool that illustrates the relationships among the central phenomenon, conditions, and actions/interactions identified through Grounded Theory, representing the final stage that summarizes and integrates the study's findings.

In this conditional matrix, the central phenomena were identified as the “formation of a negative impressions of the course” and “discomfort with the unfamiliar learning environment.” The causes (causal conditions) of these phenomena include “absence of learning motivation” and “lack of information”, which are explained in the “confusion” stage. During the progression of the course, additional negative contextual conditions emerge, contributing to the “disappointment” stage. Subsequently, mediating conditions such as a “clear sense of goal”, “factors causing unpleasant group activity experiences”, and “emotional harm caused by instructors and peers” influence the strategies for actions/interactions adopted by the learners.

Depending on these conditions, learners choose strategies such as “independent exploration of the course’s meaning” or “neglecting the course’s progression”, corresponding to the “adaptation” stage. Finally, learners reach the “experience formation” stage, where they achieve personal motivation and discover unique meanings within the learning process by navigating through different conditions and strategies.

3 THE NECESSITY OF DEVELOPING AN EVALUATION SCALE

Survey scales are collections of specific questions designed to gather data for validating or demonstrating the issues addressed in research, serving as a prominent method of data collection across various social science fields. To collect data for evaluating and researching education, it is essential to have valid and verified scales that extend beyond merely assessing the characteristics, emotions, and preferences of survey participants [15]. Given that we have developed a new theoretical model through methods not previously attempted in the field of design in Korea, there is a clear need to develop a scale for its validation and practical application in education. To facilitate the broader application of our rigorously developed qualitative theoretical model, it is necessary to transform it into a quantitative research scale. This necessity arises from the abstract nature of the concepts related to the experiences that constitute the theoretical model. Concepts such as personal emotions, experiences, attitudes, responses, and outcomes are inherently abstract and require conversion into reliable and valid scales to be quantitatively utilized in research.

Therefore, we aim to develop and present a scale for measuring learning experiences based on the localized theoretical model previously established. This scale will reflect the local culture and context, capturing cultural specificity while also offering the potential for extensibility in future research endeavors. A simplified overview of the process for the forthcoming scale development research is illustrated in Figure 3.

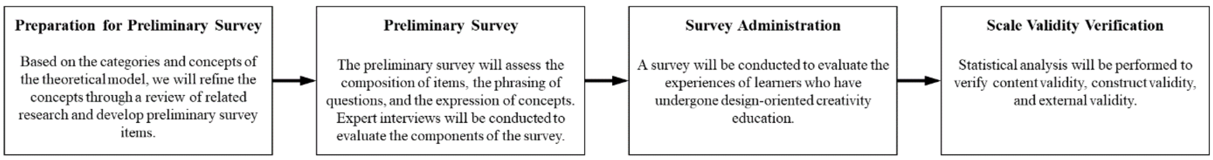

Figure 3. Research Process for Developing a Learning Experience Evaluation Scale

The process outlined in Figure 3 can be summarized as follows. First, during the preliminary preparation stage, we transformed the categories and concepts of our previously developed theoretical model into survey items. We reviewed these items to ensure their clarity and merged highly similar items while refining broad ones into more specific terms. Simultaneously, we examined related prior studies to secure the clarity of the concepts included in the survey and meticulously reviewed the set of preliminary survey items to maintain consistency with our theoretical framework.

Second, in the preliminary survey phase, we will determine the most effective questioning method and assess the reliability of the items with design education experts. This step will help finalize the question format for the main survey, and we will refine the item structure by revisiting the integration and segmentation process.

In the third stage, we will conduct a survey among students at D University in Korea who have taken Design-Oriented Creativity Course. In the fourth stage, we will analyze the data using statistical methods.

The goal of this analysis is to verify the content validity, construct validity, and external validity of the scale for evaluating learning experiences in design-oriented creativity education.
Through this research, we aim to convert a theory developed through qualitative methodology into a tool for gathering quantitative data, thus contributing to a novel form of design education research in Korea that has not been attempted before.

4 CONCLUSION

This study introduced the process of developing a localized theory within our project and outlined a study for developing an evaluation scale based on this theory. We discussed the significance of creativity and conducted an in-depth review of related research, leading to a comprehensive analysis of creativity studies in the Korean design sector. Consequently, we identified issues such as the absence of localized theories, reliance on foreign theories, a focus on the perspectives of researchers and educators, and a trend towards quantitative research. We utilized a Grounded Theory approach to develop a new theory based on the learning experiences of students in Design-Oriented Creativity Course. Research data were collected based on experiences of these participants who had engaged with the course. The raw data underwent analysis through the processes of open coding, axial coding, and selective coding, which were repeated until theoretical saturation was achieved. Through this process, we derived a Grounded Theory explaining the formation of learning experiences in the course. Focusing on the core categories identified in the Grounded Theory, we systematically formulated hypotheses for various subcategories and presented a conditional matrix that comprehensively integrates the core aspects of the Grounded Theory. This approach yielded distinctive results that previous research had not presented.
We aim to further advance this work by converting the developed qualitative theory into a quantitative research scale. This is because qualitative research can provide an in-depth interpretation of specific phenomena but may not be sufficient to explain them as universal phenomena. Therefore, we aim to conduct a study to transform the meaning-based codes, which are components of the Grounded Theory we developed, into items suitable for quantitative research. Through this process, we intend to explore the potential of using our Grounded Theory as a tool for measuring universal phenomena. To achieve this, following the outlined methodology, we will develop a scale through a meticulous process to ensure its reliability and validity, ultimately contributing to research on the design and development of educational models in the field of design. We anticipate that the scale, once developed, will facilitate the acquisition of reliable learning experience data, which can be broadly utilized for improving current curricula, designing new creativity education, and developing educational models.

ACKNOWLEDGMENTS

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DISSEMINATION OF DIGITAL HERITAGE USING MEDIA TECHNOLOGY - INTANGIBLE CULTURAL HERITAGE OF KOREA, DONGNAE CRANE DANCE -

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ABSTRACT
The digital transformation of cultural heritage is being pursued in various ways to enhance public awareness and accessibility through the use of media technology. This study focuses on converting the motion data of the bearer of the Intangible cultural heritage *'Dongnae Crane Dance'* in Busan, Korea, into digital media content. Research findings enables the exploration of ways to go beyond the conservation and transmission of cultural heritage in its original form, to widely disseminate it as sustainable digital heritage to contemporary users. This study is expected to serve as a starting point for the general public to re-evaluate the value of digital heritage and induce positive changes in perception. It is anticipated that the dissemination of the cultural value of the *'Dongnae Crane Dance'* through various media in the future will create multifaceted added value.

Keywords: Intangible Cultural Heritage, Digital Heritage, Digital Transformation, Digital Media Content

1 INTRODUCTION

Countries around the world are increasingly recognizing the importance of preserving their unique cult ural heritage as a key element in shaping national identity. In an effort to preserve and utilize their cult ural heritage, they are taking various measures[1].

The Korea Heritage Service's framework for cultural heritage utilization consists of three stages: production (investigation, excavation, research), preservation and management (restoration, preservation, management), and utilization (application, dissemination, diffusion). This preservation system connects the value chain from the discovery to the utilization of cultural heritage[2]. Tan and Rahama argued that effective interpretation and experience of digital heritage sites require a comprehensive method that accommodates diverse end-users, addresses narrative linearity, manages subjectivity in content creation[3]. They emphasize the need for methods that provoke thought instead of merely instructing, aligning with Freeman Tilden's view that interpretation should reveal meanings and relationships through direct experience and media, rather than just convey factual information[4]. Therefore, to enhance public awareness and empathy towards cultural heritage, it is necessary to develop utilization methods that disseminate cultural heritage from the user's perspective, going beyond the traditional viewpoints of conservation and transmission.

Around the world recognizes cultural values and potential of cultural heritage as important assets that must be actively preserved and protected. In particular, the Intangible cultural heritage of dance, which heavily relies on human transmission, increasingly necessitates the use of digital technology for recording and preservation to prevent its disappearance.

Motion capture, a prominent technology for digitally recording Intangible cultural heritage, precisely digitizes human movements to document and preserve the actions of traditional performers[5]. A notable example occurred at the 2016 International Intangible Heritage Film Festival in *Jeonju*, where the "*Salpuri* Dance" by the Mrs. Lee Maebang (former honorary bearer) was recreated as a hologram using motion capture data, allowing his daughter to perform alongside it[6]. Additionally, the "300 Years of

Hakka Kungfu" exhibition digitalized Hong Kong martial arts to spread the value of Intangible cultural heritage[7]. While utilizing advanced technology to replicate Intangible cultural heritage sustains its vitality and spreads its value, it faces limitations in maintaining long-term public interest. Therefore, there is a need to continuously expose Intangible cultural heritage content through highly accessible media to keep the public engaged.

This project aims to record the dance movements of Mr. Lee Seonghune the bearer of the Dongrae Crane Dance, an Intangible cultural heritage of *Busan* (Korea), using motion capture technology for conservation and transmission. Additionally, by utilizing the bearer motion data through digital media content, the project seeks to widely disseminate this heritage to a diverse audience, thereby establishing it as a digital heritage.

2 BACKGROUND

2.1 Korea '*Pungnyu*' *(풍류/風流)*

'Pungnyu' as the source of East Asian aesthetics, can be understood as a form of play or game between humans and nature. It is not merely a superficial observation of appearances but rather a deep engagem ent with the essence of phenomena, where one reaches the core of their true nature through playful exp loration. The term '*Pungnyu'* literally means *"to flow with the wind,"* suggesting a state of effortless m ovement without attachment or constraint, and can be viewed as a cultural phenomenon that embraces play or playfulness[8].

This concept is shared across Korea, China, and Japan, though with regional variations in emphasis. In China, '*Pungnyu'* highlights freedom and unrestrained spontaneity. In Japan, it takes on a more aestheticized meaning, emphasizing elegance, refinement, and the beauty of external appearance. In Korea, however, '*Pungnyu'* manifests in a more philosophical and spiritual manner, with a focus on religiosity and thought. This can be seen in the concept of '*Sininmyohap (神人妙合)*', which refers to the mystical union between gods and humans as co-subjects seeking integration. This idea is reflected in traditional Korean practices such as *'Pansori', 'Salpuri'*, and *'Gut'*, where the intervention of nature or spiritual forces is invoked to resolve human issues[9]. In this context, Korean '*Pungnyu'* functions as a mediator between the human world and the divine, where art becomes an act of ritual imbued with a strong shamanistic character.

Thus, Korean '*Pungnyu'* can be described as a state of entering into nature, breathing in harmony with it, and physically attuning oneself to the rhythms of life that nature evokes. It signifies an awakened and open mindset that is receptive to the universe and all living things.

The spirit manifested in Korean Pungnyu can be explained through three distinct types. First, there is *'Heung (興)'*, an energy that exudes positivity and brightness, actively engaging with reality through a lens of optimism. Second, *'Han (恨)'* reflects a passive, often melancholic view, embodying a sense of alienation and the internalization of a negative or sorrowful perspective on life. Lastly, *'Mushim (無心)'* represents a transcendent state that moves beyond the dualistic thinking of positivity and negativity, good and evil, joy and sorrow, a sense of detachment and equanimity toward the world.

Thus, the essence of Korean '*Pungnyu'* lies in the dynamic interplay of these three elements, which fluidly interact and harmonize with one another within a larger whole. This harmonious relationship becomes a vehicle for expressing the unique beauty of Korean aesthetics.

2.2 Dance using birds in intangible cultural heritage

Dances that imitate the form or movement of birds exist not only in Korea but also across the world. This can be attributed to humanity's admiration for birds' wings, which symbolize the desire to soar freely. In Korea, a specific dance centered around the crane has been preserved as part of its intangible cultural heritage. This dance reflects the essence of '*Pungnyu'*, Korea's aesthetic philosophy, symbolizing the transmission of divine virtues to humanity through the crane, as well as embodying images of longevity and prosperity.

Korea's intangible cultural heritage utilizing these techniques appears in two forms as follows.

The first is a dance where people wear masks and costumes in the shape of cranes and dance like real cranes. This is a court dance designated as Important Intangible Cultural Property No. 40. In this dance, performers wear masks and costumes resembling cranes, imitating the crane's movements, such as shaking its body, pecking at the ground with its beak, and touching beaks together before pulling away[10]. The second is the *'Dongnae Crane Dance'*, an intangible heritage of Busan, where dancers wear white robes and black hats, resembling the elegant figure of a crane[11]. This dance, named after the crane due to its visual similarities, highlights the free-spirited improvisation and personal flair that embody the core of Korean *'Pungnyu'*.

The crane dance of court dance

Dongrae crane dance of local cultural heritage

Figure 1. Korean intangible cultural heritage, Crane Dance

2.3 Local cultural heritage *'Dongnae Crane Dance'*

The *'Dongnae Crane Dance'* is a traditional folk dance that was designated as Intangible Cultural Heritage No. 3 in 1972 by the city of Busan, South Korea. Since there are no written records documenting the origins of this dance, its history has been reconstructed based on the testimonies of elderly residents from the Dongnae region.[12]

The '*Dongnae Crane Dance'* originated from the festivities surrounding the traditional tug-of-war held during the first full moon of the lunar calendar (Jeongwol Daeboreum). During this event, master dancers would perform various improvised dances. According to these testimonies, it is said that

"one renowned dancer, dressed in the traditional outer robe (dopo) and wearing a black hat (gat), began dancing gracefully to the deotbaegi rhythm. Someone remarked, 'It looks like a crane dancing,' and from that moment, the dance became known as the Crane Dance. Over time, movements imitating a crane were added, and this evolved into the Dongnae Crane Dance as we know it today."[13]

The movement of the black hat and flowing white dopo robe evokes the image of a crane in flight, while the refined, elegant gestures of the dance convey the symbolic grace and nobility associated with the crane. The performance of the Dongnae Crane Dance is typically divided into six sections, featuring 16 distinct dance movements, including elements of improvisation.

In terms of costume, the dancers wear white trousers and an outer robe (*dopo*), along with white socks (*beoseon*) and traditional straw shoes (*mituri*). Additionally, a black hat is worn on the topknot and a white tassel is tied on the chest.

The accompanying musical ensemble consists of a '*kkwaenggwari*', '*jing*', four janggu (double-headed drums), and four buk (barrel drums), with vocal rhythmic chants (gu-eum) enhancing the performance.

The music for this performance consists of instruments such as the '*kkwaenggwari*' (1), '*jing*' (1), *'janggo'* (4), and *'buk'* (4), and accompanied by *'gueum'* (vocal rhythmic syllables).

03 DIGITAL TRANSFORMATION OF INTANGIBLE CULTURAL HERITAGE

Currently, the *'Dongnae Crane Dance'* since the materials only record content passed down orally, lacks a systematic framework for converting its original knowledge resources into digital form, necessitating digital transformation to develop and promote content based on cultural resources. The process of producing digital media content for the *'Dongnae Crane Dance'* involves the following steps. First, the dance movements of Mr. Lee Seonghune, a recognized bearer of Intangible cultural heritage, are recorded using motion capture technology and systematically categorized for preservation. Second, the motion capture data is combined with VFX technology(such as 3D modeling texturing, lighting, and animation) to create a 3D character to consider historical accuracy. Third, this character is utilized to produce various digital media content. The specific production process is illustrated in Figure 2.

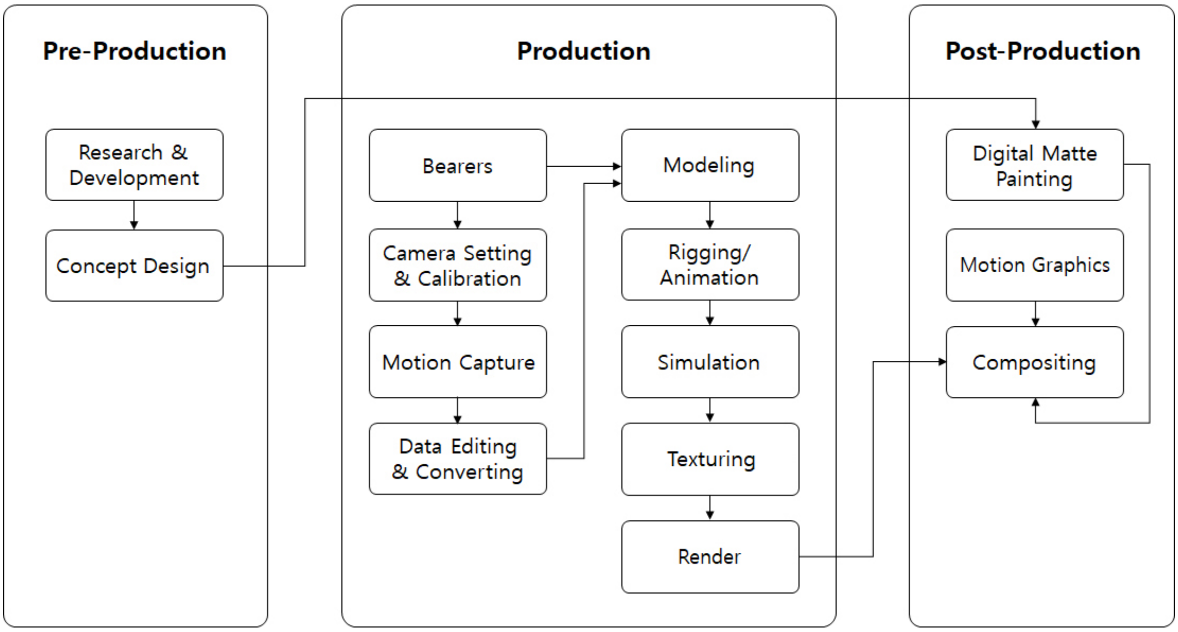

Figure 2. Digital media Content Creation Process using VFX Process

3.1 Digital Transformation of *'Dongnae Crane Dance'*

The process of digitally recording the dance movements of the *'Dongnae Crane Dance'* involves several steps. First, camera setup and calibration are performed to establish the center of the capture space. The position and orientation of the cameras are adjusted, ensuring optimal space for the subject's movements. Subsequently the dance movements of Mr. Lee Seonghune are recorded, using the OptiTrack motion capture system with 24 Primex cameras, capturing data at 180fps for approximately 13 minutes of continuous movement. The trajectory data of the performer's dance movements is then created by calculating the displacement differences from the 26 markers attached to various joints.

The initial editing of the original digital data is completed using Motive, while the secondary editing is performed using Autodesk Maya to correct any data loss or irregularities. Additionally, during the conversion process, the marker position values in the motion data are transformed into motion data with a skeletal structure. This transformed motion data is segmented by individual dance movements for systematic recording and preservation.

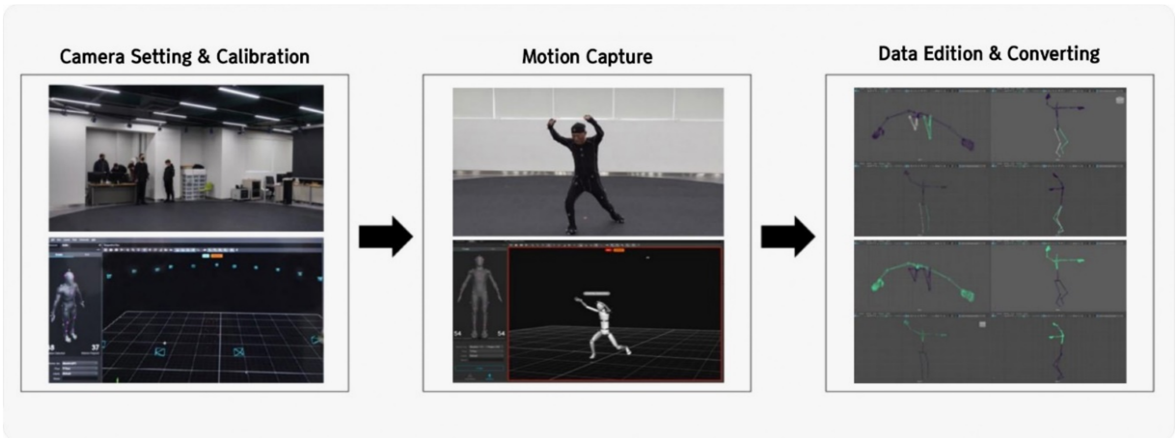

Figure 3. Dance Movement Data Extraction

3.2 Production of 3D Characters for *'Dongnae Crane Dance'*

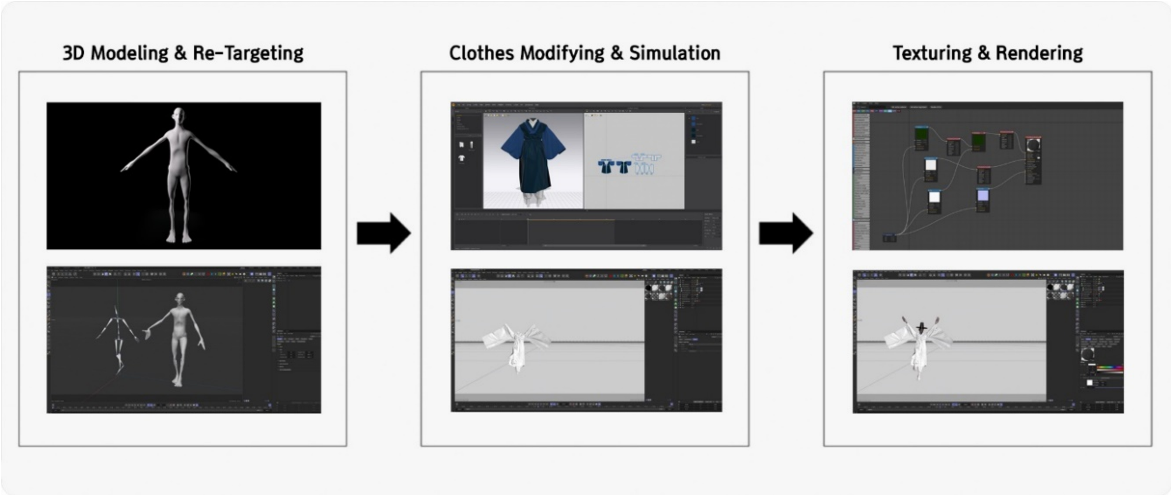

Figure 4. Re-Targeting the Motion Data from the 'Dongnae Crane Dance' onto a 3D Character

The process of re-targeting the motion data of the *'Dongnae Crane Dance'* to 3D characters involves several steps. This process utilizes software programs such as Blender (for frame drop), Cinema 4D (for modeling, rigging, animation, and rendering), and Marvelous Designer (for clothes modifying and simulation). First, to facilitate smooth rigging and animation, the motion data captured at 180fps is downsampled to 24fps and converted to FBX format for optimization. After completing these preliminary tasks, a 3D character is modeled with historical accuracy and the motion data is re-targeted to this character. Any errors that occur during this process, such as arm and finger distortions, are corrected through key animation. The re-targeted 3D character is then dressed in traditional Korean *hanbok*, and simulations are conducted. During this phase, errors arose due to the vigorous movements of the *'Dongnae Crane Dance'* and the flowing motion of the *hanbok*. These issues were addressed by directly modifying the skeleton of the motion data through rigging or adjusting the simulation values to ensure the '*hanbok'* moves naturally. Finally, detailed texturing is applied to the simulated 3D character, and camera and lighting setups are configured. The final rendering is completed using OctaneRender. The resulting 3D character is then utilized in the production of digital media content.

3.3 Production of Digital Media Content Utilizing Original Digital Data of *'Dongnae Crane Dance'*

The primary goal of this digital media content is to emphasize the diverse dance movements of the *'Dongnae Crane Dance'* through a short teaser trailer that employs cinematic ambiance and techniques. By stimulating the audience's curiosity, the teaser aims to generate interest and engagement with the *'Dongnae Crane Dance'*.

The dance movements of the *'Dongnae Crane Dance'* used in the production process do not depict the crane realistically ('*Moimu'*). Instead, the crane's imagery symbolically emerges from the dance itself. Among the 16 different dance movements, six that resemble the motions of a crane were selected: '*Hwalkaetjit ttwim'*, symbolizing the crane's cheerful flight; '*Dolim'*, mimicking a crane circling with wings fully spread as if searching for food; '*Jwawoo hwalkae'*, portraying a crane joyfully fluttering in delight; *beagim,* depicting a crane leaping with wings spread wide; '*Sokuri',* showing a crane walking leisurely with its wings slightly raised; and '*Ilja',* performed with both arms fully extended to the sides. Each dance movement symbolically reflects specific crane characteristics, bringing out the essence of the crane within the dance.

In the digital media content intro, the peaks and rocks of Geumjeongsan-Mountain, a prominent mountain in Busan, are used as a backdrop to effectively depict the image of '*hanryang'* in nature. Additionally, natural elements were added to the calligraphy of *'Dongnae Crane Dance'* to make it resemble part of a mountain, and an ink wash effect was used to create an elegant and sophisticated atmosphere like a scene in a movie. (Figure 5)

Figure 5 Dance Movements of the 'Dongnae Crane Dance', Composed like a scene from a movie

The digital media content concept is "introducing the dance movements of the *'Dongnae Crane Dance'* while the crane fly." Specifically, "A crane flies along the mountain ranges of Geumjeongsan- Mountain. As the crane's perspective follows, the dance movements of the *'Dongnae Crane Dance'* appear over an indistinct '*hoek'*(a line or dot made with a single brush stroke). The dance movements, crane, and '*hoek'* blend with nature, and the strokes, previously seen in fragments, form into the calligraphy of *'Dongnae Crane Dance'* and disappear with the wind." The concept design is as shown in Figure 6.

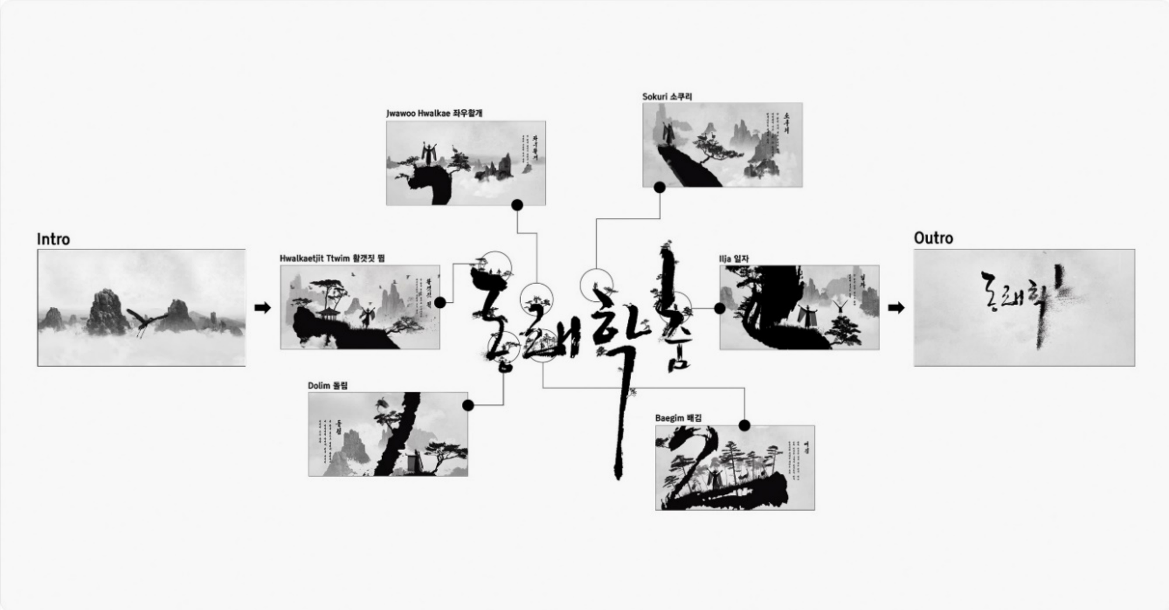

Figure 6. Digital Media Contents Concept Designed using the Calligraphy of ‘Dongnae Crane Dance’

(The calligraphy for “Dongnae Crane Dance” was produced by the Busan Metropolitan City Department of Culture and Arts.)

3.4 Utilization of Digital Media Content of *‘Dongnae Crane Dance’*

This digital media content was previewed at the LED Well on the 2nd floor of Dongseo University’s New Millennium Digital Contents Techno Tower. While no official surveys were conducted during the screening period, several positive pieces of feedback were received. Overall, the content was praised for its sophisticated and contemporary interpretation of traditional themes, successfully blending classic elegance with modern sensibilities. Additionally, the presentation of the dance’s name and style provided a deep understanding of the culture and significance of the *‘Dongnae Crane Dance’*. However, there were suggestions that accurate verification of the crane’s ecological characteristics is necessary, requests to enjoy various contents related to *‘Dongnae Crane Dance’*.

Figure 7. *Visitors Watching ‘Dongnae Crane Dance’s Digital Media Contents*

4 CONCLUSION

This project successfully recorded and preserved the dance movements of *'Dongnae Crane Dance'* by Mr. Lee Seonghune the bearer as digital data and produced it as digital media content.

The original digital data of the *'Dongnae Crane Dance'* consists of digital motion data of the dance movements of bearer, utilizing motion capture technology, and a 3D character that can be used in various digital content. The digital media content created using these two digital resources effectively conveys the unique sentiment of the *'Dongnae Crane Dance'* by capturing the core dance movements in a brief and intense presentation, delivering modern sensibilities and appeal.

The outcomes of the project leverage the dissemination power of digital media to enhance accessibility and re-evaluate the values of diversity and coexistence and can mark a step forward in enhancing public perception and recognition.

Future plans involve using the digital resources of the *'Dongnae Crane Dance'* in a One Source Multi-Use (OSMU) approach to spread across various media. This strategy aims not only to preserve and reproduce the original form of the *'Dongnae Crane Dance'*, thereby enhancing its cultural value but also to create added value in multiple areas such as regional promotion and tourism enhancement.

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THE NON-MATERIAL ASPECT OF ENGINEERING DESIGN: CONSTRUCTING AN ENGINEERING THINKING MODEL LED BY SERVICE DESIGN

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ABSTRACT
With the digital transformation of society, factors such as culture, emotions, experiences, meanings, values, and other non-material aspects are becoming central issues in current engineering design processes. The design objects in engineering are undergoing a transformation from tangible artifacts to intangible artifacts, yet the functional rationality engineering thinking models struggles to effectively engage in discussions concerning non-material aspects. This paper adopts a constructivist philosophical paradigm, rooted in the Contemporary Chinese design theory system, to review the development of service design in engineering activities and construct an engineering thinking model led by service design. The proposed engineering thinking model can improve and even resolve non-material aspects of engineering design issues, complementing traditional functional rationality engineering thinking model, guiding engineering design towards a more inclusive future transformation, and providing new perspectives and methods for progress in the field of engineering design.

Keywords: Service Design, Engineering Thinking Model led by Service Design, Engineering Design, Thinking Model, Non-material Factors

1 INTRODUCTION

Engineering is a deliberate human activity that creates artificial objects and realities using various resources and elements[1]. From the ancient ancestors of primitive societies constructing nests and dwellings to meet the survival needs of their clans, human history of creating social artifacts through engineering began[2]. Throughout history, from metallurgy and papermaking to water management, transportation, high-speed trains, airplanes, navigation, and aerospace, humans have created countless engineering marvels. Engineering has become a concentrated reflection of the essential forces of humanity, creating the material foundation of human society, charting the material progression of human civilization, driving changes in social structures, shaping the human spiritual world, and lifestyle.

Since the Industrial Revolution, emerging production technologies have driven changes in modes of production, leading to increasing specialization in engineering activities[3]. "Design" has become a crucial link in the integrated process of engineering concepts, design theories, design methods, and design knowledge[4], separating from implementation, operation, maintenance, and other steps in engineering activities. Engineers now unanimously agree that a design perspective must precede material creation activities, making engineering design the origin and source of social productivity development. The level of engineering design has become one of the decisive factors in a country's or region's comprehensive innovation and competitive capabilities.

Since its inception, engineering design has been influenced by the technical rationality of the Industrial Revolution, becoming one of the fields most influenced by a paradigm of rational problem-solving. This influence has led to the development of engineering thinking models characterized by functional rationality, adept at addressing material aspects of engineering problems such as materials, technology, structures, and functions. For example, Peter Checkland proposed functional decomposition and part-whole theory in engineering, focusing on analyzing the sub-functions of each part rather than the composition of the whole[5]. By identifying and analyzing sub-functions, Engineering designers can define the relationship between the functional parts of an engineering concept and the whole concept[6]. Herbert A. Simon suggested understanding and analyzing complex systems through a hierarchical structure. Complex systems can be divided into multiple levels, each with specific functions and characteristics. Higher-level decision-making and control involve lower-level operations and execution, simplifying the analysis of complex problems[7]. Christopher Alexander emphasized the holistic nature of design, suggesting that architectural design should consider all components and their relationships, emphasizing the interaction between architecture, the environment, and society, advocating design as a holistic, organic process[8].

However, with the increasing refinement of material civilization, attention to tangible engineering is gradually diminishing, leading to a growing demand for service design in the engineering interaction process, with an increasing need for intangible experiences. Engineering design is undergoing a transformation from tangible artifacts to intangible artifacts. As Richard Buchanan pointed out, "The thing is important, but the halo around the thing is more interesting." [9] Non-material attributes such as culture, emotions, order, experiences, values, meanings, and other intangible aspects are becoming central issues in current engineering design processes. In the service economy era, engineering has been endowed with new values and meanings. Traditional tangible engineering projects alone cannot meet people's needs for engineering. Only when tangible engineering projects and intangible service design are organically combined can a complete engineering composition be achieved. However, the functional rationality engineering thinking models struggles to effectively engage in discussions concerning non-material aspects, resulting in current engineering designs inadequately considering user experiences and needs at the micro level, overlooking local cultural values and lacking humanistic care at the meso level, and failing to shape social structures and drive social development at the macro level.

The first Design Methods Conference held in London in 1962 marked the beginning of design research. Today, contemporary design research has broadened the scope of design. In contrast to traditional engineering design as a phase of engineering activities, design is now actively involved in all phases of engineering activities, focusing on complex socio-technical issues for the future. In 1984, Shostach proposed the design concept of combining tangible products with intangible services in "Designing Services That Deliver." [10] Subsequently, the concept of service design gradually emerged and began to be widely applied across various fields such as management and industry. Currently, academia generally considers service design emphasizes the understanding of the user's context, and requires its grasp of the holistic and systematic, and the ultimate output of meaningful results[11]. The introduction of service design provides a new perspective beyond technical rationality for understanding non-material aspects of engineering design discussions.

2 RESEARCH QUESTIONS

This paper aims to introduce the perspective of service design into engineering activities, construct an engineering thinking model led by service design, and shift from the material practices of traditional engineering design to the experiential practices of service design.

This research includes one primary research question and two secondary research questions.

[PRQ] How can service design thinking be integrated into engineering design to address contemporary challenges in engineering design at the levels of basic functionality, cultural experience, and social value, and promote a more comprehensive and sustainable future development of engineering?

[SQ1] How can we trace the evolutionary process of service design in engineering activities at different times, recognize the characteristics and roles of service design in engineering activities in different historical contexts, and then clarify the features and capabilities that contemporary engineering activities should possess in service design?

[SQ2] How can we construct a service design-led engineering thinking model and apply it to address non-material attribute issues in contemporary engineering design?.

3 THEORETICAL FOUNDATION

This research adopts the "Contemporary Chinese Design Theory System" proposed by Zou Qichang as the theoretical tool to understand phenomenon of service design in engineering activities, and thus provides guidance for the construction of engineering thinking model led by service design.

Zou Qichang's "Contemporary Chinese Design Theory System" is rooted in traditional Chinese design resources while incorporating advanced design experiences from around the world. It consists of three main systems: Meta Design Theory System, Parx Design Theory System, and Social Design Theory System, focusing on the fundamental concepts, basic thinking, basic categories, basic systems, core values, and other issues of the theoretical objects. The Meta Design Theory System studies the basic concepts and categories of the design object. The Parx Design Theory System addresses specific design problems in the artificial world. The Social Design Theory System explores design order and social order.

Traditional engineering design often emphasizes material aspects such as technology and structures, while design led by designer focuses focus on non-material aspects such as humanity, culture, and society. Zou Qichang's theory connects basic functionality, cultural experience, and social value, facilitating the analysis of service design problems in engineering design from synchronic, historical, and morphological perspectives. It helps identify the reasons for intangible user experiences in engineering, understand the necessity of introducing service design into engineering, and better comprehend non-material aspects in engineering design phenomena. The basic framework of Contemporary Chinese Design Theory System as can be seen in figure1.

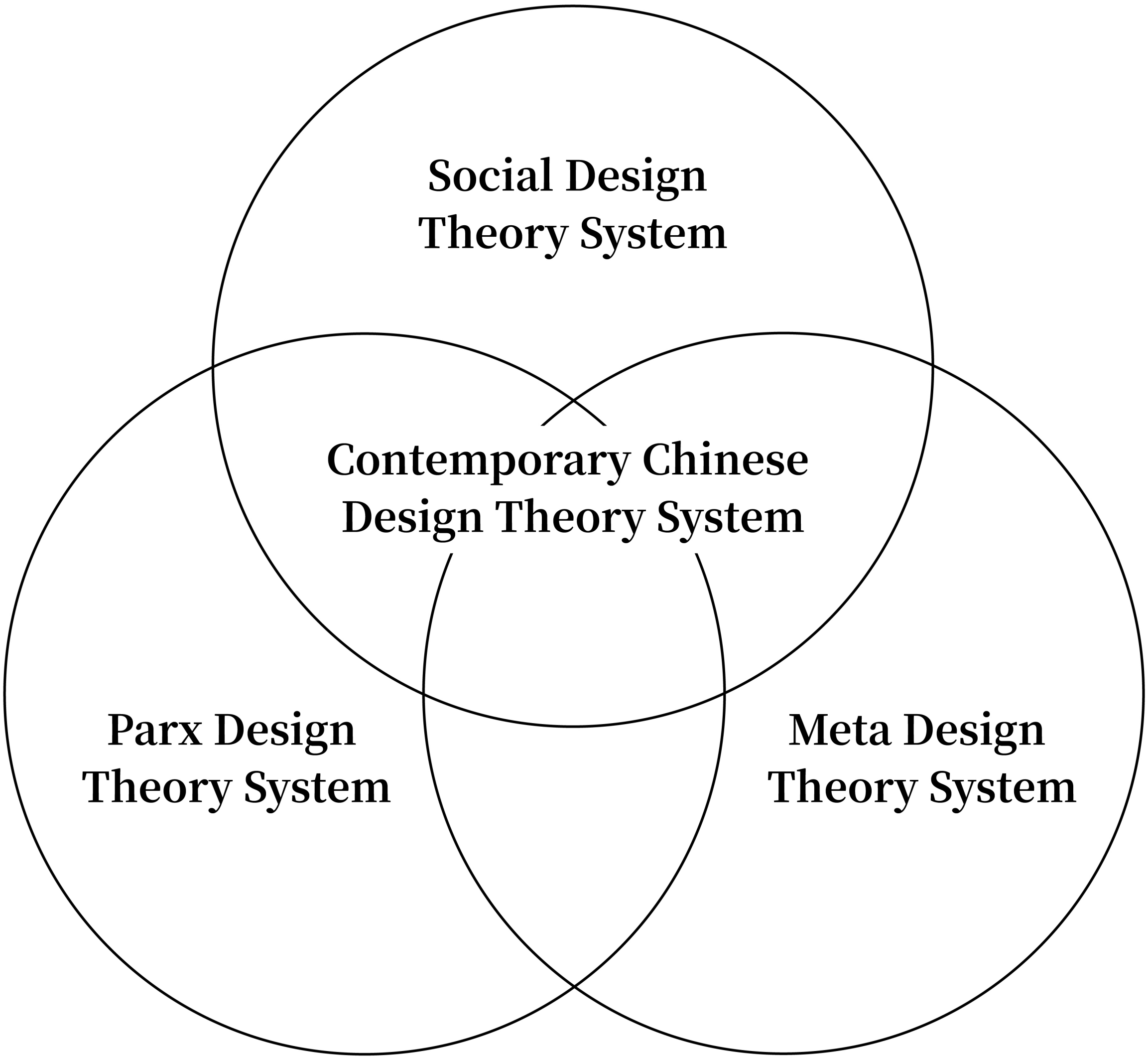

Figure 1. Basic Framework of the Contemporary Chinese Design Theory System

4 EVOLUTION OF SERVICE DESIGN IN ENGINEERING ACTIVITIES

In order to delve into the evolution of service design in engineering design and its impact across different periods, to gain a clearer understanding of the importance and necessity of service design in engineering design. We analyze the development trajectory of service design in engineering activities during the handicraft era, the industrial revolution era, and the digital age from a diachronic perspective, dissecting the characteristics and roles of service design in different historical contexts. This lays a more profound and comprehensive foundation for the subsequent construction of an engineering thinking model led by service design.

4.1 Service Design Issues in Engineering during the Handicraft Era

During the handicraft era, although service design did not exist explicitly in its modern concept, its essence and practices played a crucial role in engineering activities. While there were no dedicated service designers in the modern sense, craftsmen integrated the concepts of service design into their design work.

In the handicraft era, the main actors of service design were skilled craftsmen. Craftsmen emerged as technically specialized roles with the refinement of social division of labor. As early as the Paleolithic era, with the emergence of technical specialization, the identity of craftsmen was born. With the progress of human society, craftsmen evolved into an independent social group, inheriting rich experiential knowledge and mastering certain technical principles. During the handicraft era in engineering activities, craftsmen not only considered the basic functions of buildings in their design and implementation of engineering projects but also took into account the needs and experiences of users. This implies that engineering activities during the handicraft era already began to focus on the emotional and social values of the design objects.

Taking the garden engineering of ancient China as an example, these engineering activities not only provided spaces for daily living, but also reflected the owner's and aesthetic pursuits through landscape layout and architectural design. Craftsmen needed to consider adapting to the natural environmental factors of different seasons and climate conditions, continuously observing adjusting design schemes, and optimizing the garden to meet different functional and aesthetic needs at different areas. This diverse demand for practical functions, emotional value, and aesthetic pursuit precisely the vivid embodiment of service design in the engineering projects of the handicraft period.

Overall, although service design during the handicraft era did not have a modern clear definition, the core concepts of user-centricity, focus on experience and emotional value, and iterative and optimized design practices were already reflected and practiced. This laid a solid foundation for the subsequent development of service design in engineering.

4.2 Service Design Issues in Engineering during the Industrial Era

With the wave of the Industrial Revolution sweeping through society, the field of engineering design underwent significant changes. During this period, production shifted from traditional workshop craftsmanship to mechanized large-scale production. The scientific and technological inventions became the core drivers of engineering progress, accelerating the pace of industrialization. In this context, modern engineering design and the role of engineers emerged, fundamentally altering the role of service design in engineering.

During the Industrial Revolution era, the design protagonists in engineering shifted from craftsmen to modern engineers with defined professional identities and social status. With the specialization of engineering roles, the role of engineering designers began to emerge, specializing in design work. Since engineering activities often required collaboration among numerous technical personnel, engineers played a crucial role in service design, considering not only the technical implementation of engineering projects but also the social value and user experience of the projects.

The concept of service design saw further development and refinement during the Industrial Revolution era. Engineers began to realize that engineering activities not only took place in the natural environment but also aimed to create artificial environments suitable for human living. They focused on intangible artifacts such as social orders guided by engineering projects. Engineering designers needed to consider the social benefits of engineering projects based on design standards and regulations, transforming design concepts into concrete implementable solutions. During this period, engineering activities achieved the basic functions of engineering projects and began to explore usability aspects such as human-machine interactions.

4.3 Service Design Issues in Engineering during the Digital Age

Since the 19th century, the rise of industrial production has greatly propelled changes in the production methods of engineering design and the industrialization process of society. The ongoing Fourth Industrial Revolution we are experiencing is characterized by the deep integration of the internet and artificial intelligence. Engineering design is transitioning towards digitization, presenting more possibilities for service design in engineering.

In engineering design in the digital age, engineering projects have shifted from material to non-material attributes. Engineering designers need to collaborate with experts in technology, society, management, and other fields for innovation, and co-create value. This integrated business design focuses on the technical implementation of products, emphasizes service design and delivery to meet user needs and enhance user experience. During this transformation, the design protagonists in engineering have evolved into a composite system composed of engineering designers and highly intelligent artificial intelligence algorithms and robots. Engineering designers continue to undertake technical, creative, and cultural work. While artificial intelligence reduces the technical barriers to participation in engineering design, allowing stakeholders in engineering projects to participate more in the conceptual generation of engineering design.

Firstly, engineering design objects in the digital age exhibit significant characteristics of multi-disciplinarity, complexity, and diversity. Engineering designers are beginning to possess interdisciplinary knowledge systems to solve nonlinear engineering design problems. Engineering design now not only addresses tangible issues such as technology, structures, and aesthetics but also tackles intangible aspects such as the interaction between engineering objects and social systems, human experiences, interactions, values, and more. The service design is increasingly involved in the entire process of engineering, helping engineering designers better understand user needs, preferences, and behavioral habits to design products and services that are more aligned with user expectations. Engineering designers are beginning to focus on user-centered design, gaining deep insights into user needs, expectations, and challenges, tailoring solutions that better meet practical requirements for users.

Secondly, in engineering in the digital age, service design also involves optimizing interaction processes, interface design, information architecture, and more for products or services. By designing intuitive, concise, and user-friendly interfaces, users can complete tasks more quickly, reduce cognitive burdens, and enhance the fluidity and efficiency of their experiences. Personalized design and intelligent recommendation systems can provide users with more personalized service experiences based on their preferences and behavioral habits, enhancing user engagement and satisfaction.

5 CONSTRUCTION OF A ENGINEERING THINKING MODEL LED BY SERVICE DESIGN

This chapter mainly constructs an engineering thinking model led by service design from the dimensions of basic functions, cultural experience, and social value, in order to understand and even solve the intangible aspects of engineering such as culture and value.

5.1 Basic Functionality Dimension of the Thinking Model

Today, in rapidly evolving technological and increasingly complex social environments, the field of engineering faces unprecedented challenges that often exceed the scope of solutions provided by a single discipline or technology. Service design offers a powerful tool for integrating knowledge and optimizing engineering practices across different fields.

Firstly, the core of the engineering thinking model led by service design lies in promoting interdisciplinary integration. When faced with complex engineering problems, traditional single-discipline approaches often struggle to provide comprehensive solutions. The engineering thinking model led by service design encourages collaboration among experts from different fields, integrating specialized knowledge from various disciplines, enhancing the efficiency and effectiveness of problem-solving, coordinating the needs and constraints of different parties, and achieving more balanced and comprehensive engineering solutions.

Secondly, the engineering thinking model led by service design emphasizes the construction of dynamic technology clusters. In a rapidly changing technological environment, static technological thinking is no longer sufficient for the needs of the engineering field. Service design advocates for design-centered approaches, abandoning singular technological solutions, constructing interactive and highly integrated dynamic technology clusters to supplement the limitations of single technologies, support continuous technological updates and innovations, encourage the development of new technologies, and fundamentally improve engineering issues from the source to achieve sustainability.

Thirdly, the engineering thinking model led by service design can fully understand and address the complexity and uncertainty of engineering problems in social systems. Contemporary engineering problems within social systems often involve nonlinear, complex, dynamic interactions among multiple factors. The proposed thinking model can swiftly respond to the anti-solution problems in engineering systems, address new demands arising from changing contexts, and significantly enhance the capacity to solve complex social problems in engineering.

5.2 Cultural Experience Dimension of the Thinking Model

The onset of the Industrial Revolution brought about significant technological advancements and economic prosperity to society, empowering further transformations of the natural environment and the creation of artificial worlds by humans. This greatly altered human survival and lifestyle but also led to a distancing in social relationships between individuals, between humans and nature, and between humans and society. The cultural experience dimension responds to the exploration of cultural experiences in engineering. Service design not only focuses on technological progress and economic prosperity but also strives to establish connections between humans and nature, society, exploring and responding to human aspects in engineering design, constructing a more harmonious and sustainable artificial world.

Firstly, the engineering thinking model led by service design can improve traditional thinking centered solely on technology or products, shifting towards a user-centered approach, respecting individual differences, returning to care for human nature, and responding to societal needs. Engineering projects are not limited to a technical perspective but integrate more humanistic care and social responsibility into engineering design. Through the proposed thinking model, engineers can better understand user needs, creating solutions that not only meet functional requirements but also enhance the quality of life for users.

Secondly, in constructing interactions between humans and society, nature, engineering design should focus on the combination of technology and life, considering the harmonious coexistence of design with the environment, life, and civilization. Engineers, in the design process, can consider the impact of engineering on the natural environment, pursue long-term ecological development, integrate sustainable development principles into design, and achieve harmonious coexistence between humans and nature, technology, and ecology.

Thirdly, in imbuing artificial worlds with meaning and value, the purpose of service design is to enhance human well-being. Engineers should contemplate the impact of engineering on society and culture, as well as how it satisfies people's aspirations for a better life. The goal of service design is to create a living environment that is both high-tech and filled with humanistic care, embodying integrity, natural human qualities, and visions of urban life, providing users with cultural experiences that align with local cultural backgrounds.

In summary, at the cultural experience dimension, the engineering thinking model led by service design requires engineers to consider not only the performance and efficiency of technology in the design process but also focus on human needs, social responsibilities, and environmental sustainability. Through service design, engineering designers can construct a more harmonious, sustainable artificial world, achieving unity between humans and nature, design and environment, design and life, design and civilization, technology and life.

5.3 Social Value Dimension of the Thinking Model

The engineering thinking model led by service design aims to create valuable user experiences and humanistic values, transforming engineering projects from singular technological solutions to comprehensive social and cultural phenomena, thereby realizing the social value of engineering.

Firstly, the service design-led engineering thinking model understands the localized needs and real constraints nurtured by different regional cultures, emphasizing the integration of engineering projects with local cultures and respecting cultural diversity. Service design can connect stakeholders from different cultural backgrounds, ensuring that engineering projects meet the needs of local communities, promoting overall harmony and development in society.

Secondly, in terms of the experience and humanistic value of engineering projects, the engineering thinking model led by service design transcends a purely technological perspective, focusing on the intangible values constructed by engineering projects. It encourages engineers to create interactive interfaces between humans and artificial environments, natural environments, constructing harmonious relationships between humans and society, humans and nature. By deeply understanding user needs and social values, the proposed thinking model takes a holistic approach from the perspective of the social system, assuming the responsibility of safeguarding the future development of society.

Thirdly, the engineering thinking model led by service design advocates a high sense of responsibility towards society, improving design purposes, returning to social morals and ethical norms, using the power of engineering design to balance the multiple interests in societal contexts, driving social reform and long-term development. It actively promotes engineering design for marginalized groups, addressing the unique challenges faced by these groups under existing designs, pushing society towards a more just, equal, and inclusive direction. It can provide a forward-looking perspective, pursuing a long-term and holistic order of human development, using engineering design to strive for a high-quality state of unified material and spiritual civilization. Basic Framework of the engineering thinking model led by service design as can be seen in figure2.

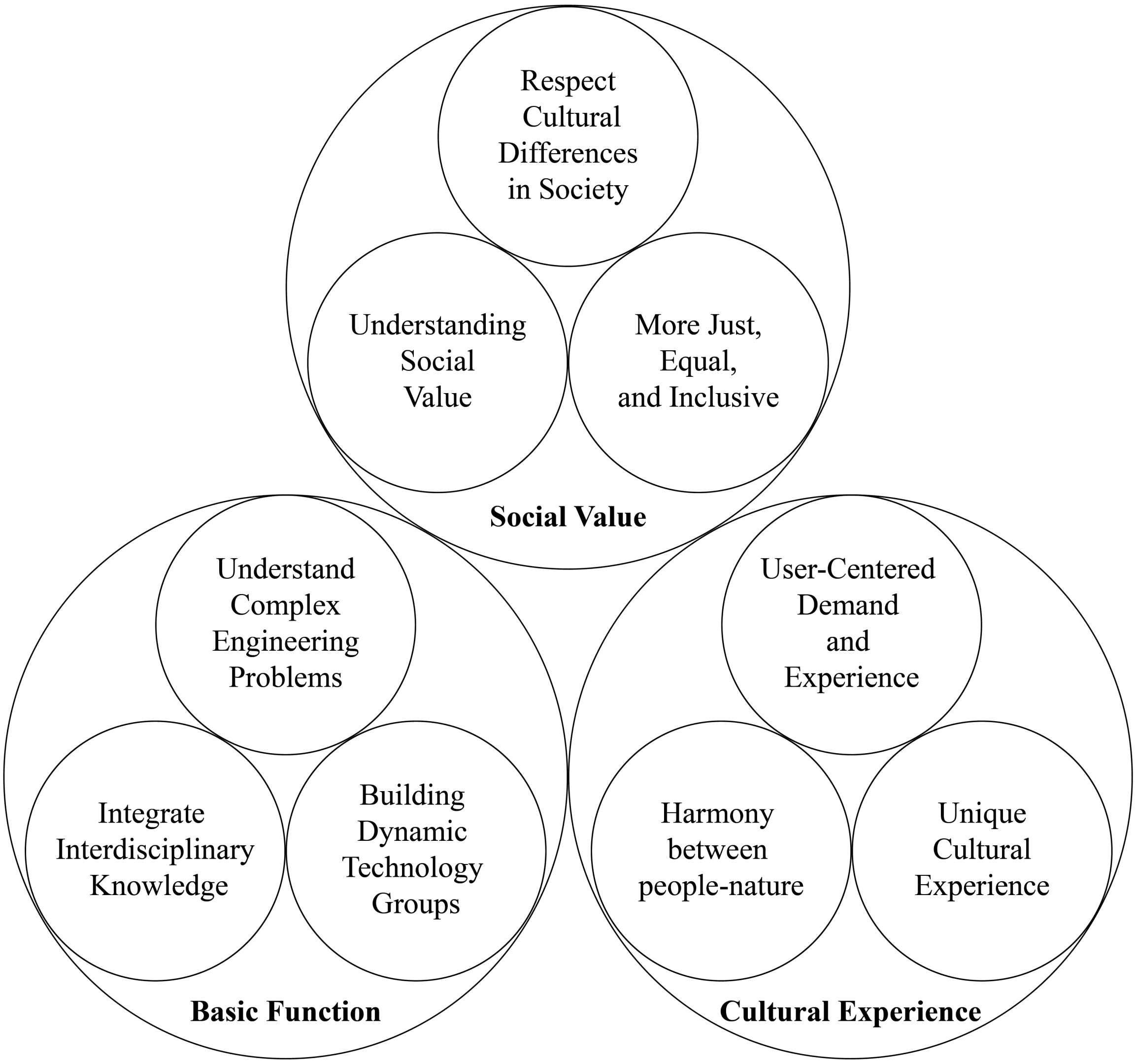

Figure 2. Basic Framework of the engineering thinking model led by service design

5.4 Interaction mechanism with existing thinking models

Generally speaking, existing engineering activities can be roughly divided into three stages: design planning, implementation construction, and operation maintenance. Design planning is the first stage of engineering activities, involving the conception and imagination of the "artefact" and its construction process, expressed through drawings, models, and schemes to represent the initial concept of the engineering. Implementation construction is the second stage of engineering activities, involving the application of various technical means and the use of natural materials to build the process of converting the engineering concept scheme into a specific project, which requires handling the relationships between people and people, and people and the environment. Operation maintenance is the third stage of engineering, involving the operation of engineering projects in specific social contexts, responding to specific engineering phenomena in social environments. It can be seen that in the functional rationality engineering thinking model, engineering design is generally located in the first stage of the engineering activity process, providing conceptual design for the engineering. Meanwhile, each step of the engineering design needs to address the intangible user experience issues, but there is no relationship between the steps, so it cannot well intervene in the discussion of the intangible level. The phenomena of engineering design addressed by the functional rationality engineering thinking models and the engineering thinking model led by service design are shown in table1.

Table 1. The phenomena of engineering design addressed by the functional rationality engineering thinking models and the engineering thinking model led by service design

Number	Functional Rationality Engineering Thinking Models	Engineering Thinking Model Led By Service Design
1	Materials	Culture
2	Form	Emotion
3	Structure	Experience
4	Function	Meaning
5	Technology	Aesthetics

The engineering design thinking model proposed in this paper can be divided into three levels: basic function, cultural experience, and social value, each playing a role in the various stages of the traditional thinking model, complementing the existing thinking model to jointly address the service design issues of engineering design.

Firstly, in the design planning stage of the traditional engineering design thinking model, the thinking model proposed in this study precedes the understanding of the complexity and uncertainty in the social system, which helps to design engineering projects that can adapt to changes in social contexts and meet challenges, handling the relationships between people and people, and people and the environment in a more reasonable way. Meanwhile, the thinking model proposed in this paper encourages the construction of dynamic technology clusters, providing technology for the functional updates of engineering projects during operation. Secondly, in the implementation operation stage of the traditional engineering design thinking model, the thinking model proposed in this study can build cross-disciplinary teams, providing a platform for knowledge sharing among stakeholders in the engineering project, helping the relevant parties understand the entire process of the engineering and each other's work, and balancing the interests of various parties in the social context. Thirdly, in the maintenance stage of the traditional engineering design thinking model, thanks to the construction of dynamic technology clusters, the maintenance stage of the thinking model proposed in this study can promptly respond to new demands posed by social contexts to engineering projects, adding new functions to the projects or maintaining their usability, thus meeting the requirements of different social contexts for engineering projects and enhancing the user experience. The Interaction mechanism with existing thinking models is shown in table2.

Table 2. The Interaction mechanism with existing thinking models

Number	The Process of Traditional Engineering Project	The interaction Mechanism of the Thinking Model
1	Design	Understanding the complexity and uncertainty in social systems
		Addressing relationships between people and between people and the environment
2	Construction	Building cross-disciplinary teams
		Providing a platform for knowledge sharing among stakeholders in engineering projects
3	Maintenance	Responding promptly to new demands placed on engineering projects by social contexts
		Adding new features to the project

6 CONCLUSION AND FUTURE WORK

This paper explores the importance of service design in engineering design, reviews the development trajectory of service design in engineering activities, and constructs a engineering thinking model led by service design based on the theoretical framework of Contemporary Chinese design theory. It provides new perspectives and methods for addressing experience, value, and other non-material attribute-related issues in the field of engineering design. It is important to emphasize that the engineering thinking model proposed in this paper aims to efficiently address non-material phenomena in engineering design, as the commonly used functional rational engineering thinking model is adept at solving material-related issues. When facing increasingly complex socio-technical system problems, both approaches have their strengths and can complement each other. Future work will focus on testing and this thinking model, refining its details, further driving innovation in the field of engineering design, and meeting the complex demands of modern society for engineering projects.

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GENERATIVE ARTIFICIAL INTELLIGENCE (AIGC)-DRIVEN INNOVATION IN RURAL ART CONSTRUCTION: VALUE LOGIC, ACTION FRAMEWORK AND PATH CHOICE

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ABSTRACT
The integration of Generative Artificial Intelligence (AIGC) into artistic rural construction introduces transformative opportunities for addressing longstanding challenges in rural revitalization. AIGC enables the dynamic generation of cultural symbols, deepens community participation through interactive design platforms, and facilitates the commercialization of cultural resources. This study explores how AIGC can enhance the depth of cultural excavation, empower local communities in co-creation processes, and extend the market adaptability of cultural symbols. By synthesizing theoretical frameworks and practical case studies, the research establishes a comprehensive action framework for leveraging AIGC to advance cultural, social, and economic dimensions of rural revitalization. The findings contribute to the development of innovative strategies for sustainable rural development and the global dissemination of local cultural resources.

Keywords: Generative Artificial Intelligence (AIGC), Artistic Rural Construction, Rural Revitalization, Cultural Symbol Generation,Community Participation, Cultural Commercialization

1 INTRODUCTION

In the context of China's rural revitalization strategy, the integration of cultural heritage with technological innovation has become essential for achieving sustainable development. Artistic rural construction—a concept emphasizing the creative reimagination of rural cultural resources—has emerged as a key strategy for advancing rural cultural, social, and economic transformation. It involves preserving and revitalizing local traditions, crafts, and spaces while infusing them with contemporary significance to foster community identity and economic growth [1], [2].

Despite its potential, artistic rural construction faces persistent challenges. These include insufficient depth in cultural excavation, limited community engagement, and the incomplete commercialization of cultural value chains. Traditional methods often struggle to transform symbolic resources into adaptive, modern expressions while maintaining cultural authenticity. In response to these challenges, Generative Artificial Intelligence (AIGC) offers transformative solutions. By leveraging technologies such as Generative Adversarial Networks (GANs) and multimodal data analysis, AIGC enables the efficient extraction and dynamic transformation of cultural symbols into diverse, market-ready forms [3], [4]. These technological tools offer new opportunities to enhance the adaptability and appeal of local culture in broader contexts.

AIGC also holds potential to revolutionize the participatory framework of artistic rural construction. Historically, rural communities have often been passive recipients of externally designed interventions. However, AIGC's interactive platforms and real-time generative capabilities allow community members to become active contributors to design processes. This aligns with broader theories of participatory design and place-making, which emphasize the importance of community engagement in fostering a sense of ownership and identity [4], [5].

This study explores the intersection of AIGC and artistic rural construction through three key dimensions: (1) the dynamic generation of cultural symbols, (2) enhanced community participation through technological empowerment, and (3) the market extension of cultural resources through innovative commercialization strategies. By synthesizing insights from recent theoretical advances and practical case studies [1], [2], [6], the research aims to propose a comprehensive framework for leveraging AIGC to advance rural revitalization efforts.

2 VALUE LOGIC: CORE INNOVATION OF AIGCDRIVEN RURAL ART CONSTRUCTION

2.1 Symbol Generation: Dynamic Adaptability of Cultural Resources

The extraction of cultural symbols is a key step in understanding and applying regional cultural resources, involving the identification and refinement of representative and symbolic signs from a rich array of cultural elements. Lomant proposed a logical relationship of "symbol-text-culture-symbol domain," emphasizing the central role of text within the cultural symbol system, and noted that through restructured formations, new "significations" can be constituted. Shen Liqin [7] in her research highlighted the application of regional cultural symbols in visual communication design, stating that these symbols are not only a reflection of cultural sedimentation in specific regional environments but also exhibit the unique geographical characteristics of a region, reflecting the connection between geographical environment and cultural features. The extraction of cultural symbols is a multidimensional and interdisciplinary process, requiring designers and researchers to not only deeply understand the connotations of regional culture but also master the methods of transforming these cultural elements into symbols with visual and symbolic significance.

Rural cultural resources are the core assets of Rural Art Construction, including natural landscapes, historical legends, folk beliefs, traditional skills, etc., and their potential value can be brought into full play through symbolic expression, dynamic narrative and market transformation. Bourdieu's [8] theory of “cultural capital” points out that the symbolic production and capitalization of cultural resources is the key to their economic benefits and social value. Generative artificial intelligence (AIGC) provides a new tool for the symbolization and dynamization of cultural resources. Unlike traditional art interventions that rely on manual excavation of cultural motifs, AIGC is able to extract cultural symbols, visual patterns and story motifs from local resources through deep learning technology, generating cultural content adapted to different media. Symbol is the core expression of cultural resources, and it is also the key element in constructing locality and cultural identity in Rural Art Construction. According to Peirce's semiotic theory [9], the meaning of a symbol consists of the triad of sign, object, and interpreter, and the effective generation of cultural symbols relies on the dynamic adaptability of a specific field and context. Taking the Echigo Tsumari Art Festival in Japan as an example, the traditional symbols of the rice landscape were redesigned by artists as village installations and public art elements, and this kind of “localized” art practice greatly enhances the symbolic recognition of local culture. In Rural Art Construction, the refinement and generation of symbols is often a laborintensive process that relies on the designer's subjective experience, which can easily lead to a semantic disconnect or a single form of symbols.

Generative Artificial Intelligence (AIGC) provides a revolutionary technological path for symbol generation through corpus analysis and Generative Adversarial Networks (GAN). First of all, AIGC can extract the core matrices of cultural symbols from local records, historical archives and oral data through deep learning of multimodal data (e.g., text, image, and speech) Extracting the core matrices in rural local cultural resources, such as traditional craft patterns, regional architectural styles, and historical stories. And through Generative Adversarial Network (GAN) technology, diverse symbolic forms are created.Goodfellow et al. [3] pointed out that GAN can quickly generate highquality visual symbolic styles with diversity through the interactive optimization of generation and discrimination.

Rural Art Construction emphasizes the coexistence of “locality” and “contemporaneity” of cultural resources, and Kwon [10] pointed out in the theory of “sitebased art” that the development of rural cultural resources is not only material, but also the reconstruction of symbols and meanings. With the intervention of AIGC, the dynamic generation of cultural resources can realize the transformation from local cultural value to global communication value.

2.2 Collaborative Optimization: Deepening Community Engagement and Design

Feedback Mechanisms

The core of Rural Art Construction lies not only in the result, but also in the process. Spirit of Place is an important goal of rural space design, which emphasizes the emotional connection between space and people and cultural identity. Multisubject collaboration in the design process especially the deep participation of the community determines whether the design results can be compatible with local culture and social needs. However, in the traditional model, villagers' participation is mostly limited to the expression of needs and feedback at a later stage, and lacks realtime influence on the design program, resulting in a deviation between the design outcome and the actual needs.
Ecosystem theory [11] emphasizes that the operation of a complex system requires all parties to achieve a dynamic balance in resource sharing and information interaction. Neuberschutz's Spirit of Place Theory [12] points out that the core value of place is to stimulate people's emotional resonance and local identity [13]. Rural Art Construction realizes the emotional creation of vernacular space through interventional design, while AIGC helps designers transform traditional material space into "place memory" full of cultural narratives with its symbolic optimization ability. AIGC supports villagers to participate in the design process in real time through an interactive platform. Villagers can not only choose building colors and patterns, but also suggest changes to the spatial layout based on community consensus. The designers use AIGC to generate quick optimization solutions, so that the villagers' opinions can be instantly transformed into visualized design results. This realtime feedback mechanism greatly shortens the long adjustment cycle in traditional design and enhances the villagers' sense of identity and belonging to the design outcome. Agamben's [14] theory on the subjectivity of cultural production states that the value of technology lies in empowering individuals to become participants and decision makers in design and production. Through the collaborative optimization of AIGC, the villagers are no longer the object of "being designed", but become the subject of design cocreation, and this indepth participation lays the foundation for the design quality and social identity of the rural habitat.This deep participation lays the foundation for the quality of rural habitat design and social identity.

2.3 Symbolic economy: from cultural expression to economic empowerment

Symbolic Economy is an interdisciplinary concept that integrates fields such as economics, sociology, cultural studies, and communication studies. It emphasizes the central role of symbols in economic activities and how these symbols influence and shape social structures and cultural practices. Peter Drucker first introduced the concept of the symbolic economy in 1986, contrasting it with the real economy and highlighting the importance of capital movement within the symbolic economy [15] . In the context of China, Yaqin Wang [16] explored the application of the symbolic economy in the rural revitalization strategy, emphasizing the significance of symbolic identity in the integrated development of urban and rural areas. She pointed out that the separation between urban and rura areas is largely based on cultural and social divisions rooted in economic foundations, and that the symbolic economy offers a new perspective for understanding and addressing this issue. Wei Ye Zhou [17] analyzed the new trends of cultural and artistic production and dissemination within the symbolic economy from the dual perspectives of globalization and localization, stressing the importance of protecting and developing local culture and arts in the era of globalization.

The value of Rural Art Construction is not only embodied in the enhancement of spatial aesthetics, but also in the economic transformation potential of cultural resources. The goal of rural revitalization is not only limited to cultural renaissance, but also lies in the realization of economic benefits through the marketization of cultural resources. Bourdieu's theory of "cultural capital" points out that cultural resources can only create economic value through symbolic production and marketization [18]. The marketization and IPization of symbols is the core path to realize the economic empowerment of cultural resources. The theory of creative economy [19] points out that cultural symbols can create great economic value in the fields of tourism, cultural creation and digital content through the combination of creativity and industry. However, symbols in traditional design are mostly limited to the expression of physical space, which makes it difficult to form a wider market extensibility.
Through multimodal symbol generation and dynamic adaptation, AIGC gives cultural resources more industrial transformation possibilities. For example, if the festival cultural symbols of Longtan Village in Pingnan are generated through AIGC, they can not only be applied to public art installations, but also be extended to packaging of tourist souvenirs, scenic area guide systems and digital marketing materials.

Combined with AR/VR technology, these symbols can also be integrated into virtual tours and immersive experiences to enhance tourists' cultural perception and consumption willingness.
In addition, the symbols generated by AIGC are replicable and scalable, and can be used to create brand images with regional cultural recognition through IPbased design.AIGC provides a highly efficient path for symbol IPization, and empowers the symbols to be applied across scenarios by combining virtual and real dualscenarios. For example, the festival symbols of Longtan Village in Pingnan can be extended to digital souvenirs, virtual interactive exhibitions and other diversified industrial chains after combining with AIGC, which will ultimately form a closed loop of value from culture to economy.

3 FRAMEWORK FOR ACTION: AIGC-DRIVEN IMPLEMENTATION PATH FOR RURAL ART CONSTRUCTION

Rural Art Construction requires a systematic path to realize closed-loop innovation from the refinement of cultural resources to community collaboration and then to economic extension. Artificial Intelligence Generative (AIGC) provides technical support and practical guidance for the whole chain workflow of design, and its action framework can be divided into three core links: data-driven, collaboration-driven, and industry-driven, and ultimately forms an integrated closed-loop of symbol generation, community collaboration, and market transformation.

3.1 Datadriven: intelligent distillation of local cultural resources

Rural Art Construction requires a systematic path to realize closedloop innovation from the refinement of cultural resources to community collaboration and then to economic extension. Artificial Intelligence Generative (AIGC) provides technical support and practical guidance for the whole chain workflow of design, and its action framework can be divided into three core links: datadriven, collaborationdriven, and industrydriven, and ultimately forms an integrated closedloop of symbol generation, community collaboration, and market transformation.

Datadriven: intelligent refinement of local cultural resources

Local cultural resources are the core materials of Rural Art Construction. AIGC systematically integrates the traditionally scattered cultural resources through datadriven integration, laying the foundation for symbol generation and design optimization.
The dissemination and experience of rural culture requires the support of an effective narrative system, which is an important link between cultural resources and audiences, and AIGC is able to transform rural cultural resources into dynamic narrative content suitable for multiple media through multimodal generation technology, deepening its expressive effect. Jung's [20] "archetypal theory" points out that cultural narratives can stimulate the sense of identity in the collective unconscious, and AIGC's multimodal generation provides technical support for the enrichment of the narrative system. For example, the narrative theme of rural cultural creation can be generated through AIGC to produce short videos, animated displays or augmented reality (AR) interactive content, providing tourists with multisensory cultural experiences.

Data collection and integration: corpus construction and multimodal analysis

Digitization of local cultural resources is the first task of the design, and AIGC integrates multimodal data such as text, image, audio, etc. through the construction of a largescale corpus to conduct indepth analysis of local cultural resources. By collecting historical documents, architectural drawings, folklore photos and oral histories of the countryside, a cultural database covering symbols, styles and narratives is formed [5], which can provide rich data support for AIGC's precise adaptation in symbol generation. Based on big data and multimodal deep learning, AIGC can realize intelligent extraction of rural cultural resources and dynamic generation of symbols. Traditional design can only generate limited symbol styles based on villagers' memories, while AIGC can generate richer symbol models through corpus and multimodal data.

Symbol Generation and Optimization: Dynamic Generation of Diverse Design Solutions

Based on the corpus, AIGC utilizes Generative Adversarial Network (GAN) technology for dynamic symbol generation and diversified design. Its key advantage lies in the balance between semantic consistency and visual diversity of symbols. For example, the "Haniwa" project in Yuanyang, Yunnan, reconstructs the rural cultural narrative through handicrafts and local legends. However, the traditional method of narrative expansion is limited to the individual creativity of the artist and the manual generation process, which can be optimized by the intervention of AIGC: on the one hand, local legends and historical materials are extracted from the linguistic model to rebuild the diversity of cultural narratives; on the other hand, these narratives are transformed into dynamic forms of communication through the technology of image generation and video generation, which gives the cultural communication stronger attraction and marketability potential. In the future, these generated contents can also be adapted to the needs of multilingualism, promoting the global communication of local cultural resources.

3.2 Collaborationdriven: communityled design cocreation

The core of rural architectural design lies in its collaborative nature. Designers, villagers and policy makers need to participate together in the design process in order to realize the combination of functionality and culture. However, the technical threshold of the traditional design model is high, and the role of community members, especially villagers, in the design is more limited to providing basic needs, while it is difficult to participate in the process of detail design and symbol generation. This problem is particularly prominent in the transformation of Xucun's public space, where villagers' opinions are mainly focused on functional zoning and infrastructure construction, with less participation in pattern selection and visual style, resulting in a lack of cultural identity in the design outcome [1].

AIGC provides a new path of technological empowerment for multisubject collaboration, the core of which lies in the realization of lowthreshold design participation and realtime feedback through an interactive platform. Adger [11] pointed out in ecosystem theory that the efficient operation of a complex system relies on the equal collaboration and resource sharing of the participating subjects. through the construction of a visualized design platform, AIGC connects the villagers, designers, and policy makers in the same collaborative interface. , enabling villagers to select or adjust symbol styles, building colors and spatial layouts in real time, thus enhancing the efficiency and depth of collaboration.

For example, if the AIGC platform is introduced to the Xu Village project, villagers can compare multiple symbols through the interface and choose the design that best meets their cultural preferences. The designers can then use AIGC to optimize the generated solutions based on the feedback from the community, forming a closed loop of dynamic collaboration between the designers and the community. Agamben [14] suggests that empowering community subjectivity is an important way to realize cultural production and identity. Through the lowthreshold technical support of AIGC, community members are transformed from “passive receivers” to “active creators”, which significantly enhances the cultural appropriateness and sense of community belonging in rural architectural design.

AIGC's realtime generation capability supports the adjustment of the program according to the feedback at any time during the design process. For example, in the remodeling of Xucun's public space, AIGC can generate a variety of symbol styles for villagers to vote on. Through this realtime feedback, the designers were able to quickly iterate the symbol styles and spatial layout, so that the final result would be more in line with the needs of the community and local cultural characteristics. The realtime feedback mechanism not only improves the efficiency of the design, but also strengthens the community's sense of identity with the design results.

3.3 Industrydriven: IPization of symbols and market extension

The extension of the value of Rural Art Construction needs to rely on the market transformation of symbols. AIGC realizes the economic empowerment of cultural resources through the multimodal generation of symbols and crossscene adaptation.

Crossscene application of symbols: from habitat to cultural and digital content

Rural cultural and creative IP is a bridge between the symbolization and marketization of cultural resources, and its construction process usually involves image design, story construction and communication strategy development.AIGC can support the whole process of generating and adjusting the IP from the initial creative idea to the dynamic optimization, so as to realize the rapid expansion of the IP ecosystem.Mark and Pearson [21] suggest that successful IP requires multiple qualities of “emotional connection, storytelling and commercial suitability”, and AIGC has unique advantages in generating and optimizing storytelling and connection.

The symbols generated by AIGC are not only applicable to habitat design, but can also be extended to the development of cultural and creative products and digital content. For example, the festival symbols of Longtan Village in Pingnan can be generated through AIGC to create handicraft packaging designs, tourist souvenir theme patterns and scenic area guide systems, realizing the crossscene transformation of symbols from physical space to consumer products. This path of symbol IPization turns cultural resources into economic drivers with lasting market value [19].

Digital technology support: AR/VR combined immersive cultural experience

Combined with AIGCgenerated symbols, AR/VR technology can provide an immersive cultural experience for rural design outcomes. The art symbols of Echigo Tsumari in Japan have not only strengthened the local brand image through IPbased operation, but also driven the rapid growth of the surrounding tourism industry. In the digital transformation of Li Xiang public space, the symbols generated by AIGC can be embedded in the guided tour application through AR technology, so that tourists can experience the cultural stories behind the architectural symbols through mobile devices. This kind of technological empowerment not only enhances the cultural perception of tourists, but also expands the market application scenarios of the symbols.

4 PATH SELECTION: PROMOTION STRATEGY OF AIGC MODEL IN RURAL ART CONSTRUCTION

The potential application of generative artificial intelligence (AIGC) in Rural Art Construction provides a brand new technological path for rural revitalization. However, its largescale promotion and application still need to overcome multiple challenges such as technology adaptation, resource integration and community acceptance. In order to realize the landing of AIGCdriven design mode, it is necessary to develop targeted promotion strategies in five aspects: policy support, community empowerment, resource integration, technology adaptation and evaluation system.

4.1 Policy Support: Policy Mechanism for Promoting the Integration of Technology and Culture

Policy support is the basic guarantee for the promotion of the AIGC model in rural design. The rural revitalization strategy provides a policy direction for the integration of technology and culture, but specific to the application of AIGC, the support content needs to be further refined to ensure that the technology can serve the actual needs.

Specialized Funds and R&D Incentives

The government should set up a special fund to support the R&D and landing of AIGC technology in the field of rural design. For enterprises and organizations that develop symbol generation algorithms, cultural corpora and interactive design tools, tax breaks or financial incentives can be provided. In practice, competitive grants can be used to incentivize technology companies to develop solutions that are better suited to rural needs.

Legal Framework and Intellectual Property Protection

Ensure that the symbols and designs generated by the AIGC are protected in the field of intellectual property. The IPbased design of symbols involves the complex issue of transforming cultural resources. Policies should clarify the ownership of symbols and the mechanism for distributing economic benefits, so as to avoid the loss of local culture due to the misuse of resources.

Pilot Regional Policies

Encourage local governments to carry out technical pilots in combination with their own characteristics. For example, for villages rich in resources but technologically backward, they can prioritize the implementation of basic cultural data collection and symbol generation; while for villages and towns with mature tourism industries, they can focus on promoting the application of AIGC in the development and marketing of cultural and creative products.

4.2 Community empowerment: improving the feasibility and acceptance of technology application

Rural communities are the direct beneficiaries of habitat design and important participants in symbol generation and design optimization. However, the lack of community awareness of the technology and the high threshold for its use may be the main resistance to its promotion, and the promotion of AIGC needs to improve the acceptance and application capacity of the technology through community empowerment.

Technology Training and Application Support
Design a tiered technology training program for village residents. For example, a beginner's course helps villagers understand the basic functions of AIGC and its application in symbol generation; an advanced course can be designed for community designers and village managers to train them how to use AIGC to generate multiscenario adapted symbol schemes. This stepbystep approach not only reduces the learning difficulty, but also ensures the effective transfer of technical knowledge.

Technical localization and operational simplification
Develop more intuitive and easytouse design tools. For example, create mobilefriendly apps that enable villagers to select a favorite symbol style via a touch screen or engage in simple symbol design decisions. Similar practices can lower the barrier to participation for nonspecialized users and increase the popularity of technology tools.

Communityled and Cultural Identity
Enhance the relevance between symbol design and cultural expression through community participation. For example, in the design and renovation of Xu Village, AIGC can generate multiple cultural symbol styles for villagers to choose from, and incorporate the final choice into the design scheme. This communityoriented mode of technology application not only enhances the cultural appropriateness of symbol generation, but also strengthens the villagers' sense of belonging to the design results.

4.3 Resource Integration: Multiparty Collaboration among Government, Enterprises and Academia

The promotion of AIGC in Rural Art Construction requires the establishment of a resource integration mechanism with multiparty collaboration. The public sector, private enterprises and academic institutions, as core participants, share the tasks of technology research and development, resource allocation and cultural excavation.

PPP Model (PublicPrivate Partnership)
The publicprivate partnership (PPP) model is an effective resource integration mechanism. The government provides policy support and financial guarantee, private enterprises are responsible for the development and promotion of AIGC technology, and academic institutions optimize the science and adaptability of technology application through research and evaluation [22]. For example, in the pilot project in Pingnan County, the government funded the establishment of a cultural resources database, the technology enterprise provided development services for symbol generation algorithms, and the academic institution provided theoretical support for data collection and semantic verification of symbols.

Interdisciplinary Collaboration and Knowledge Transformation
The complexity of Rural Art Construction requires multidisciplinary collaboration. Disciplines such as architecture, design, computer science and cultural studies need to work together to promote AIGC. For example, symbol generation requires architecture to provide scenario requirements, cultural studies to ensure semantic accuracy of symbols, and computer science to develop efficient generation algorithms. This interdisciplinary collaboration not only improves technical suitability, but also promotes practical translation of research results.

4.4 Technological Adaptation: Technological Localization for Different Rural Resource Characteristics

As there are significant differences in cultural resources and technological conditions in villages, the promotion of AIGC needs to be centered on scenario-based adaptation and the development of technological tools and solutions that meet the needs of different villages.

Technology development tailored to local conditions
Develop customized tools for different types of villages. For example, for villages that focus on traditional handicrafts, AIGC can strengthen the ability to generate symbolic patterns; while villages

and towns that feature natural landscapes need to highlight the functions of landscape symbol generation and application scenario optimization.

Symbol optimization for cultural semantics
Ensure that AIGC generated symbols are aligned with the semantic logic of local culture. For example, by introducing local cultural experts to participate in corpus construction and symbol semantic calibration, cultural misinterpretation or semantic bias is avoided in the symbol generation process. Peirce's [9] theory of semiotics points out that the meaning of symbols lies in their fitness with specific cultural contexts, and this fitness is the core of technology localization.

Flexible design of technological environments
Develop multiple versions of the AIGC tool to address differences in village technology environments. For example, in villages with limited equipment resources, a simplified version of the tool is provided, focusing on the basic functions of symbol generation; while in villages and towns with better technological conditions, a full-featured version is promoted to support the whole process of symbol design and market transformation.

4.5 Evaluation system: designing an innovative mechanism for evaluating and optimizing the impact of the technology.

In order to ensure the promotion effect of the AIGC model, a scientific evaluation system needs to be established to comprehensively assess the quality and impact of the technology application. The evaluation system should cover the three core dimensions of symbol generation quality, community participation depth and market transformation benefits.

Evaluation of Symbol Generation Quality
The quality of symbol generation is assessed through the semantic consistency, visual appeal and cultural appropriateness of the symbols. For example, in the design of Hao Tang Village, the adaptability of the generated symbols in multiple scenarios can be quantitatively analyzed, as well as whether the symbols successfully reflect local cultural characteristics [3].

Assessment of the depth of community participation
Examine the breadth and depth of community participation in the design process, including the number of participants, the number of feedbacks, and the decisionmaking weight. Agamben [14] suggests that empowering the community to take ownership of the design is the key to enhancing cultural expression, and that the evaluation system should focus on whether villagers have truly influenced the design decisions.

Evaluation of Market Transformation Benefits
The market transformation of symbols is quantitatively analyzed, including the sales of cultural and creative products, the growth of tourism income and brand recognition of the symbol application. For example, the results of symbol IPization of Longtan Village in Pingnan can be evaluated by sales data of tourism souvenirs and feedback from tourists' satisfaction.

Feedback mechanism for continuous optimization
Optimize technical tools and promotion strategies based on evaluation results. For example, in scenarios where the quality of symbol generation is low, adjust the content of the corpus or optimize the generation algorithm; in cases where community participation is insufficient, add technical training and interactive design sessions to enhance participation.

5 CONCLUSION: SYSTEMATIC PROMOTION STRATEGY TO PROMOTE AIGC'S COMPREHENSIVE LANDING

Through the allround implementation of policy support, community empowerment, resource integration, technology adaptation and evaluation system, the AIGC model is able to form a sustainable promotion path in Rural Art Construction. This systematic promotion strategy not only solves the limitations of current design practice, but also provides a new paradigm for the integration of technology and culture in rural revitalization. However, the application of technology still needs to be localized in depth in the local cultural context to avoid "symbolic distortion" or "cultural fragmentation". In the future, how to further combine generative technology with local rural practices, and promote multisubject symbiosis and crossscene integration will become an important topic in AIGC's Rural Art Construction research.

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RESEARCH ON THE CONSTRUCTION OF THE “THREE FITS” (SMA) SUSTAINABLE FASHION DESIGN MODEL FOR SPORTSWEAR, APPAREL AND EQUIPMENT BASED ON THE WHOLE INDUSTRY CHAIN

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ABSTRACT
Against the backdrop of sustained global economic development, social and environmental problems caused by the traditional growth model have become increasingly prominent, posing a threat to human survival. In order to promote harmonious coexistence between man and nature and enhance global well-being, the concept of sustainable development has emerged. In 2015, the UN proposed 17 Sustainable Development Goals (SDGs) and adopted a comprehensive strategy to address social, economic and environmental challenges under the framework of environment, society and governance (ESG). As a key area of environmental impact, the fashion industry has attracted widespread attention. Therefore, the design community has begun to incorporate sustainable concepts and explore ways to combine with SDGs. From the perspective of the whole industry chain, this paper focuses on the sportswear, apparel and equipment industry and constructs a "Three Fits" (SMA) sustainable fashion design model, aiming to promote the green transformation of the fashion industry and contribute to the Circular Economy. In the process of implementing the "Three Fits" (SMA) model, this paper analyzes the intersection and dynamics of the three dimensions of environmental, market suitability and social applicability, and verifies the scalability of the model through actual cases in the product design and development stage. This paper reveals the existing challenges of this model as well, as defining industry boundaries, quantitative assessment of carbon emissions, and emphasizes a well-thought-out design strategy which is essential to the whole life cycle of the design product.

Keywords: Whole industry chain, Sustainable fashion, Sportswear, apparel and equipment, “Three Fits” (SMA) sustainable fashion design model

1 INTRODUCTION

Globally, the improvement of environmental protection awareness has made sustainable development a common goal pursued by all walks of life. In response to environmental challenges such as climate change, China is actively promoting the realization of carbon neutrality goals and advocating a green and low-carbon lifestyle for all people[1]. Against this background, the sportswear, apparel and equipment industry is also facing transformation and upgrading, seeking new paths for sustainable development [2].

This study focuses on the role of each key link in the chain (producers, designers, consumers, etc.) from the perspective of the whole industry chain, reveals the current status and progress of sustainable fashion in the sportswear, apparel and equipment industry from the dimensions of sustainable color matching and recycled material application, identifies the challenges faced, and proposes solutions.

To this end, this study combines theoretical analysis with practical guidance to preliminarily construct a multi-module "Three Fits" (SMA) sustainable fashion design model, and explores the methods and means of effectively implementing sustainable development strategies from the aspects of design innovation, construction of recycling system, and enhancement of consumer environmental awareness, aiming to provide a solid theoretical foundation and practical guide for the sustainable development of the sportswear, apparel and equipment industry, help the industry move towards a green and sustainable future, and achieve the harmonious unity of environmental protection and economic growth [3].

2 CONSTRUCTION AND ANALYSIS OF KEY LINKS IN THE WHOLE INDUSTRY CHAIN OF SPORTSWEAR, APPAREL AND EQUIPMENT

2.1 Dividing the sustainable development responsibilities of participants in the chain by "roles"

In the grand plan of promoting the sustainable development of the sportswear, apparel and equipment industry, every part of the industry chain is crucial. To achieve this goal, all participants must assume their respective responsibilities and, through scientific and effective division of labor and cooperation, enable the industry to move towards a sustainable development path more efficiently and contribute to the future of the earth. List below shows all the participants and their respective responsibilities:

- Raw material suppliers:
  - Ensure the materials supplied are from reliable and sustainable sources;
  - Give priority to the use of environmentally friendly materials, such as organic cotton and recycled polyester;
  - Implement fair trade and responsible carbon management systems to achieve sustainable development requirements;
  - Build traceable environmental standards to enhance the sense of responsibility of the supply chain and provide strong support for sustainable design of downstream enterprises.
- Product designers:
  - Pursue the beauty and practicality of products;
  - Fully consider the environmental impact and ensure the easy dis-assemblability, maintain and recycle of the product designed;
  - Adopt sustainable and environmentally friendly dyeing processes to realize the reduction of the resource consumption, to achieve a dual balance between environmental protection and functionality [4-5].
- Manufacturers:
  - Adopt clean technology and energy-saving equipment;
  - Reduce waste and pollution;
  - Promote environmentally friendly process management such as water recycling and the application of solar and wind energy;
  - Strive to minimize production waste and effectively handle remaining materials through recycling and reuse to minimize environmental impact [6].
- Distributors and Retailers:
  - Reduce carbon emissions by optimizing logistics networks;
  - Adopt green energy vehicles and optimizing transportation routes;
  - Increase consumers' awareness and recognition of sustainable products through education and marketing activities.
- Consumers:
  - Being the key force driving market changes;
  - Support sustainable development goals by choosing environmentally friendly products;
  - Participate in recycling programs and reducing waste;
  - Make choices and provide feedback which directly influence market trends and corporate decisions, guide the industry towards a more environmentally friendly direction [1-7-8].
- Recyclers and Processors:
  - Being responsible for reprocessing old products and recycled materials;
  - Provide sustainable recycled materials;
  - Continuously improve recycling efficiency and quality through the development of new technologies;
  - Expand the application scope of recycled materials;
  - Reduce dependence on primary resources;
  - Promote the recycling of resources.
- Governments and regulatory agencies:
  - Regulate the sustainable development of the industry by formulating policies and regulations;
  - Encourage enterprises to establish strict standards and certification systems through tax incentives and subsidy incentives to ensure the sustainability of product design and production

processes.

- Non-Governmental Organizations and public interest groups:
  - Support sustainable development practices by raising public awareness, supervising corporate behavior, and providing professional advice;
  - Promote social attention to environmental issues through education, research, and publicity activities [9].

2.2 Construction and challenges of a sustainable recycling system for sportswear, apparel and equipment textiles

Building a sustainable recycling system for sportswear, apparel and equipment textiles is extremely important for the development of Circular Economy and environmental protection. Using block chain and Internet of Things technologies, we can establish an efficient carbon management of the whole supply chain traceability platform [Figure 1], achieve full-chain transparency and real-time data collection, and provide the industry with a feasible sustainable development plan. The concept of recycling should be integrated into the design and production stages, with priority given to recycled materials and easy-to-classify labels. It is necessary to mobilize manufacturers, retailers, recyclers, environmental organizations and the public to participate, and the government should introduce incentives and extended responsibility policies to ensure that companies fulfill their recycling obligations.

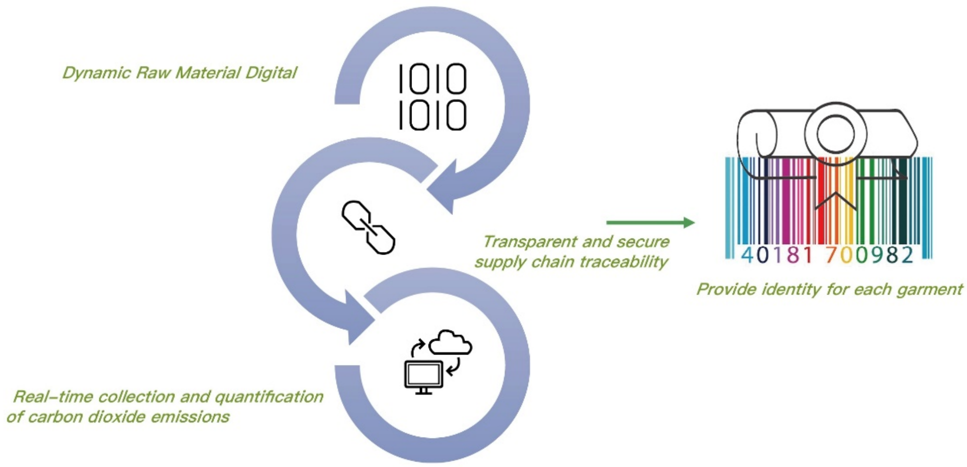

Figure 1. Carbon management whole supply chain traceability platform

Faced with challenges in the recycling system of sportswear, apparel and equipment textiles, such as material complexity and diversity of decorative materials, as well as recycling efficiency and strength of recycled materials, recycling companies need to strengthen technology research and development, reduce costs, and improve material quality. The government should improve laws and regulations, clarify responsibilities, and enhance consumer environmental awareness and participation through publicity and incentives. At the same time, a unified recycling standard and certification system should be established to ensure the standardization and transparency of the recycling and regeneration process. These measures jointly promote the sustainable recycling of sportswear, apparel and equipment textiles and achieve efficient resource utilization and environmental protection goals.

2.3 Consumer awareness and acceptance of sustainable sportswear, apparel and equipment products

Consumer attention to sustainable sportswear and equipment has increased significantly in recent years. Data shows that global online searches for sustainable products have increased by 71% [10] in the past five years. Among them, 88% of consumers said they would pay attention to the environmental protection attributes of products, and 80% of consumers aged 18 to 34 were willing to pay more for environmentally friendly products. At the same time, 66% of consumers will consider the sustainability of products when purchasing, especially among the younger generation, 75% are more inclined to choose sustainable products. However, although 78% of consumers want to buy products from companies that are more environmentally conscious, many people are still unable to tell which products are sustainable due to low recognition, which leads to a gap between perception and actual purchasing behavior [11-12].

When choosing sustainable products, consumers tend to integrate environmental protection into their lifestyles, such as second-hand transactions and low-carbon travel, but they still face challenges such as high prices, difficulty in identification and lack of logos, which affect their purchasing decisions. In order to narrow the gap between cognition and actual behavior, analyzation of consumer consumption awareness in terms of sustainability might lead companies and marketers to improve the public's understanding of sustainable development [13-14]:

- Public education;
- Product or brand's environmental stories telling;
- Demonstration of the production transparent processes;
- Optimization the versatility and high quality of products;
- Combination added values such as teamwork and multiculturalism;
- Adoption of reasonable pricing strategies;
- Enhance customer stickiness by rewards or activities.

2.4 Establishment and optimization of chemical regeneration system in material recycling

Most of the regenerating or recycling concept products currently available to consumers are "bottle-to-fiber recycling" based on the physical method technology that began to be industrialized more than 10 years ago, which is an "Open-loop recycling". But Textile to Textile (T2T) or be called fiber-to-fiber recycling is a technology that converts waste textiles into new textile materials through chemical treatment method which is a "Closed-loop recycling". As the role of product designer, the T2T material recycling is an important aspect for considering the whole life of a product during the design process. The establishment and optimization of this system involves the following steps [Figure 2]: first, establish a collection network for waste textiles, and classify and clean them to decompose textiles, decolorize and remove impurities; second, convert fibers into renewable monomers or polymers through chemical processes, purify and recycle them, and re-spin them into fibers; at the same time, perform performance testing and certification on recycled textiles to ensure that they meet industry standards. The entire system needs to be integrated into a coherent, closed-loop system, and continuously optimize technology to improve recycling efficiency and reduce environmental impact. Economic analysis, environmental life cycle assessment, policy and regulatory support, market education and promotion, and cooperation with industry chain partners are all important strategies to promote the sustainable development of the T2T chemical recycling system. Through these measures, high-value recycling of waste textiles can be achieved, and the environmental friendliness and economic benefits of the textile industry can be promoted [15-16].

Figure 2. Textile to Textile (T2T) Chemical Regeneration Production Flow Chart

3 CONSTRUCTION AND ANALYSIS OF THE “THREE FITS” (SMA) SUSTAINABLE FASHION DESIGN MODEL FRAMEWORK

3.1 Construction of the “Three Fits” (SMA) sustainable fashion design model framework

The "Three Fits" (SMA) sustainable fashion design model framework is a comprehensive design method that integrates three key dimensions: Suitability (social aspect), Moderation (environmental aspect) and Applicability (economic aspect), aiming to achieve a perfect balance between product design in terms of sustainability, market competitiveness, and user experience. This model framework not only focuses on the entire life cycle of the product, but also emphasizes the consideration of the environmental impact, market demand, and user use of the product at the design stage by clarify industry boundaries [Table 1]. This model supports companies to meet consumers' needs for health, comfort, and functionality through innovative design, while responding to environmental trends, using sustainable materials, and enhancing brand image and market competitiveness.

In the sustainable methodology of the whole industrial chain, design plays a vital role. Design not only needs to consider the beauty and practicality of the product, but also needs to go deep into the selection of materials, optimization of the production process, and recycling and reuse of the product after use. Through the application of the SMA model, the design team can better coordinate various factors in the product development process to ensure that the final product meets the requirements of sustainable development and the needs of the market and users, thereby maximizing economic, environmental, and social value.

Table 1. Clarification of industry boundaries under the “Three Fits” (SMA) sustainable fashion design model framework

S - suitability			M - moderation			A - applicability		
Social aspect			Environmental aspect			Economic aspect		
Organization	Research	Standard	Intelligence	Materials	Manufacture	Brand	Consumer	Recycle
Policy formulation, supervision and evaluation	Entire product life cycle design and research	Standards system establish-ment	Technology empowering, emissions reduction and efficiency increase	Eco-friendly materials develop and use	Clean technology and energy-efficient equipment use	Eco-friendly products promotion and consumer awareness guidance	Recycling activities participation	Effectivity and utilization rate improve-ment

3.2 Analysis of the “Three Fits” (SMA) sustainable fashion design model framework

3.2.1 Intersectionality analysis

Intersectionality analysis explores the interrelationships between the three key dimensions of environmental Suitability, Market suitability, and social Applicability which refers to the “Three Fits” (SMA) model. The results revealed the interactions and potential synergies between them, while also pointing out possible conflicts. Based on these findings, this study strives to find a balance in design decisions, aiming to ensure that products can meet market needs and adapt to the actual usage habits of society while reducing their impact on the environment.

3.2.2 Dynamicity analysis

Dynamicity analysis conducts a comprehensive assessment of the entire life cycle of the product from the research and design stage to market decline, and focused on the impact of external environmental changes on the “Three Fits” (SMA) sustainable fashion design model. These external environmental changes include but are not limited to key factors such as technological progress, market trends, consumer behavior, and policy adjustments. The dynamicity analysis was implemented to ensure the adaptability and flexibility of the model in the face of these changes, and the design strategy was adjusted accordingly to maintain its continued effectiveness and relevance.

3.2.3 Sustainability assessment

To ensure the long-term sustainability of the design, this study adopted a systematic assessment method that aims to comprehensively quantify the environmental, social and economic impacts of the product throughout its life cycle. Quantitative analysis tools including key indicators such as carbon emissions, resource consumption rate, cost savings and user satisfaction were used. These indicators not only help to quantify the environmental impact of the product during its life cycle, but also measure its contribution to social welfare and economic growth. By using these quantitative indicators, the sustainability performance of the product can be deeply analyzed, thereby providing a scientific basis for the continuous improvement of product design to promote long-term sustainable development. List below shows steps to evaluate product carbon footprint:

1. Constitution of the process diagram which specifies each stage of the product life cycle from the raw materials to its disposal, including all material, energy and waste flows;
2. Clarification of the industry boundaries and calculate carbon emissions in order to determine actions priorities;
3. Collection of the data on material usage, activities and emission factors;
4. Evaluation of the accuracy of carbon footprint analysis.

3.2.4 Implementation challenges

During the implementation process, this study found a series of potential challenges, including technical difficulties, cost control, market acceptance and supply chain integration. In order to meet these challenges, a variety of solutions were explored and implemented, including technology research and development, partnership building, policy advocacy and market education. These comprehensive analyses and strategies ensure that the "three Fits" (SMA) model not only fully considers the needs of the environment, market and society when guiding product design, but also fully considers the various stages of the product life cycle and changes in the external environment. This approach helps promote the sustainability of design and maximize economic, environmental and social value.

3.3 “Three Fits” (SMA) sustainable fashion design standards and design grading

In the implementation of the "Three Fits" (SMA) sustainable fashion design model [Figure 3], the concepts of design standards and design grading were introduced to ensure the comprehensiveness and sustainability of product design. Design standards are a series of guidelines to be followed during the design process, covering the three dimensions of social Suitability, environmental Moderation and economic Applicability to achieve a perfect balance in product design. Design grading divides the design into different levels or categories based on the performance of the product in these three dimensions, so as to more effectively manage and optimize the design process [17].

In terms of design standards, the SMA model emphasizes the need to consider the environmental impact, market demand and actual use of the product in the design stage. The design team needs to use a series of quantitative indicators to measure the sustainable performance of the design, such as carbon emissions, resource consumption rate, cost savings and user satisfaction [18]. These indicators help ensure that the product design not only meets current needs but also has long-term sustainability.

In terms of design grading, by evaluating the performance of each design solution in the environmental, market and social dimensions, the design team can determine which solutions are more in line with the requirements of the SMA model. This hierarchical approach helps identify and prioritize those design solutions that perform best in terms of sustainability, product competitiveness and user experience [19].

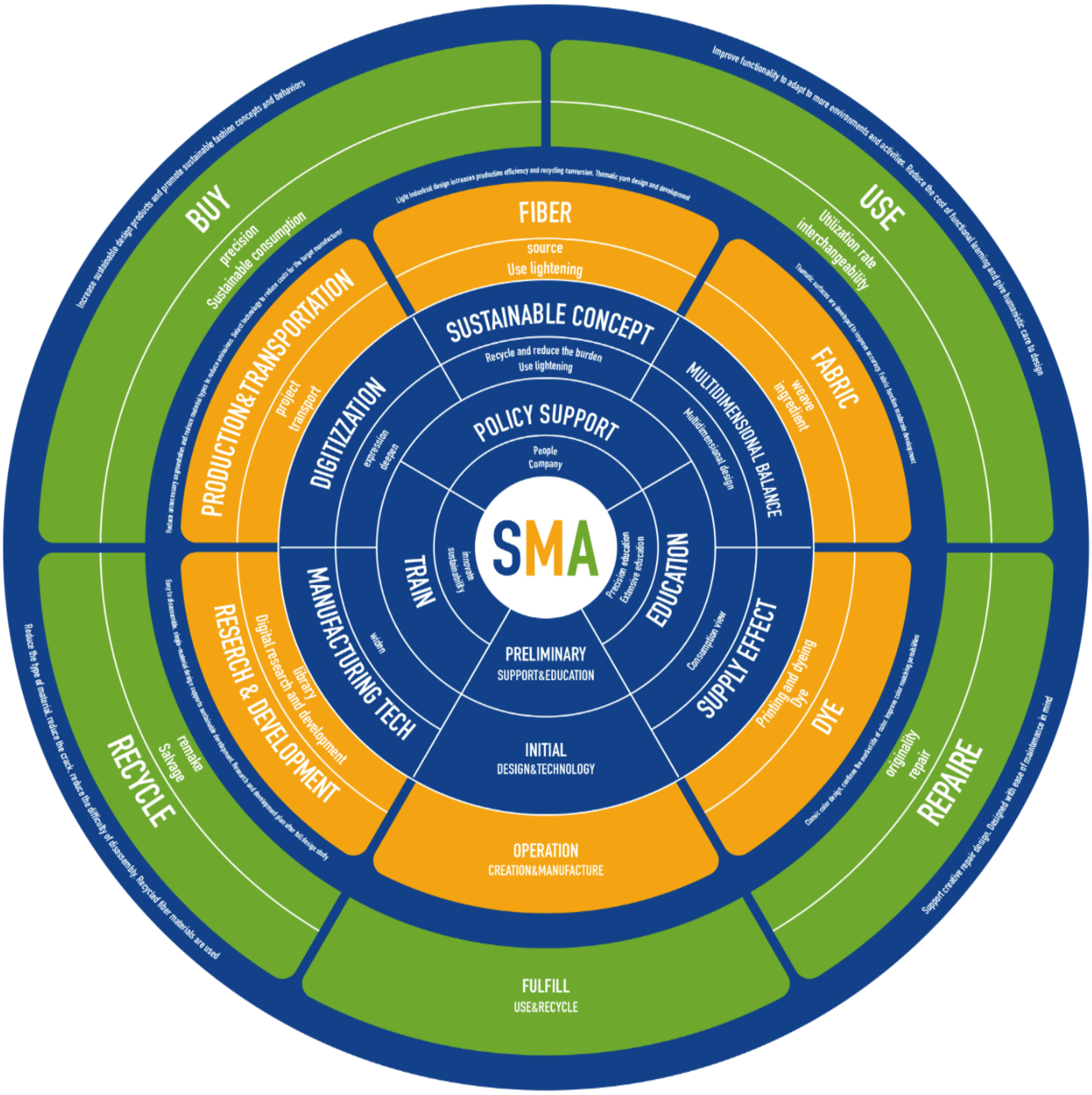

Figure 3. "Three Fits" sustainable fashion design model

3.4 Implementation of the "Three Fits" (SMA) sustainable fashion design model in ISPO Award-winning design product "Composite Structure Camping Down Jacket" and its commercialization

The winner of ISPO Award 2022 "Composite Structure Camping Down Jacket" [Figure 4] led by the authors is a sportswear design product designed and developed based on the "Three Fits" (SMA) sustainable fashion design model. The basic design concept is to integrate the sustainable concept throughout the entire processes of design, manufacturing, using, recycling and other phases, which was in the past, mainly focused only on the materials aspect. The "Three Fits" (SMA) sustainable fashion design model emphasizes minimizing waste and reducing production costs to the lowest possible level by accurately identifying functional requirements and corresponding to the most appropriate material use, abandons blindly pursuing advanced manufacturing technology and materials which will result in putting pressure on labor and consuming too many resources during the production process. The authors believe the design which comply the sustainable standards should not generate waste while meeting the multi-requirements and goals of design process.

Figure 4. Winner of ISPO Award 2022 “Composite Structure Camping Down Jacket”

The design path of this product is the practice and exploration of the "Three Fits" (SMA) Sustainable fashion design model from the perspective of social, environmental and economic aspects [Table 2]. The "Composite Structure Camping Down Jacket" is unique in its warmth-keeping function. The designer focuses on improving consumers' wearing experience and strives to make all functions easy to use, thereby increasing the frequency of use of functions, improving product practicality and reducing the burden of use. Unlike simply enhancing warmth, the designer pursues a balance of heat and moisture in static and dynamic states to ensure that the wearer remains comfortable while keeping warm and avoids discomfort caused by heat and moisture imbalance. The product's matrix dynamic adjustment system helps the wearer maintain warmth and comfort in various environments by regulating heat and moisture, reducing discomfort and heat loss caused by temperature differences and sweat. In addition, the composite style structure design supports at least 8 styling conversions, providing more matching options. Scarves and windbreaker jackets can be freely combined with other clothing to meet consumers' needs for fashion matching and functional expansion, ultimately extending the service life of the product.

Table 2. Design process based on the “Three Fits” (SMA) sustainable fashion design model

S - suitability	M - moderation	A - applicability
Social aspect	Environmental aspect	Economic aspect
Research on the multi-form and combination design style [figure. 5] to decrease purchase frequency by increasing occasions of dressing	Use of Primaloft® as inner material which is down blends and resist on humidity and animal friendly	Use of digital brand communication and marketing methods [figure. 6] to avoid the traditional photo shooting which potentially reduce the emission of CO2
	Use of a matrix dynamic adjustment system	Use of homogenous material as outer fabric to maximize the rate of recycle and regeneration

Figure 5. “Buy one, Get eight” multi-form and combination design

Figure 6. Digital brand communication and marketing methods

The sustainable design concept of this product, its enormous range of variation, functional for camping and also for urban life, easy-entry idea (If you have this “jacket”, you are equipped for everything, thus "Buy one, Get eight"), sustainable and well-thought-out design concept, easy to use, minimalistic, urban and inclusive design convinced the jury [20]. After winning the award, with the authors’ authorization, the commercialization [Figure 7] of the product by BOSIDENG, a Global Leader in Down Jackets manufacturer, is a sustainable extension attempt of the design results of the "Three Fits" (SMA) sustainable fashion design model in the fields of production, manufacturing, distribution and retail.

Figure 7. Commercialization of the “Composite Structure Camping Down Jacket” by BOSIDENG

4. CONCLUSION

This paper explores the paths of sustainable fashion of sportswear, apparel and equipment in the context of the whole industry chain, and constructs a "Three Fits" (SMA) sustainable fashion design model, which provides theoretical support and practical guidance for the sustainable development of the sportswear, apparel and equipment industry. The research results show that participants in all links of the whole industry chain should jointly assume the responsibility of sustainable development, apply sustainable technologies, improve consumers' awareness and acceptance of sustainable products, give full play to the role of color matching in conveying sustainable information, and the chemical recycling system of material recycling.

In the process of implementing the "Three Fits" (SMA) sustainable fashion design model, the author analyzes the intersection and dynamics between the three dimensions of environmental suitability, market suitability and social applicability, evaluates the sustainability of products, and verifies the scalability of the model with actual design cases in the application scenarios of the design and product development stage. Although there exist still challenges in the implementation process, such as the clarification of industry boundaries, quantitative assessment of carbon emissions, quantification and evaluation the sustainable development status of the sportswear, apparel and equipment industry, a well-thought-out design strategy which is essential to the whole life cycle of the design product should be prioritized and emphasized in order to promote the harmonious coexistence of the sportswear, apparel and equipment industry in environmental protection and Circular Economy and furthermore, to reach the Sustainable Development Goals (SDGs) from the prospective of fashion industry.

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THE MUSEUM MARKETING MIX IN ENHANCING CITY BRANDING: A CASE STUDY OF SHANGHAI

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ABSTRACT
This paper aims to identify readable marketing attributes and their connotations on museum-driven city branding by applying the theory of the 5P museum marketing mix by Philip Kotler. Methodologically, a comparative study of Shanghai and London was conducted based on the analytic tool and systematic process. The qualitative approach was used by looking at the aspect of museums on the official tourism websites of the two cities. To delve into the research context, the idea of meaning-making was focused in the scope of the research topic. The key findings of the analysis are as follows. Firstly, the examples of museums in Shanghai and London illustrate the diverse range of museum infrastructure. Art museums play a vital role in promoting tourism, while non-art sectors such as transport and fashion design emphasize the industrial strengths of the cities. Secondly, the message of promotion is that well-designed museum exhibition portfolios can help shaping the city's image. Finally, the study found that the principles of museum marketing theory can be strategically used to develop branding strategies for cities, such as positioning.

Keywords: City Branding, 5P Museum Marketing Mix, Product Variety, Exhibition, Shanghai, London

1 INTRODUCTION

The global trend of city branding often involves using landmark museums as a key strategy. This approach has been explored in discussions ranging from city marketing to urban policy. The outcome(s) of leveraging museums to promote cities, such as in London and Bilbao, have been analyzed from various interdisciplinary perspectives, including, sociology, politics, and economics. The theory of product brand has been applied to the creation of brand images for cities, from corporate museums like the Gucci Museum [1] to iconic architectures such as the Bilbao Guggenheim [10]. Research on tourism websites has emerged to analyze the content of these sites from the perspective of multimodal texts [8]. However, socio-economic disparities, the effects of global warming, and the ongoing impact of COVID-19 have all adversely affected museum visits around the world, significantly influencing the tourism profits of global cities [14]. As a result, the museum industry in tourist destinations requires improved and more effective management strategies.

Western museums have built a strong reputation and achieved business success by representing their attractive cities. In contrast, several museums in Asia, located in cities like Seoul, Tokyo, Hong Kong, Singapore, Beijing, and Shanghai, have recently emerged in the museum and tourism market. This phenomenon reflects the development of city brands in Asia, aiming to compete with other city brands at an international level. As of 2022, there were over 6,091 museums in China [18]. In Shanghai, 162 museums were registered as of May 2023 and the number of visitors far exceeding the national average [20].

Academic research on related subjects supports the recognition of the importance of museum in China. Some discussions highlight key issues in regard to the role of museum industry in the nation, including the following: the relationship between the tourism business and museum development in Chinese history [3]; the construction of identity in museums from political perspectives [13]; the evaluation of Online activities of Chinese museums during the COVID-19 era in terms of social and financial advantages [4]; the impact of exhibition marketing on the assessment of exhibition performance [11]; and promotion of exhibition industry in tourism consumption within the digital economy [12].

Some criteria for assessing a city's brand include studying the city and its quality of cultural institutions such as museums. London has built their strong reputation as one of the leading city brands and global museum destinations. The record of visitor numbers has proved the international popularity of the symbolic museums in the city such as the British Museum.

Based on the research background, the study aims to identify the unique marketing features of museums and exhibitions along with their implications for culture-driven city branding. To achieve this, the study employs the features of the 5P museum marketing mix and conducts a comparative analysis of Shanghai and London by examining their official tourism websites. In theory, Philip Kotler's approach to museum marketing and strategy is utilized to support the analysis.

2 LITERATURE REVIEW

2.1 Museum marketing

The theoretical foundation of the 5P museum marketing mix in this research draws from Kotler's writings [6]. He adapted his product marketing theory for the museum sector, establishing a framework based on traditional marketing principles. A key question in his work is, "How does a museum plan strategically and maximize marketing's value?" [6, xxii in Preface]. He stated that museums have a responsibility to their customers to provide "transformative experiences" [6, pp. 5-6]. To achieve this goal, differentiation is necessary to compete with other cultural facility in the museum market. The theory explores product marketing principles for museums, including target segmentation and brand strategy.

In the section of strategic marketing, the five elements are product, price, people, promotion, and place. The notion of exhibition encompasses its role in product variety, price, and promotion within the description. Details of the five elements are as follows. The product element includes product variety, design, features, and brand name; within the sub-element of product variety, the attributes encompass exhibitions, programs, retail, quality are presented; price element includes admission fees, membership fees, special exhibition fees, discounts, and allowances; people element includes board, managers, staff, hierarchies, and teams; promotion element includes advertising, public relations, direct marketing, E-communications, exhibition promotions, and tours promotions; and place element includes channels, locations, transport, inventory, and Internet.

Due to limited data available on the official sites of the two cities, the research concentrated on the content of product for the analytical part. In the analysis sections, the concepts of product variety, design, features, and brand name were applied to construct the context of the findings.

2.2 Competitiveness: City brands and museums

To select cities for the analysis, four criteria were considered: (1) international reputation, (2) city brand assessment, (3) museum popularity, and (4) academic publication. To support the justification for selecting the cities, several references were consulted.

Regarding city brand competitiveness, London ranked first, while Shanghai ranked fifty-fourth according to the City Index 2023 [21]. Shanghai has emerged as a compatible business city brand internationally [15]. From a national perspective, China and the UK rank highest among countries worldwide by the estimated number of museums in 2021 [16].

In terms of museum popularity, the list of the most-visit museums in 2023 [24] highlights the strengths of both China and the UK through their successful tourism products: In China, cities like Beijing, Nanjing, Guangzhou, and Shanghai are key venues for popular facilities, such as the National Museum of China and the China Science and Technology Museum in Beijing, and the Shanghai Science and Technology Museum. The UK, several leading cultural institutions in London made the list, including the British Museum, Victoria & Albert Museum, and the National Gallery. When examining art museum popularity, London demonstrates that its museum industry significantly contributes to the economy and tourism, based on their reputation, quality, and variety; for example, the British Museum ranked second, and the Tate Modern ranked fifth [22]. In contrast to London, Shanghai has not been widely recognized for its art museums within the data.

In research, comprehensive topics have been created on the two cities, covering from art museums to policy in recent years: For Shanghai, the phenomenon of building private art museums and its social and business background [5]; and study on Chinese music heritage from museum management perspectives [7]. For London, multiple dimensions of art museums as a social component of cities [9]; and the value of textile design through the achievement of the Royal School of Needlework [2].

Research question
There is a lack of research on museum marketing, particularly concerning exhibitions and their role in city branding, based on marketing reference. This study aims to fill this gap in knowledge and explore related issues. Based on the key themes identified in the literature review, the research question has been formulated: What are the key elements of museum marketing concerning product variety, and how do these elements relate to branding cities?

3 METHOD

3.1 Data collection

The data was collected from two types of sources. (1) peer-reviewed journals and books, and (2) material from the official tourism websites of Shanghai and London. Additionally, statistics data on city brand assessment and museum visitor; web articles such as newspapers and magazines were used to support the research. Data collection for the sites was conducted between September and November 2024. Following presents the list of the websites and their management organizations. In Shanghai, the official tourism website is Meet Shanghai [17], which is managed by the Shanghai Municipal Administration of Culture and Tourism. On the site, there is also a dedicated section titled Bon App [19], which focuses on museums and exhibitions, and is managed by City News Service. In London, the official tourism website is known as Visit London [23], which is managed by London & Partners, and is supported by the Mayor of London.

3.2 Data analysis

The theoretical framework for this analysis is based on the section of 5P elements of the museum marketing mix as outlined in the book, Museum Marketing and Strategy. In this theory, the category of exhibition is clearly detailed with its key aspects. The main elements and their sub-elements including: product (product variety), price (special exhibition fees), and promotion (exhibition promotions). This research specifically focuses on the element of ‘product variety’ as it relates to the research topic. The analysis consisted of three steps: (1) categorizing museums and exhibitions by navigation, types, and fields, (2) examining the genres and themes of exhibitions, and (3) exploring the connection between marketing strategies and city branding. To conduct the analysis, a meaning-making approach was utilized to produce substantial insights for the research findings.

4 FINDINGS

4.1 Categorization of museums and exhibitions

Navigation
The purpose of this analysis section is to examine how the websites position their selected cultural items to attract audiences in relation to the visual portrayal of a city. In Shanghai, the system for navigating museums and exhibitions on the site is organized as follows: The museum introduction titled Top Museums X Bon App! and is prominently displayed on the first page. The exhibition dates range from fall 2024 to summer 2025. Museums are categorized under Service as a sub-category of Art & Culture, while exhibitions are listed under the title Events, which falls under the sub-category of Exhibition.
In contrast to Shanghai, London employs a different approach to showcasing its key museums and exhibitions. For museum introductions, it uses the sections of Sightseeing and Top London Attractions. The exhibition section is categorized under Leisure and What’s On (the latter being a sub-category under Art/Exhibition). To gather sufficient data for analysis, the three categories were selected for the research including: All art and exhibitions in London, 10 best museum exhibitions in November, and 10 best art exhibitions in November. The total number of museums and exhibitions promoted in the selected categories on the websites of both cities is as follows: Shanghai has 102 museums and 33 exhibitions, while London features 139 museums and 55 exhibitions. (Note: The count of exhibitions in London includes those categorized under the section of art/exhibition.)
The findings show that both city websites employ distinct approaches to design the navigation system and present the city’s cultural offerings to wider audiences. In Shanghai, there is an individual source that provides preliminary information about the city’s museums and exhibitions. In London, the

approach involves positioning key museum products across various categories and reiterating specific examples.

Types and fields

In Shanghai, defining types of museums reveals a variety of purposes aimed at wider target segmentation. Attributes of creating the art and entertainment infrastructure in the city include: complex cultural spaces such as museums and historic sites, and cafés and furniture stores; theme parks; experience places such as virtual reality and DIY; and focus on kids such as playgrounds. Additionally, presenting a category of library in the section implies an expandable concept of museums from arts to books.

The key fields represented by these museums include: arts such as photography and music; design such as aminated miniature, metal toy, and propaganda posters; science/technology such as aerospace, tunnel, and flight; socio-culture such as public security; product such as tobacco and automobile; history such as Jewish refugees and natural history; and finance such as bank. From a design perspective, the fields of animation and miniature stand out as distinctive. Additionally, the internationally franchised museum brand, Madame Tussauds Shanghai, is emphasized.

In contrast to Shanghai, London presents various ways to define its representative urban facility. Four titles of the categories are included: London Museums and Galleries, Our Top Picks, Museums in London for Kids, and Quirky Museums. The classification of museum type presents a diverse array of marketing opportunities, include: outdoor activity such as sport, sightseeing, walking, and theme parks; cultural space such as cafés and book stores; history such as historic sites and houses, and statues; theatre performance such as pantomime; and entertainment venues. The variety allows for creative approaches to engage different audiences effectively. London also highlighted their landmarks, Madame Tussauds London, and London Transport Museum as one of the leading attractions.

The findings show that both city websites utilize a detailed segmentation of museum positioning and introductions. Shanghai emphasizes the creation of a complex cultural space, while London showcases its iconic landmarks, ranging from residential houses to unique items displayed in small museums. The summary of the analysis is presented in Table 1.

Table 1. Categorization of museums and exhibitions

Attribute	Shanghai	London
Navigation	Simplicity of presenting museums and exhibitions.	Enhancing the visibility of museums and exhibitions.
Types and fields	Developing versatile venues for cultural experiences.	Transforming the concept of museums into the cityscape.

4.2 Genres and themes of exhibitions

In Shanghai, the city's achievement in the international museum market is presented within the strategic portfolio including the following. The vitality of the exhibition content clearly reflects the city's vision to be a prominent global player in the art market. For example, the highlighted promotion examples showcase the masterpieces of Turner, Picasso, Mathieu, Pittman, and Rodin. Presentation of the distinctive photography by African artists and graffiti by American artists reflects the expansion of exhibition genres. The exhibition of films presented the historical exchanges between China and Serbia. The introduction of the local and young generation known as Bluerider implies a niche market for paintings. Furthermore, thematic curation that draws upon the city's history, such as Shanghai in National Day, connects to the city's identity.

The exhibition titled Gabrielle Chanel. Fashion Manifesto demonstrates Shanghai's recognition as a global destination. This show was previously launched in the iconic museums in New York, Los Angeles, and Paris before arriving Shanghai [25]. The promotional descriptions, such as "Shanghai for museum landmark" and "From Shanghai to Paris" imply that the city aims to position itself as a culturally vibrant international venue.

Collaborations, such as the introduction of the masterpiece collections from the Tate Britain to the Museum of Art Pudong in the exhibition titled Dialogues with Turner: Evoking the Sublime, and the joint exhibition between the Hong Kong Museum of Art and the Shanghai Museum on the fragrance culture in Chinese history titled The Hong Kong Jockey Club Series: Fragrance of Time, are valuable initiatives [26], [27].

In contrast to Shanghai, London's examples address cultural trends and scientific innovation, from the digital-based multisensory art of Seoul titled Hello, Delight! to the display of the plastination technique titled Body Worlds. In fashion, a couple of eye-catching events present the city's leadership in the related industry such as NAOMI: In Fashion and Vogue: Inventing the Runway. A global success entertainer, including Taylor Swift London Mural, was introduced. In terms of historical figures of the city, from Churchill in politics to Jack the Ripper in crime were focused to present the city. The exhibition featuring David Hockney, a London-based prominent contemporary artist was also a highlight. From social perspectives, the change of British in 1970s and gender issues of South Africa were presented.

Regarding place branding, the city and its cultural facilities serve as a showcase that reintroduces lesser-known locations for street art, multicultural cuisines such as Polish and Japanese, and unique bookstores offering diverse literature from Africa to Asia titled New Bacon Books. The emphasis on the value of artists and architects influences how cities are portrayed like Norman Foster's design work of the Gherkin, and the grand exhibition titled Monet in London at the Courtauld Gallery. Kensington Palace and Japan House London in Kensington area are prominently featured for city marketing.

In terms of the city's identity, the Transport Museum London serves as a compelling illustration of the city's innovative character in the field of industrial design. The promotional texts support the analysis, "The showcase of transport icons and their groundbreaking design, from the iconic red London bus, first ever Tube map design and the world's first underground steam train."

The findings show that both city websites offer creative dimensions through thematic curation and a cross-genre approach. In Shanghai, the events exemplify the city's rapid growth as a compatible art museum destination, while London highlights its visible identity as an international city brand in terms of marketing cultural material. The summary of the analysis is presented in Table 2.

Table 2. Genres and themes of exhibitions

Attribute	Shanghai	London
Genres	Fine arts to cosmetic culture	Fine arts to fashion events
Themes	Art-based cultural vibrancy Reintroduction: city's story	Multicultural inspiration Iconic figures and trends

4.3 Connection between museum marketing and city branding

This section of the analysis focuses on synthesizing the key marketing ideas from the previous discussions. In the table, the horizontal axis represents elements of city branding, while the vertical axis indicates the key elements of product. The design category in this analysis refers to the genres and themes of exhibitions (4.2). The summary of the analysis is presented in Table 3.

Table 3. Connection between museum marketing and city branding

Attribute	Shanghai	London
Product variety	Growth: City positioning	Visibility: Portfolio asset
Design	Heritage/technology-driven	Cross-disciplinary approach
Features	Building city competitiveness	International city leadership
Brand name	Collaboration strategy	Reputation: City-based icons

5 CONCLUSIONS

Based on the key findings of the analysis, a couple of further topics for meaning-making were developed to contextualize the answer to the research question from product variety perspectives. Firstly, the examples of museums in Shanghai and London represent the diverse range of museum infrastructure. Art museums function as a key component in promoting tourism, whereas non-art sectors, including fashion and transport design, focus on showcasing the industrial strengths of their cities. Secondly, the message of promotion is that well-developed museum exhibition portfolios can support enhancing the image of the city. Lastly, the study found that the principles of museum marketing theory can be strategically used to develop branding strategies for cities, such as positioning. Consequently, this paper can provide insights into the contemporary museum marketing practices of the city, thereby contributing to urban governance. The study limits the provision of sufficient data from the selected sites to draw significant conclusions about city branding. Further study can be conducted through visitor surveys and interviews with related stakeholders.

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OPTIMIZING TOURISM FACTORY DESIGN: A STRATEGIC FRAMEWORK FOR ENHANCING VISITOR EXPERIENCE THROUGH SPATIAL ZONING AND VISUAL GRAPH ANALYSIS

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ABSTRACT
This study aims to enhance visitor experience in tourism factory by developing a strategic framework for spatial design, using the Hwa Meei's "Eye Fun Vision" tourism factory as a case study. The research employs expert consensus techniques, such as the Delphi method, and space syntax analysis to identify key spatial elements and optimize the layout of factory tour spaces. The findings highlight the importance of spatial zoning, connectivity, and visitor engagement in creating effective and memorable factory tours. Through case analysis of major factory tours in South Korea, Taiwan, Japan, Germany, and the United States, the study identifies critical zones such as introduction, history, manufacture, activity, and sales. A Visual Graph Analysis (VGA) of the Hwa Meei tour space further reveals how visual connectivity and integration can enhance visitor flow and interaction. The results show that strategically arranged zones, with interactive elements and well-designed movement paths, significantly improve visitor engagement. The study offers practical recommendations for applying this spatial design framework to various industries, promoting the growth of industrial tourism. This research contributes to the field by providing a structured approach to factory tour design, combining both expert insights and data-driven spatial analysis to create visitor-centric, educational, and brand-enhancing experiences.

Keywords: Tourism Factory, Industrial Tourism, Spatial Zoning, Visual Graph Analysis

1 INTRODUCTION

The growing trend of industrial tourism, which involves guided tours through manufacturing facilities, offers companies a unique opportunity to engage with the public while showcasing their production processes and brand history. This type of tourism fosters brand loyalty and provides educational value, allowing visitors to experience firsthand how products are made and understand the history and culture behind the brand. When visitors enter a tourism factory, they typically follow a predetermined path designed by the factory tour organizers. Therefore, the sequence and organization of the spatial design within tourism factories significantly impact the visitor experience. Properly planned spatial layouts not only guide visitor movement effectively but also influence how they engage with the factory environment and interpret its narratives (Hillier & Hanson, 1984 [6]; Turner et al., 2001 [20]).

Existing studies provide a foundation for understanding the spatial components necessary for booming industrial tourism. Jia (2010) emphasized integrating dynamic displays and interactive activities to actively engage visitors, making tours more immersive [1]. Lee (2015) identified accessibility, including amenities such as galleries and souvenir shops, and curated experiential activities as vital contributors to tourist satisfaction in factory settings [2]. Lin (2019) further highlighted the role of service experiences and cultural and educational heritage preservation in attracting and retaining visitors [3]. Although these studies deal with the importance of interactive and experiential elements, they fail to address the spatial organization of tours and their impact on the quality of visitor experiences. Moreover, although they discuss key experiential aspects, they must deeply explore how spatial sequencing and organizational strategies within tourism factories influence visitor behavior and satisfaction.

To address this gap, insights from the fields of museum and theme park design provide a valuable framework for understanding spatial dynamics in industrial tourism. Dera and Ridzqo (2021) discussed the application of spatial zoning to organize spaces to optimize visitor flow and enhance engagement [4]. Similarly, Peponis et al. (2004) and Turner et al. (2005) have demonstrated the effectiveness of space syntax techniques in analyzing and designing spaces to facilitate movement and interaction, particularly in environments with complex spatial layouts such as museums [5][7]. These approaches suggest that integrating spatial analysis into factory tour design can create an environment where visitors interact meaningfully with exhibits, fostering deeper brand connections.

In response to the need for a structured approach to factory tour spatial design, this study aims to develop a strategic framework that enhances the visitor experience through spatial zoning based on Delphi and visual graph analysis (VGA). Using the Hwa Meei "Eye Fun Vision" tourism factory in Taiwan as a case study, this research combines expert consensus techniques, such as the Delphi method, with case study analysis. Additionally, it incorporates space syntax analysis to identify and optimize the spatial zoning of factory tours, ensuring a practical and visitor-centric design approach. This study's findings are expected to offer actionable insights for industries seeking to enhance visitor experiences while reinforcing corporate identity through strategic tourism factory spatial design.

2 RELATED WORKS

2.1 Essential factors and elements in devleoping tourism factories

Research in industrial tourism highlights key elements that enhance the appeal of destinations like galleries and factory tours. Lee’s (2015) study organized 34 determinants into a hierarchical structure, focusing on accessibility, amenities, and ancillary services. Analyses of tourist sites emphasize experiential activities, such as video/photo galleries, brand history exhibitions, and production process observations, which foster deeper visitor engagement [2]. Lin (2019), using the Network Relationship Map (NRM), identified product exhibitions, marketing promotions, service experiences, and educational heritage conservation as critical drivers of service value [3].

Jia’s (2010) research emphasized integrating experiential tourism into industrial sites through dynamic displays and interactive experiences, highlighting production processes and company history [1]. The concept of spatial zoning, applied in theme parks and museums, has been used to examine the impact of spatial organization on visitor experiences. Dera and Ridzqo's (2021) study of zoo landscapes demonstrated that strategically placed exhibit zones enhance educational and recreational value [4], while Yoo’s research on Samsung and SK exhibition halls explored how spatial division delivers effective brand messages [8, 9].

These studies underscore the importance of strategic spatial organization, product exhibitions, and interactive experiences in making industrial tourist sites more appealing and providing visitors with memorable and educational experiences.

2.2 Expert consensus techniques and space syntax method for museum and tourism

Expert consensus techniques like the Delphi method, the Analytical Hierarchy Process (AHP), and space syntax are widely used to enhance spatial layouts in museums and tourism. These methods integrate expert insights and analyze spatial configurations to optimize movement and engagement.

The Delphi method refines expert input through iterative surveys to reach a consensus on spatial design issues. Ruhanen (2004) applied it to develop sustainable tourism strategies [10], while Garrod et al. (2011) used it for heritage tourism to improve space organization for storytelling [11]. In museums, Zatori et al. (2016) applied Delphi to prioritize elements that enhance visitor engagement [12], while Hsu et al. (2011) used AHP to rank spatial components like exhibit accessibility, helping planners create more structured layouts [13].

Space syntax, particularly Visual Graph Analysis (VGA), examines the relationships between spaces and their impact on visitor movement. Peponis et al. (2004) applied space syntax at MoMA, revealing that visually integrated areas encouraged exploration, enhancing visitor interaction [5]. Nubani et al. (2018) used visibility graph analysis to compute exhibit visibility and movement patterns [14], while Li et al. (2020) applied space syntax to analyze museums in China, resulting in rearranged layouts for better visitor experiences [15]. These methods—Delphi, AHP, and space syntax—have proven effective in identifying key design elements and optimizing visitor experiences by analyzing spatial layouts.

3 METHODOLOGY

This study focuses on optimizing the spatial design of factory tours by identifying vital spatial elements through case studies and the Delphi method. These elements are organized into a systematic zoning framework. Visual Graph Analysis (VGA) data plays a crucial role by demonstrating how these spatial elements interact and influence visitor movement patterns, validating the proposed design in real-world settings.

3.1 Case analysis of tourism factory

We conducted case studies of representative factory tours and field visits to analyze space zoning and the content elements within factory tours. The study focused on eyewear companies such as Hwa Meei and factory tours in industrial tourism countries, including South Korea, Japan, Taiwan, Germany, and the United States. We selected two representative factory tours from each country, focusing on light manufacturing industries (e.g., apparel, cosmetics, and eyewear). For each case, spaces were analyzed through on-site visits, videos, and literature. Examples include Zeiss in Germany, Oakley's factory tour in the United States, and the Megane Museum in Japan. In South Korea, the Amore Factory was selected, and in Taiwan, the Eminent Creative Luggage Tourist Factory. Four factories were visited in Asia, while US and German cases were studied via secondary sources. This approach provided a robust framework for understanding spatial zoning's role in enhancing visitor experiences in tourism factory.

Table 1. Representative Cases of Tourism Factory

Company	Sector	Sub-areas
Amore Factory (Korea)	Cosmetics	Introduction of Founder/CEO, Manufacture Process, Photozone, Company History, Company Product History, DIY, Manufacture Equipment, Manufacture Process
Eminent Creative Luggage Tourist Factory (Taiwan)	Luggage	Photo Zone, Introduction of Founder/CEO, Company History, Company Product history, Manufacture Equipment, Manufacture Process, Company Product Line, Quiz, DIY, Cafe, Goods Shop
Megane museum (Japan)	Eyewear	Introduction of Founder/CEO, Company History, Company Product History, Product history, Manufacture Equipment, DIY, Cafe, Goods Shop, Company Product Line
Shiseido Factory (Japan)	Cosmetics	Manufacture process, company product history, hands-on activity, DIY, Company History, Photozone, Manufacture Equipment, Manufacture Process, Company Product Line,
ZEISS Museum (Germany)	Eyewear	Company History, Company Product History, Goods Shop, Hands-on Activity, Company Product Line Archive, PhotoZone
Oakley Factory Tour (United States)	Eyewear	Introduction of Founder/CEO, Company History, Hands-on Activity, Manufacture Process, Company Product History, Goods Shop, Company Product Line, Cafe

The factory tour cases are organized by country, company, sector, and sub-areas. This study compares the critical features of factories and museums across South Korea, Taiwan, Japan, Germany, and the United States. South Korea's Amore Factory (cosmetics) includes sub-areas like introducing the founder/CEO, manufacturing process, photo zone, company/product history, DIY, and manufacturing devices. Taiwan’s Eminent Creative Luggage Tourist Factory (luggage) features a photo zone, company history, product line, quizzes, DIY, a café, and a goods shop. Japan’s Megane Museum (eyewear) and Shiseido Osaka Ibaraki Factory (cosmetics) focus on manufacturing processes, company history, DIY, and interactive activities. Germany’s ZEISS Museum (eyewear) includes company/product history, a goods shop, hands-on activities, and a product line. In the US, Oakley’s Factory Tour (eyewear) covers sub-areas like the Founder/CEO introduction, company history, hands-on activities, manufacture, and a café. The six representative cases mentioned above were used to identify critical spatial elements for factory tours. In this study, the cafeteria was excluded from the analysis of Hwa Meei visitors. The 12 identified spatial elements were: photo zone, founder and CEO introduction, company history, product history, overall product history, manufacture equipment, manufacture process, product line, games and quizzes, hands-on activities, DIY, and goods shop.

3.2 Delphi method for space zoning

3.2.1. Delphi method

The Delphi method defined factory tour space zoning and its content elements. This qualitative technique gathers expert opinions in multiple rounds until a consensus is reached (Linstone & Turoff, 1975) [16]. First, experts related to the subject are selected, forming a panel of 10–15 members (Ven & Delbecq, 1974) [17]. A primary questionnaire is self-administered to gather initial insights. A second questionnaire is developed based on responses, using a 5-point Likert scale for more straightforward statistical analysis. The Delphi process continues until expert opinions converge, and content validity, convergence, consensus, and stability are measured after each round. Lawshe's (1975) formula for Content Validity Ratio (CVR) is used to determine the importance of each element, where a CVR value of 1.0 indicates complete agreement among experts [18]. Questions with lower CVR values are re-evaluated or removed, ensuring only the most relevant elements are retained for spatial zoning.

$$CVR = \frac{N_e - (\frac{N}{2})}{\frac{N}{2}} \tag{1}$$

Table 2. The minimum Threshold for CVR based on the Number of Respondents

N	5	6	7	8	9	10	11	12	13	14	15	20	25	30	35	40
Min.	.99	.99	.99	.75	.78	.62	.59	.56	.54	.51	.49	.42	.37	.33	.31	.29

The degree of convergence measures the alignment of expert opinions. It is calculated by comparing the third quartile (Q3, 75%) and first quartile (Q1, 25%) of expert responses. A convergence value of less than 0.50 indicates well-aligned opinions. Consensus is determined when 50% of experts agree on a response, with a consensus score greater than 0.75 reflecting strong agreement. The Stability Coefficient is calculated by dividing the mean by the standard deviation (SD) to obtain the Coefficient of Variation (CV). A CV of less than 0.50 suggests that expert opinions are stable, helping to determine whether to proceed with or conclude the Delphi survey.

$$Convergence = \frac{Q_3 - Q_1}{2} \tag{2}$$

$$Consensus = 1 - \frac{Q_3 - Q_1}{Median} \tag{3}$$

$$CV = \frac{SD}{Mean} \tag{4}$$

This study conducted four Delphi surveys with experts to identify critical factors for space zoning and content organization in tourism factories. The Delphi panel consisted of 10 experts (7 women, 3 men) aged 34 to 51, all with at least a bachelor's degree. Their expertise spanned political science, cultural arts, architectural planning, environmental art design, and more, ensuring a well-rounded approach. Professionally, they held roles in strategic planning, content management, academia, and museum curation, with 4 to 24 years of experience, providing a solid foundation for the Delphi process. In the first Delphi survey, participants reviewed spatial elements and definitions of 12 tourism factories, selecting 'agree,' 'disagree,' or 'complement,' and suggesting modifications if needed. Based on these responses, a second questionnaire presented revised elements, with participants asked to rate their appropriateness—the third questionnaire focused on areas of disagreement, refining the expert consensus on zoning. A CVR value of .62 or higher was considered valid for inclusion in this study.

3.2.2. Outcomes of delphi

In the first Delphi survey, the researcher proposed 12 spatial elements for the factory tour: photo zone, introduction of the founder and CEO, company history, company product history, product entire history, manufacture equipment, manufacture process, company product line, games and quizzes, hands-on activities, DIY experience, and goods shop. After the first round of expert feedback, the spatial elements were adjusted, and 13 elements were identified. Notably, the introduction of the founder and CEO was replaced with “Company Founding Background and MVC,” games and quizzes were removed, and three new elements—information center, community contribution, and café—were added. Additionally, “DIY Experience” was renamed to “DIY Workshop,” and “Manufacture Process” was expanded to include both manufacturing equipment and processes.

During the second Delphi survey, further adjustments were made. “Product Entire History” was removed, as it received a low Content Validity Ratio (CVR 0.2), low agreement (0.375), and high convergence (1.25), indicating it was not deemed essential by the experts. The remaining 12 elements were agreed upon, including the photo zone, company founding background and MVC, company history, company product history, company product manufacturing process, company product line archive, hands-on and interactive activities, DIY workshop, goods shop, information desk, company ESG (replacing community contribution), and café.

In the third Delphi survey, the definition of “Company ESG” did not reach consensus (CVR 0.4, agreement 0.625, convergence 0.75). Therefore, the name and definition of this element were revised for the fourth round. After the fourth Delphi survey, the final set of 11 spatial elements was established. These included the photo zone, company founding background and MVC, company history, company product history, company product manufacturing process, company product line archive, hands-on and interactive activities, DIY workshop, goods shop, information desk, and café.

Table 2. Spatial Zoning for Tourism Factory

Order	Zone	Sub-areas
1	Information	13) Information Desk
2	Introduction	2) Cooperation Founding Background & MVC
3	History	3) Company History, 4) Company Product History
4	Manufacture	7) Manufacture Process, 8)Company Product Line Archive
*	Activity	10) Hands-on/Interactive Activity, 11) DIY Workshop
	Sales	12) Goods Shop, 15) Cafe
	Attraction	1) Photo Zone

The “Eye Fun Vision” tourism factory is meticulously designed to maximize visitor engagement through six distinct zones, each tailored to provide a unique and memorable experience. The zones labeled Information, Introduction, History, and Manufacture follow a sequential order, ensuring a logical narrative that guides visitors through the journey of Hwa Meei’s legacy and manufacturing expertise. Conversely, the zones marked with an asterisk (Activity, Sales, and Attraction) are flexible in their exploration, allowing visitors to engage with them based on individual preferences and interests.

The Information Zone serves as the starting point, welcoming visitors at the information desk and preparing them for their tour. The journey continues to the Introduction Zone, featuring the "See Hwa Meei" exhibit, which introduces the brand's founding background, vision, and mission, laying a solid foundation of corporate identity.

The History Zone delves into the development of the eyewear industry and Hwa Meei’s corporate legacy, showcasing exhibits like the “Domestic Eyeglasses Industry” and the “Hwa Meei Enterprise Timeline.” Following this is the Manufacture Zone, where visitors gain insight into the technical and creative processes of eyewear production through displays such as the “Celebrity Wall,” “4 Kinds of Eyeglasses Scene Display,” and “Lens Manufacturing Process.”

The Activity Zone, offering high interactivity and educational value, provides hands-on experiences like “Frames DIY” and exhibits on “Different Eye Pathologies” and “Sports Visual Knowledge.” Immersive activities include tests like “Amplitude of Accommodation,” “Laser Lenses Resolution,” and “Impact Resistance in Different Lenses.” Visitors can also use advanced eyewear technologies, such as “Army Protective Eyewear.”

The Sales Zone caters to visitors interested in purchasing eyewear and souvenirs, with a glasses shop and vending cart offering curated items. Finally, the Attraction Zone captivates visitors with visually stunning displays, including the “Owl Collection Display” and the “3D Painted Wall,” providing photo opportunities that encourage sharing and engagement.

Table 3. Spatial Zoning for Hwa Meei's Eye Fun Vision

Order	Zone	Sub-areas of Hwa Meei
1	Information	X
2	Introduction	See Hwa Meei
3	History	Domestic Eyeglasses Industry, Hwa Meei Enterprise Timeline
4	Manufacture	Celebrity Wall, 4 kinds of Eyeglasses scene display, Lens Manufacturing Process
*	Activity	Frames DIY, Hand Eye Coordination Toy, Different Eye Pathologies, Sports Visual Knowledge, First Hand Experience of Color Lenses, 3D glasses Experience, Amplitude of Accommodation Testing, Laser Lenses Resolution Test, UV Lens Tester, Impact Resistance in different Lenses, Army Protective Eyewear
	Sales	Glasses Shop, Vending Cart
	Attraction	Owl Collection Display, 3D Painted Wall

4 CASE STUDY AND VISUAL GRAPH ANALYSIS

4.1 Environmental setting of Hwa Meei's Eye Fun Vision

Hwa Meei, a global sports eyewear manufacturer, established the 'Eye Fun Vision' tourist factory in 2016. The main goal of the factory tour is to showcase the heritage of eyewear manufacturing in Taiwan and raise awareness about vision protection and correction. Eye Fun Vision, Taiwan's first eyewear tourism factory, is designed to reflect Hwa Meei's corporate identity and features the brand's owl mascot. The facility provides visitors with insights into eyewear production's industrial and cultural aspects, offering experiences like DIY sunglasses-making, interactive optical games, professional optometry services, and a wide range of eyewear products. The space is divided into four main areas and 21 sub-areas.

This table lists the 21 subareas within the Hwa Meei Optical Company tourism factory, categorized into four main areas. Area 1 focuses on the history of Hwa Meei, featuring subareas such as "See Hwa Meei," "Owl Collection Display," "3D Painted Wall," and "Celebrity Wall." Area 2 highlights the eyewear industry and Hwa Meei's corporate timeline, with subareas including "Domestic Eyeglasses Industry," "4 Kinds of Glasses Scene Display," "Hwa Meei Enterprise Timeline," and "Frames DIY." Area 3 is dedicated to various eye conditions and lens testing, with subareas like "Different Eye Pathologies," "Amplitude of Accommodation Testing," and "Military Protective Glasses." Area 4 consists of the "Glasses Shop," where visitors can purchase eyewear, marking the final stop in the tourism factory. Each area presents a distinct theme, providing visitors with a diverse range of experiences as they explore critical elements of eyewear production, history, and technology.

Figure 1. Hwa Meei's Tourism Factory 'Eye Fun Vision'

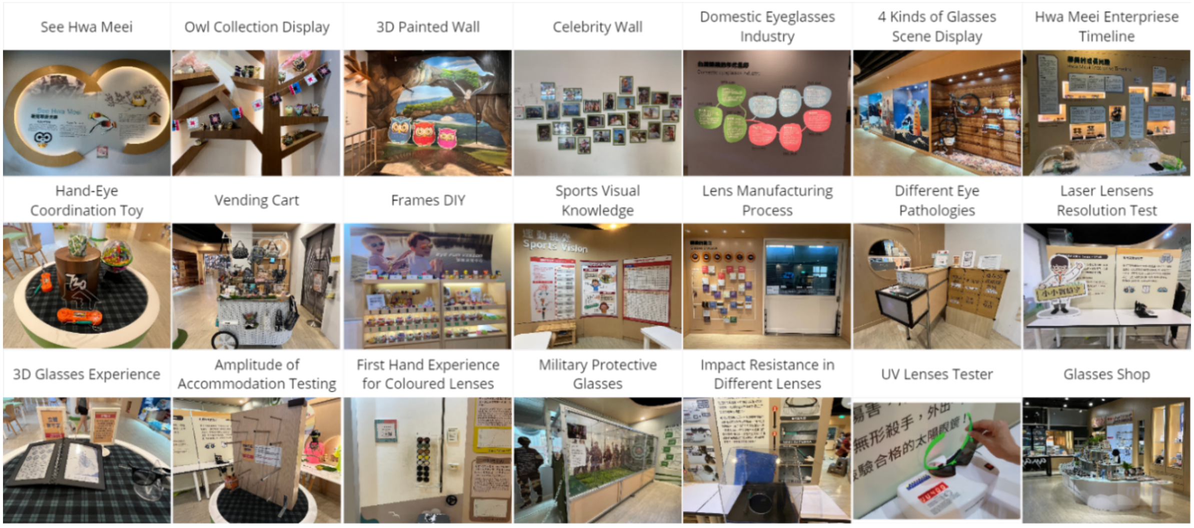

Figure 2. 21 Sub-areas of Hwa Meei's Tourism Factory 'Eye Fun Vision'

4.2 Spatial analysis of Hwa Meei tourism factory with delphi

This study aimed to identify and optimize sub-areas' design within the existing Hwa Meei factory tour using the Delphi method. The 21 sub-areas were categorized into six zones: Introduction, History, Manufacture, Activity, Sales, and Attraction. Since the Information Zone was irrelevant to the Hwa Meei factory, it was excluded from the zoning. Each zone was assigned a unique color for clarity: orange for Introduction, blue for History, green for Manufacture, yellow for Activity, red for Sales, and purple for Attraction. Initial analysis of the existing layout revealed significant issues with the spatial zoning and sequence of the sub-areas. The zones were disorganized to facilitate a logical flow or enhance visitor engagement. Based on the Delphi method, expert feedback was used to reorganize the sub-areas into a more practical layout.

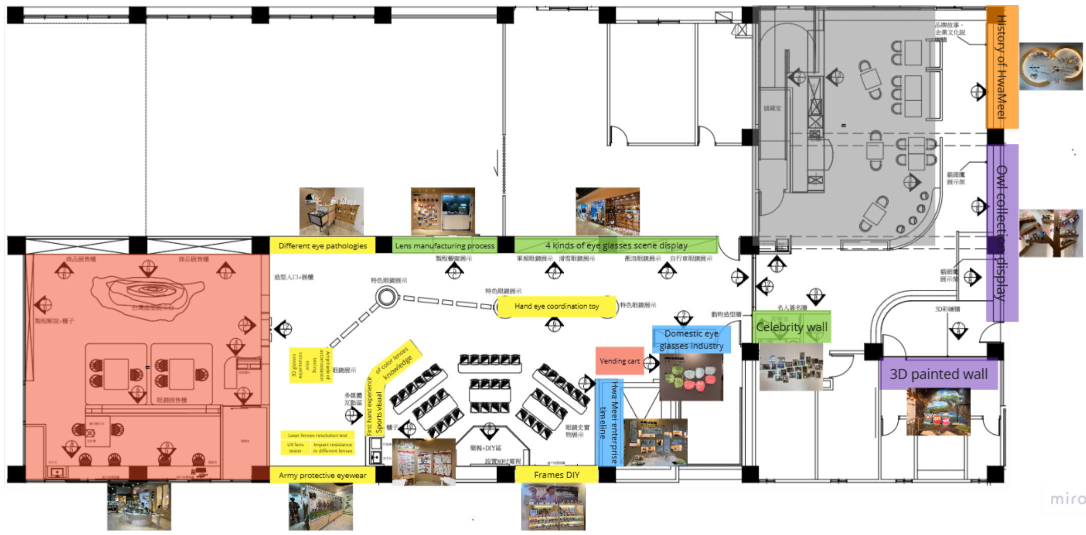

Figure 3. Before Zoning and Ordering: Initial Layout of the tourism factory Subareas

The optimized layout arranged the Introduction, History, and Manufacture zones sequentially, as these zones require a logical narrative flow to convey essential brand and production insights. On the other hand, the Activity, Sales, and Attraction zones, which do not depend on a fixed order, were strategically positioned to maximize visitor engagement and flow flexibility.

The orange Introduction Zone, placed at the beginning of the tour, serves as the entry point for visitors to familiarize themselves with the brand's identity. This zone includes the "See Hwa Meei" exhibit, which highlights the company's founding background, mission, vision, and corporate values, providing a foundation for understanding the tour's narrative.

Following the Introduction Zone, the purple Attraction Zone, located prominently at the entrance, features visually captivating elements like the 3D Painted Wall and Owl Collection. These displays are designed to immediately grab visitors' attention and set a positive tone for the tour while offering memorable photo opportunities.
The blue History Zone included exhibits such as the History of Hwa Meei, the Domestic Eyeglass Industry, and the Enterprise Timeline, providing a rich historical context and showcasing the company's heritage. The green Manufacture Zone highlighted technical and creative aspects of eyewear production with displays like the Lens Manufacturing Process and Celebrity Wall, offering an engaging insight into the brand's craftsmanship. The red Sales Zone contained the Vending Cart and Glasses Shop, allowing visitors to purchase products and souvenirs. Finally, the yellow Activity Zone featured highly interactive exhibits, such as Frames DIY, 3D Glasses Experience, and various lens testing areas, offering hands-on activities that enhance engagement and educational value.

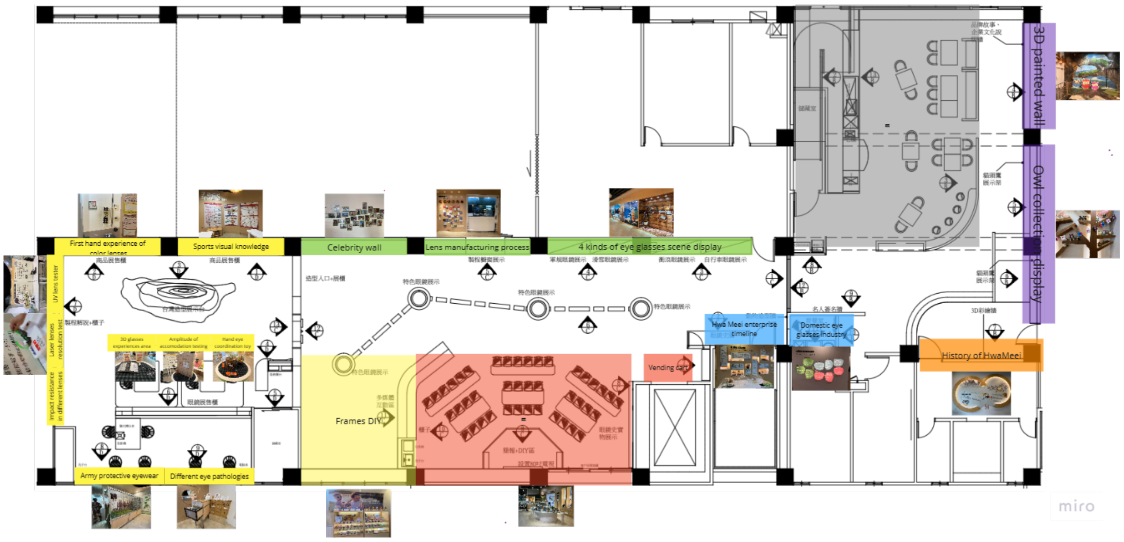

Figure 4. After Zoning and Ordering: Optimized Layout Based on Spatial Zoning and Visitor Flow

4.3 Visual graph analysis with space syntax

The spatial structure of the Hwa Meei space was analyzed using space syntax to identify topological relationships and quantitatively describe the spatial configuration (Hillier & Hanson, 1984) [6]. The primary goal was to analyze the factory tour's spatial structure and understand visitor movement patterns. Using Visual Graph Analysis (VGA), the study evaluated the visual connectivity of the interior spaces, excluding the café (Turner et al., 2005) [19]. The VGA graph was modeled in CAD and imported into the depthmap 8.0 program for analysis, extracting metrics like connectivity, control, integration, and intelligibility (Turner, 2004) [7].
Several indicators were examined to predict visitor movement. Points with high connectivity are major intersections or key points along routes (Hillier & Hanson, 1984) [6]. High visual integration areas are accessible and often hubs for tours (Turner et al., 2005) [19]. Areas with a high visual clustering coefficient attract more attention and encourage visitors to stay longer. Visual control assesses how locations influence movement, while high visual entropy indicates areas where visitors may experience confusion (Turner, 2004) [7]. Lastly, areas with high visual mean depth are less accessible and likely receive fewer visitors (Hillier & Hanson, 1984) [6].
This analysis process was conducted in four major steps. First, the floor plan of the Hwa Meei tourism factory was digitized to prepare it for analysis within the software, ensuring accurate spatial analysis. Second, the visibility of each exhibit space and movement path was analyzed to generate a visibility graph. This allowed for an assessment of how well visually connected key exhibits or major visitor points were. Third, visitor movement paths were predicted based on the visibility analysis results and compared with actual visitor data, enabling the identification of visitor movement patterns that differed from expectations. Finally, areas requiring improvement were identified based on the analysis, and specific design enhancement measures were proposed. These included adjustments to exhibit locations, optimization of movement paths, and design modifications to strengthen visual connectivity.

The efficiency of spatial layout can be evaluated by combining the proposed spatial zones with the statistical analysis results. Using Space Syntax and performing a Visibility Graph Analysis (VGA) with Depthmap, several potential improvements in the spatial design of the Hwa Meei tourism factory, "Eye Fun Vision," were identified. Based on the VGA results, design adjustments were proposed to enhance the visual connectivity of the space, allowing visitors to experience the space more effectively.

The four main zones proposed in the study—Information, Introduction, History, and Manufacturing—were arranged in a specific sequence, identified as having high connectivity and high visual integration based on statistical analysis results. These findings suggest that visitors will move naturally along a connected path through these zones. In other words, the sequential arrangement of these zones is designed to allow visitors to experience the space efficiently and intuitively, playing a key role in maintaining a smooth flow throughout the exhibition space.

Besides, points with high visual controllability can play a crucial role in guiding the flow of visitors. Placing important information or directional elements at these points would be highly effective. This approach helps visitors naturally notice these points, obtain the necessary information, and navigate the space efficiently. The four main zones proposed in the study—Information, Introduction, History, and Manufacturing—were arranged in a specific sequence, which was identified as having high connectivity and high visual integration according to the statistical analysis results. Thus, the sequential arrangement of these zones is designed to allow visitors to experience the exhibit efficiently and intuitively, playing a crucial role in maintaining a smooth flow throughout the exhibition space.

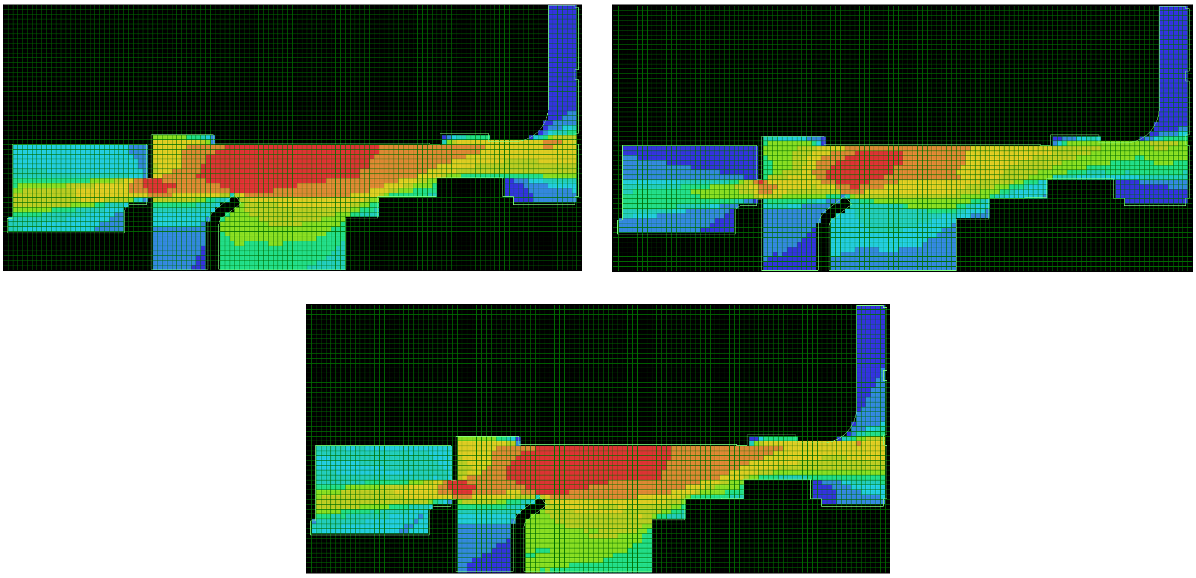

Figure 5. Connectivity, Visual Integration, and Visual Controllability

Locations with high clustering coefficients should be utilized as focal points for visitor engagement. Hands-on activities and DIY workshops have been shown to increase visitor participation significantly. Statistical analysis suggests these activities are more likely to occur in areas with high Visual Clustering Coefficients. This implies that such spaces should be intentionally designed to attract concentrated visitor attention. In other words, spaces designated for these activities should be tailored to draw visitors and enhance their participation levels naturally.

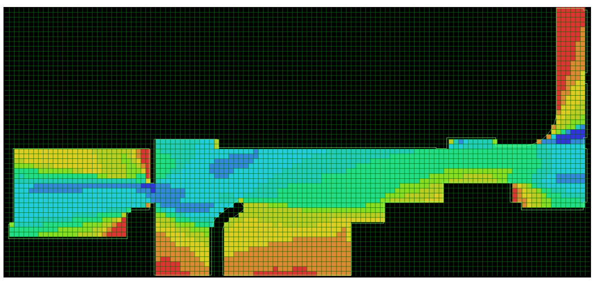

Figure 6. Visual Clustering Coefficient

5 DISCUSSION

This study aimed to enhance the spatial design of factory tours by integrating expert consensus through the Delphi method and utilizing space syntax analysis to optimize visitor movement and engagement. The research revealed critical insights into how spatial zoning and layout can significantly influence visitor experience and the practical considerations needed to design adequate tourism factory spaces. The Delphi method was instrumental in deriving key spatial elements and sub-areas essential for factory tours. The iterative rounds of expert consensus allowed for the refinement and validation of spatial components such as the photo zone, company history, manufacturing process, and hands-on activity areas.The clear division of zones—such as Information, Manufacturing, and History—ensured that the space had a logical flow, enhancing visitor understanding of both the company's history and its product manufacturing processes.

The Visual Graph Analysis (VGA) of the factory's spatial configuration, particularly the Hwa Meei "Eye Fun Vision" case, demonstrated the importance of visual connectivity and control in influencing visitor movement patterns. Areas with high connectivity, such as the photo zones and manufacturing displays, became natural hubs where visitors lingered or interacted more deeply with exhibits. This suggests that spatial elements with high integration and connectivity should be strategically placed to capture visitor attention and enhance engagement.

The analysis also identified areas of low visual integration, such as less accessible zones that required a redesign to improve their visibility and engagement potential. The study's findings underline the significance of thoughtful spatial design in enhancing industrial tourism's educational and entertainment value. The integration of interactive activities, DIY workshops, and visually accessible manufacturing processes not only provides educational benefits but also strengthens brand loyalty by fostering memorable experiences. However, the research also highlighted the challenge of balancing corporate objectives (such as showcasing brand heritage) with visitor-centric design, particularly in zones like manufacturing areas, where safety and operational constraints might limit visitor interaction.

6 CONCLUSIONS

This research successfully identified and validated core spatial elements and zoning strategies for factory tours through expert consensus techniques and space syntax analysis. The study established a systematic framework that includes critical zones—such as introduction, history, and manufacturing—supported by hands-on activities and visitor-centric design strategies. Using the Delphi method, the study aligned the spatial design with expert insights. At the same time, the application of Visual Graph Analysis allowed for data-driven recommendations to optimize visitor flow and interaction.

The case analysis of the Hwa Meei "Eye Fun Vision" factory tour demonstrates the potential of well-designed factory tours to enhance visitor engagement, promote corporate identity, and provide educational value. The research contributes to industrial tourism by offering a comprehensive spatial design framework that can be adapted across various sectors and geographies. Furthermore, the findings stress the importance of integrating expert knowledge and spatial analysis tools to create more meaningful and memorable visitor experiences.

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A CASE STUDY OF ESD EDUCATION ACTIVITIES FOCUSING ON GLOBAL UNIVERSITIES

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ABSTRACT
Universities play a crucial role in the realization of the Sustainable Development Goals (SDGs). As the core of knowledge creation and talent cultivation, universities not only promote social progress through research, teaching, campus management, and social impact, but also fulfill multiple functions of social responsibility. Hundreds of millions of people around the world receive general education, professional training, and career development in universities, which makes universities uniquely positioned and widely influential in promoting Education for Sustainable Development (ESD). This study aims to analyze the key role of universities around the world in promoting SDG-oriented education, with a particular focus on how universities can enhance students' knowledge and skills and develop their sustainable development mindset through their teaching and learning services. By synthesizing cases of ESD practices in universities in different regions around the world, this study explores the impact of ESD activities on students' sustainability awareness and competence in diverse educational contexts, in order to promote a comprehensive transformation and integration of universities around the globe as they address the challenges of sustainable development.

Keywords: Education for Sustainable Development (ESD), Sustainable Development Goals (SDGs), Sustainable Design, Social Responsibility, Social Impact

1 INTRODUCTION

The adoption by the United Nations in September 2015 of Transforming Our World: The 2030 Agenda for Sustainable Development marks a major international consensus on the global response to the most pressing challenges [1]. At the heart of the agenda are the 17 Sustainable Development Goals (SDGs) and their sub-goals, which are designed to guide countries in their collective efforts to address key issues by 2030, including eradicating poverty, guaranteeing food security, protecting the planet's environment, combating climate change, and realizing fully inclusive and peaceful societies. These goals encompass complex social, economic and environmental challenges, the realization of which requires a re-examination of socio-economic modes of operation and the way in which human beings interact with nature, with an emphasis on cooperation and systematic operation among various sectors.

In the process of realizing the SDGs, ESD has become a key issue in the field of higher education. The role of universities in promoting ESD is particularly important as the core of knowledge innovation and talent cultivation. However, different regions and types of universities face diverse opportunities and challenges in implementing ESD education, and such differentiated practices and effects need to be systematically analyzed. This study aims to reveal successful implementation models and innovative practices through an in-depth analysis of ESD cases in universities in different regions around the world. By summarizing these experiences and challenges, this study not only expects to provide effective references for other universities to implement ESD education, but also hopes to provide targeted strategic recommendations for policy makers and educational administrators to promote global higher education to better adapt and serve the needs of human social development.

Despite the growing importance of Education for Sustainable Development (ESD) in global higher education, there is still a research gap in terms of systematic case studies of ESD implementation in universities around the world. Currently, most of the relevant studies focus mainly on specific regions or countries and lack comparative analyses across regions and cultures. This limitation of regional studies has resulted in an incomplete understanding of ESD implementation patterns, success factors, and challenges faced in different national and cultural contexts, thus limiting in-depth understanding of its effectiveness and sustainability [2]. This study aims to fill this gap by analysing the practices and project implementation in ESD education at De Montfort University in the UK, Jaime I University in Spain and Osaka University in Japan, and summarising the successes and challenges they have achieved in implementing ESD education. The study will adopt literature research method, comparative research method and case study method to explore the commonalities and differences in ESD practices among universities in different countries, and provide valuable references and suggestions, aiming to promote the further development and optimisation of ESD globally.

2 EDUCATION FOR SUSTAINABLE DEVELOPMENT (ESD)

2.1 Definition and development process

Education for Sustainable Development (ESD) is an educational philosophy that aims to prepare students to understand and respond to the challenges of sustainable development, with a core focus on promoting an understanding of the complex relationships between society, the economy, and the environment. ESD focuses not only on the transfer of knowledge, but also on the shaping of values, skills, and behaviours, with an emphasis on the development of critical thinking and problem-solving skills to enable students to actively participate in addressing global issues such as climate change, poverty, inequality and resource depletion [3].

The evolution of ESD can be divided into several key stages.In 1992, ESD was formally incorporated into the global agenda at the United Nations Conference on Environment and Development, emphasising the key role of education in achieving sustainable development. Subsequently, the Decade of Education for Sustainable Development Action Plan from 2005 to 2014 further promoted the popularisation of ESD and facilitated the integration of the concept of sustainable development into the education system of various countries.In 2015, the United Nations Sustainable Development Goals (SDGs) were proposed, making ESD an important tools, especially the explicit emphasis on the role of education in goal SDG 4. SDG 4 not only focuses on ensuring inclusive and equitable quality education, but also emphasises that the content of education should encompass all aspects of environmental protection, social equity, and economic sustainability, a series of developments that signify the growing importance of ESD in the global education system, demonstrating its indispensable role in the promotion of sustainable development [4].

Today, ESD is moving towards a more integrated and systemic approach that is no longer limited to environmental issues, but extends to areas such as social and economic development and cultural diversity, emphasising equity and inclusiveness in education [5]. Through these developments, ESD lays a solid foundation for the development of future citizens with a global perspective and a sense of social responsibility.

2.2 Key features and objectives

As an important educational concept for realizing sustainable development, ESD, with its distinctive features and clear objectives, is committed to enhancing students' comprehensive literacy, including deepening their understanding of the environment, enhancing their sense of social responsibility, and honing their practical skills. First of all, interdisciplinarity is a major feature of ESD, which emphasizes the interconnection between different disciplines and promotes students' understanding of complex sustainable development issues from multiple perspectives, including ecological, economic and social. This multifaceted perspective not only enhances students' ability to think systematically, but also enables them to synthesize and apply what they have learned [6]. Second, the practical nature of ESD emphasizes the enhancement of learning through hands-on practice. Through participation in projects, internships and community services, students apply what they have learned in real-life situations and enhance their ability to solve real-world problems, thus realizing the effective combination of theory and practice. At the same time, ESD has a global perspective and focuses on global challenges such as climate change, poverty and social inequality, aiming to develop students' global awareness and sense of responsibility. By understanding these issues, students are encouraged to actively participate in international affairs and pay attention to the common destiny of mankind [7].

In terms of specific objectives, ESD is committed to raising students' awareness of sustainable development, enabling them to understand the importance of sustainable development and its far-reaching impact on individuals and society, which lays the foundation for future action.

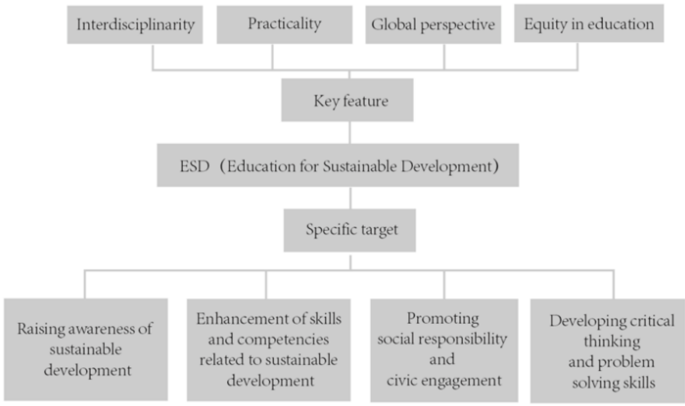

Figure 1. Key features and objectives of ESD

In addition, ESD aims to develop students' critical thinking and problem-solving skills, encouraging them to analyse complex problems in depth and come up with innovative solutions. In this way, students are not only able to identify problems, but also actively search for effective solutions. Further, ESD promotes social responsibility and civic engagement, encouraging students to actively participate in community activities, thus enhancing their impact on society and the environment [8]. Finally, through a diverse range of learning styles, ESD enhances the skills students need in the field of sustainability, including collaboration, communication, leadership, and systems thinking, to ensure that they are able to effectively respond to the challenges of the future.

3 SUSTAINABLE DEVELOPMENT GOALS (SDGS)

3.1 Summary of contents

The Sustainable Development Goals (SDGs), a core component of the 2030 Agenda for Sustainable Development adopted by the United Nations in 2015, comprise a total of 17 goals designed to comprehensively address the complex social, economic, and environmental challenges facing the world. The goals are designed not only to emphasise the importance of addressing immediate issues, but also to focus on long-term sustainability and inclusiveness, aiming to achieve social equity and ecological balance on a global scale [9].

Figure 2. The 17 goals of the SDGs

Specifically, the SDGs cover areas such as eradicating poverty, eradicating hunger, promoting good health and well-being, providing quality education, and achieving gender equality, emphasising the interconnectedness of the different goals. For example, the goals of ‘no poverty’ and ‘zero hunger’ highlightthe importance of basic livelihood security to ensure that everyone can enjoy the basic right to survival; while the goals of ‘good health and well-being’ and ‘quality education’ emphasise the interconnectedness of the different goals. The ‘good health and well-being’ and ‘quality education’ goals focus on the enhancement of human capital, emphasising that education and health are key factors in achieving personal and social development.

Looking ahead to 2030, countries must work together to address the growing global challenges and ensure the implementation of these goals. The key to the successful implementation of the SDGs lies in the establishment of effective co-operation mechanisms to promote cross-border exchanges and resource sharing, especially in the areas of education, technology transfer and financial support. Through such comprehensive cross-border collaboration, the SDGs will provide strong support for building a more just and sustainable future and realising the global vision of sustainable development [10].

3.2 Interconnections between ESD and SDGs

There is a close interconnection between Education for Sustainable Development (ESD) and the Sustainable Development Goals (SDGs), which together contribute to the achievement of SDGs [11]. ESD, as an educational concept that aims to develop the awareness and capacity of individuals and societies for sustainable development, is closely related to several of the SDGs, particularly Goal 4, "Quality Education", which is the core objective of SDG 4, "Ensure inclusive and equitable access to quality education". "Ensure inclusive and equitable quality education and promote opportunities for lifelong learning" [12]. Through the implementation of ESD, universities can more effectively support the realization of SDG4 by helping students to develop a comprehensive understanding of environmental, economic, and social issues, as well as to develop the critical thinking and innovation skills needed to address these issues.

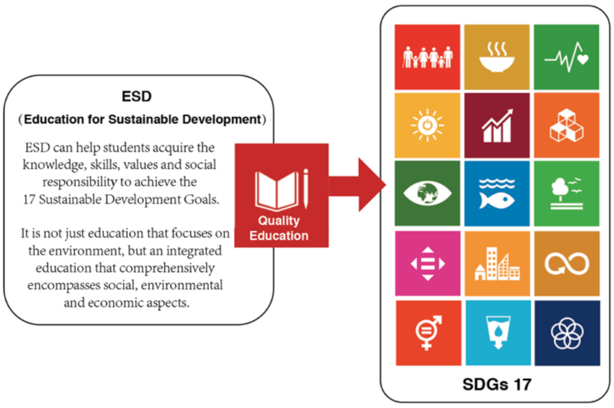

Figure 3. Graphical representation of the correlation between ESD and SDGs

In addition, ESD emphasises the quality and relevance of education, especially in developing students' sense of social responsibility and engagement, which is essential for achieving the SDGs. For example, ESD not only focuses on the transfer of knowledge, but also encourages students to practise in the real world, enhancing their practical abilities in addressing sustainable development challenges. In addition, ESD promotes an interdisciplinary learning model that enables students to explore complex sustainable development issues from multiple perspectives and thus better grasp the requirements of the SDGs. In short, ESD not only provides theoretical support and an educational framework for the realisation of the SDGs, but also lays the foundation for the development of citizens who are aware of and capable of sustainable development. Strengthening the implementation of ESD will have a profound impact on the realisation of the 2030 Agenda for Sustainable Development [13].

4 CASE STUDIES ON ESD IN GLOBAL UNIVERSITIES

4.1 Feasibility analysis

Globally, ESD has become an important research theme in higher education as a core strategy for addressing environmental challenges and promoting socio-economic development. In this study, De Montfort University (UK), Jaume I University (Spain) and Osaka University (Japan) were selected as case studies with the aim of revealing the effectiveness of ESD practices in different regions through empirical analyses. The outstanding achievements of these three universities in their respective regions not only reflect the innovation and effectiveness in the implementation of ESD globally, but also the multidimensional impact of ESD in a number of areas such as curriculum design, educator training, and research practices. Specifically, De Montfort University has been voted the most innovative eco-design university in the United Kingdom and has achieved a 40% increase in the number of collaborative projects through partnerships with Burberry, Stella McCartney and local eco-materials suppliers, resulting in a closer alignment between course content and industry needs [14]. This case demonstrates how the concept of sustainability can be effectively integrated into higher education curricula through practical projects and industry partnerships, and how ESD can be used innovatively in curriculum design. The 'ImpSDGup' training programme of the Universidad Jaume I has also been very successful in Spain and Europe. Specifically, the course improved educators' SDGs understanding by 60 per cent through regular training seminars and online learning modules, and the results were confirmed through a comparison of pre- and post-test scores [15]. This case demonstrates the effectiveness of ESD in training educators and building support systems, and emphasises the importance of professional development in promoting sustainable education. Osaka University's RISS (Research in Interdisciplinary Sustainable Solutions) programme is widely recognised in Japan and Asia. The programme aims to promote innovative research in the field of sustainability through interdisciplinary collaboration, with the core objective of integrating scientific research with practical applications to address global environmental challenges. The programme's research team has published 15 high-impact scientific papers, such as 'Advancements in Green Technology' in the Journal of Cleaner Production and 'Technology and Innovation' in the Journal of the International Society for the Advancement of Science (ISAS). Technology' in the Journal of Cleaner Production and "Impact of Renewable Energy Innovations" in Environmental Science & Technology, as well as six international research awards [16]. This case highlights the importance of ESD in research innovation and technology application, and shows how the practical application of research results can contribute to the realisation of sustainable development goals. In summary, the achievements of De Montfort University, Jaume I University and Osaka University in their respective regions not only demonstrate the significant impact of ESD practices in the United Kingdom, Spain, and Japan in terms of enhancing curriculum design, educator training and research practices, but also provide sufficient empirical support to validate the validity and representativeness of ESD practices in different regions around the world.

4.2 De Montfort University, UK - ESD innovation in fashion design programme

The UK has demonstrated remarkable characteristics and effectiveness in the field of ESD, and since 2014, ESD has been incorporated into the curriculum of many higher education institutions, forming a clear objective and a relatively well-developed programme structure. Among them, De Montfort University (DMU), as the only UK university recognised by the United Nations as a global centre for the SDGs, actively integrates the 17 SDGs into its teaching, research and university activities, and is committed to placing sustainable development at the heart of the university's work, with the aim of inspiring students to become agents of change in sustainable development concepts in their future careers. The University is committed to placing sustainability at the centre of its work, with the aim of inspiring students to become sustainable change agents in their future careers. Particularly in the field of fashion design, a subject in which De Montfort University has an advantage, the ESD teaching model implemented by De Montfort University is not only innovative, but also provides other higher education institutions with valuable practical experience and templates for ESD [17]. Within the formal curriculum, the discipline adopts two main approaches to the delivery of ESD: firstly, by integrating sustainability modules directly into the professional curriculum, and secondly, by embedding sustainable design projects into the course content. Students are asked to consider sustainability as a core concept in design throughout, beginning with design research, learning and applying sustainable design methods, and guiding the sourcing of materials and the development of design solutions. The course design requires creative structural design using used jeans, prohibits the use of additional fabrics, and encourages group sharing of used clothing remnants to maximise resources. By examining the environmental costs of denim, students gain an in-depth understanding of the pollution of denim fabrics, reflect on cutting waste and waste in commercial production, and enhance their pattern making techniques and fabric utilisation through 'zero waste' strategies, thus acquiring an effective approach to sustainable design and learning to optimise the use of resources and reduce textile waste. Student feedback showed that the implementation of the course resulted in a positive shift in attitudes towards sustainable design and a deeper understanding of sustainability issues in the industry, including the environmental impact of denim fabrics at the dyeing and finishing stages and fabric waste during the design and cutting process. These results demonstrate that university programmes should be centred on sustainability and creativity, and establish an interdisciplinary and industry-engaged problem-oriented teaching and learning environment, so as to achieve harmony and balance among the economy, society and the environment.

4.3 Jaume I University, Spain - 'ImpSDGup' training programme

The 'ImpSDGup' programme launched by the Jaume I University (UJI) in Spain aims to upgrade the skills of higher education teachers in ESD in order to adapt their subject curricula to support the United Nations 2030 Agenda for SDGs. Development Goals. The course is based on the Transformative Action Training Module for Sustainable Development (TMTAS), which provides a theoretical framework for designing and implementing transformative action in ESD [18]. The main objectives of this study are twofold. First, to systematically describe and theoretically justify the design and implementation of the ImpSDGup programme as a teacher training model to guide the effective integration of ESD into university subject curricula; and second, to investigate what ESD transformational measures were implemented in practice by the programme participants in order to assess the effectiveness and impact of the programme in practical application. In the first session, 'From the past to the present', participants will delve into the historical context of unsustainable practices and their impact on today's society. The course will introduce the basic concepts of ESD and help teachers understand their importance. By analysing historical examples and the current situation, teachers will be able to identify gaps in their own teaching, thus laying the foundation for developing students' awareness and competence in sustainable development. In the second session, 'From the present to the future', participants will focus on current concepts and competences in ESD, using the Exercise Y methodology in order to systematically analyse the existing and missing elements of sustainability in their curricula. Y-Exercise is a reflective activity that aims to identify strengths and weaknesses in a programme by guiding participants to make connections between the 'present' and the 'future'. In this process, participants will draw a Y-shaped diagram, with the left side representing the sustainability elements of the current curriculum and the right side depicting the ideal framework for a sustainable curriculum. Through this visualisation, participants are able to gain a clearer understanding of the current state of the curriculum and the direction of improvement [19], which supports subsequent curriculum optimisation. In the third session, 'The Future', participants will evaluate the sustainability performance of the existing curriculum, study successful cases at home and abroad, construct a sustainable curriculum framework that integrates environmental, social and economic balance, and then use the Transformative Action Training Model for Sustainability (TMTAS) to develop specific recommendations for curriculum improvement.

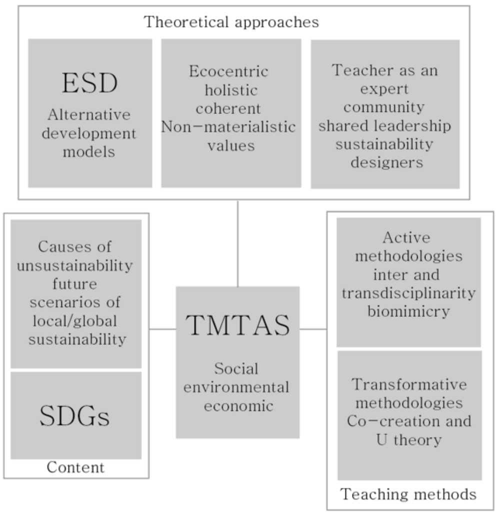

Figure 4. Training Models in Transformative Action for Sustainable Development (TMTAS)

4.4 Osaka University, Japan - RISS sustainability science programme

One of the key challenges facing modern society is the effective use of science and technology to mitigate the negative impacts of human activities on the Earth's life-support systems. To address this challenge, the Research Institute for Sustainability Science (RISS) at Osaka University in Japan has launched an innovative Sustainability Science Programme. Designed through interdisciplinary education, the programme aims to delve into the complex and dynamic interactions between natural systems and human societies. Through this programme, Osaka University has promoted the dissemination and practical application of the concepts of sustainability science, providing important theoretical and practical support for addressing global sustainability challenges. The programme offers 12 courses, including four core courses and eight sub-courses, covering a wide range of disciplinary areas and research methodologies. As the first comprehensive curriculum system of its kind in Japan, the RISS programme effectively integrates different disciplines and educational networks.

Table 1. Course descriptions in the RISS programme

Course name	Objective
Sustainability valuation methods and techniques	Introduces sustainability assessment methods and uses examples to helpstudents understand the validity and limitations of the theory
Global threatsand sustainability	Explore the causes and consequences of environmental and social change, highlighting the role of interdisciplinary approaches in sustainable development
Society and environment：human security and sustainability	Explore global human security and environmental issues and encouragesolutions through an understanding of the interactions between society and global systems
Engineering systems design for sustainable development	Covers theories of environmental management, eco-design and transport, integrating all three through group projects to propose sustainable solutions

Through these courses, students will not only be able to deepen their understanding of global and social systems, but also acquire practical skills in addressing sustainable development issues. The programmes are designed to develop students' ability to work collaboratively to address sustainable development challenges in a pluralistic context, providing them with a multidisciplinary and cross-cutting learning platform to address complex global environmental and social issues. Osaka University's RISS Sustainability Science Education Programme significantly enhances students' awareness of sustainability through its integrated interdisciplinary and interregional curriculum. The curriculum is designed with a particular emphasis on interaction with different academic and cultural backgrounds, aiming to promote students' ability to integrate the understanding and application of the three dimensions of environment, society and economy. Evaluations have shown that the programme has been effective in enhancing students‘ knowledge and skills in key academic areas, as well as their ability to work collaboratively and practically [20].

5 ANALYSIS OF COMMONALITIES AND DIFFERENCES

5.1 Commonality analysis

When analysing the practices of ESD at De Montfort University (UK), Jaume I University (Spain) and Osaka University (Japan), the notable commonality lies in how these higher education institutions have systematically integrated ESD concepts into their respective disciplines and strengthened their educational effects through practical activities. The ESD implementation strategies of these universities show the following core features: all three universities are committed to embedding ESD concepts into their curricula in order to achieve a seamless connection between educational content and practical application. This common strategies reflect a general trend in ESD practice in higher education globally, which is to enhance the practical applicability and effectiveness of education by integrating theory and practice. This trend not only demonstrates a broad global recognition of the core concepts of ESD, but also provides an effective reference model for universities. Through specific projects and cross-border cooperation, these universities have verified the validity of ESD theory in practice and further promoted the global promotion of ESD [21]. This commonality of practice underscores the systematic and comprehensive nature of ESD implementation, and embodies the common strategies and goals of educational institutions around the globe in the face of the challenges of sustainable development.

5.2 Difference analysis

Despite the existence of common goals and approaches, the practices in the cases also reveal significant differences, mainly in terms of the strategies implemented, subject areas and regional policy contexts. De Montfort University's ESD practice focuses on the field of fashion design, emphasising the close alignment of ESD principles with industry needs. This approach is effective in maximising resources and minimising waste, in line with the European fashion industry's expectation of future designers to practice social responsibility and environmental awareness in their work. Higher education policies in the UK and Europe actively encourage close collaboration between higher education institutions and industry to enhance the employability and industry adaptability of graduates. In particular, the Higher Education Funding Council for England (HEFCE) encourages ESD practice-orientated teaching and industry collaboration in HEIs, which promotes deeper integration between higher education institutions and industry [22]. These policies reflect the unique UK and European support for the ESD concept and the strategic approach, providing important policy contextual support for ESD practice at De Montfort University, thereby significantly enhancing the practical utility of educational outcomes. In contrast, ESD practice at Jaume I University focuses on a systematic training programme designed to enhance the understanding and application of the SDGs. This programme is designed to enhance educators‘ and students' knowledge of the SDGs and their application to actual teaching and daily practice. In the framework of education policies in Europe, the focus is on the professional empowerment of teachers and the full integration of SDGs. These policies advocate for sound educational support systems and encourage teachers to engage in ongoing professional development and training to enhance their effectiveness in SDGs implementation. Spain's education policies, particularly the Ley de Educación (Spanish Education Law), which articulates the direction of sustainable development in the education system and encourages the integration of SDGs into curriculum design, have provided strong policy support for the training programme at Jaume I University. These policies have not only promoted a deeper understanding and application of ESD among educators, but have also fostered continuous improvement in educational practice [23]. Osaka University's ESD practices, centred on interdisciplinary collaboration, have been particularly effective in projects that apply science and technology to areas such as environmental monitoring and renewable energy, and have won wide recognition internationally. Its Research Institute for Sustainability Science Research Institute (RISS) has introduced an integrated curriculum system comprising 12 courses in which the core and sub-courses together build a platform for interdisciplinary and inter-regional collaboration. This curriculum design not only enhances students' sustainability literacy, but also provides comprehensive theoretical and practical support for addressing global sustainability challenges [24]. The RISS programme at Osaka University promotes the innovation and application of sustainable development technologies through interdisciplinary collaborations that combine academic research with practical problem solving. This model not only highlights the unique strengths of Asian countries in integrating research and practice, but also demonstrates the important role of policy support and integration of research resources, particularly in addressing complex sustainable development challenges [25].

Table 2. Analysis of Commonalities and Differences between DMU, UJI and OU

	Commonality	Difference
DMU	Emphasis is placed on the integration of ESD theory and social practice to enhance students' comprehensive literacy and sense of social responsibility	Explore the realization path of sustainable fashion through ESD innovativedesign concepts
UJI		Emphasize the critical role of educators in the implementation of ESD
OU		Emphasize the development of interdisciplinary competencies and promote the effective integration of science and innovation

5.3 Analysis of conclusions

While ESD practices around the world exhibit many commonalities, successful implementation often relies on localized and individualized strategies. The experiences of De Montfort University, Jaume I

University and Osaka University show that universities need to flexibly adjust their ESD implementation programs according to their own policy contexts, disciplinary characteristics and geographic needs, and that they must take into full consideration the actual needs of the local society and industries, especially in the design of their curricula and the selection of their practice methods. At the same time, higher education policies have a profound impact on the implementation of ESD. Educational policies in the United Kingdom, Spain, and Japan support different ESD practice models, which not only provide educational institutions with the necessary resources and guidance, but also directly influence the design of course content and the effectiveness of implementation [26]. The support of the policy context is one of the key factors in promoting the success of ESD practice. In addition, interdisciplinary collaboration and industry alignment play an important role in enhancing the effectiveness of ESD practice [27]. This is exemplified by De Montfort University's industry alignment model, Jaume I University's systematic teacher training, and Osaka University's interdisciplinary program. Through interdisciplinary and industry collaboration, complex sustainability issues can be effectively addressed and the in-depth application of ESD concepts can be promoted. Future ESD practice should focus more on localized and personalized implementation strategies, while strengthening policy support and interdisciplinary cooperation. Higher education institutions should flexibly adjust their ESD strategies according to their own characteristics and regional needs in order to achieve the educational goals of sustainable development. By continuously innovating and optimizing ESD practices, higher education institutions around the world can better respond to the increasingly complex challenges of sustainable development and make greater contributions to the achievement of the global SDGs.

6 CONCLUSION

Based on these cases, this study recommends that global higher education institutions establish a regionally integrated support framework for implementing ESD. This framework should include the following core components: First, integration within the education system, ensuring that ESD concepts are embedded across all stages of education, from primary to higher education, creating consistent educational goals and methods to enhance overall effectiveness. Second, policy support, advocating for government and educational policies that prioritize ESD and allocate resources, including the development of specific implementation plans, financial support, and incentives. Third, industry collaboration, establishing practice-oriented ESD education programs and internship opportunities through partnerships with local industries and businesses, ensuring that ESD education content aligns with industry needs and enhances practical applicability. Fourth, community engagement, building community partnerships and organizing ESD-based educational activities to promote ESD principles, increase social impact, and foster public support for sustainable development. Finally, a long-term support network and resource-sharing platform should be established to disseminate the latest ESD knowledge and best practices, ensuring the sustainability and long-term effectiveness of implementation. This regionally integrated support framework should not only focus on systematization and comprehensiveness but also fully consider region-specific social and cultural contexts. It aims to provide practical strategies and methods for global higher education institutions to promote and deepen ESD, effectively addressing regional challenges, and facilitating both localized implementation and global integration of ESD. As a future research plan and outlook, this study aims to explore and widely promote the strengths and distinctive features between the environment, society, and ESD across the three universities, further advancing the expansion and development of representative universities globally in the field of ESD education. This study will also explore a systematic expansion plan that leverages cross-regional cooperation and resource sharing to gradually expand the influence of ESD education, ensuring that the global higher education system can widely adopt and implement sustainable development education. The plan will take into account the social, cultural, and economic differences across regions, providing universities with tailored educational models to ensure that ESD education effectively responds to the sustainable development needs of different regions, and actively contributes to the achievement of global sustainable development goals.

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RESEARCH AND PRACTICE OF DESIGN EDUCATION THROUGH "EMBODIED CO-CREATION BETWEEN UNIVERSITY AND ENTERPRISE"

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ABSTRACT
The “Intelligent Interaction Design” undergraduate program, established by the Ministry of Education in 2020, aims to cultivate high-level interdisciplinary talents proficient in both artificial intelligence and interaction design. Integrating cyber-physical systems, human-machine collaboration, and consumer experience, the program emphasizes the necessity of practical platforms for students to acquire real-world skills and engineering experience. This paper identifies key areas for improvement in the curriculum, such as scientific teaching plan design, integration of coursework with experimental practice, and optimization of university-enterprise cooperation models. It explores the relationship between embodied teaching and engineering practice, highlighting the importance of constructing embodied learning scenarios based on educational objectives. The “embodied modules” of design education is proposed to achieve learning embodiment through observation, simulation, and dialogue, supported by a well-proportioned curriculum system. The study suggests establishing on-campus workshops in collaboration with industry partners as a key strategy. These workshops facilitate project-based learning, fostering an environment of active embodied practice. By forming “embodied modules” throughout undergraduate to master's levels, the program aims to enhance students' craftsmanship spirit and effectively prepare them for the rapidly changing demands of intelligent interaction design and interdisciplinary fields.

Keywords: Intelligent Interaction Design, Embodied Education, Co-creation, Design Workshop

1 INTRODUCTION

The “Intelligent Interaction Design” undergraduate program, newly established by the Ministry of Education in 2020, aims to integrate cyber-physical systems (intelligent agents), human-machine (environment) collaboration, and consumer experience. It focuses on cultivating high-level interdisciplinary talents in “Artificial Intelligence + Interaction Design.” Therefore, similar to many other disciplines, education in this major requires not only a solid theoretical foundation but, more importantly, effective practical platforms. These platforms enable students to rapidly and solidly learn real skills through hands-on experiences during their university years, accumulating engineering experience.

To achieve this goal, there are many aspects worthy of research and improvement in the construction. These include the scientific design of teaching plans, the reasonable integration of course learning and experimental practice, significantly increasing practical projects for students, expanding the coverage of embodied experiences, reasonably customizing “experience packages” for different grade levels, and optimizing the university-enterprise cooperation model. Therefore, systematically and scientifically planning a teaching system based on embodied practice, building practical platforms for students at all levels, enhancing students’ embodied experiences, and improving the quality of talent cultivation have become important issues in the construction of the new major.

2 RESEARCH ON EMBODIMENT AND ENGINEERING EDUCATION

Numerous scholars have conducted in-depth research on students' cognitive patterns and practical teaching models using embodied theories, constructing learning contexts that align with real-world applications based on these theoretical foundations.

2.1 Research on Embodied Teaching and Cognition

Embodied education emphasizes the leading role of the "body" in education, characterized by "situationality," requiring a focus on process-oriented and experiential teaching [1]. It specifically requires teachers and students to perceive the environment through various bodily senses, forming personal experiences and metaphors to achieve cognitive learning outcomes [2]. Cao Ruixia and Gao Jing proposed a knowledge cognition logic that integrates "body–emotion–situation," allowing students to experience, think, and understand in specific contexts to enhance their core competencies [3]. Du Ermin [4], Meng Sugang and Zheng Xiuzhen [5] focus on the important role of creating situations in embodied teaching, particularly proposing five steps for immersive learning from an embodied perspective [4]. Song Yaowu and Cui Jia further constructed an "Interactive Constructivist Learning Process," achieving the goal of embodied learning through the integration of observation, simulation, and dialogue [6]. It is evident that constructing embodied scenarios based on learning objectives and tasks is an important direction for practical teaching reform.

2.2 Research on Engineering Teaching Models

Hou Jianjun et al. proposed a T-shaped educational platform model [7], dividing courses into different modules and conducting teaching activities through four levels: basic practice, engineering cognition, comprehensive practice, and innovative practice. Xiao Zhen adopted various teaching methods, introducing university-enterprise cooperation projects and academic research projects into the classroom, practicing the educational concept of "Humanism + Design + Technology + Business + Culture," and integrating enterprise and school resources to establish an online interaction design "micro-major" [8]. Ma Hui proposed specific implementation methods in teaching for studio simulation construction, skill training simulation, writing simulation, and environment simulation [10]. These teaching reform attempts align with the "highest level" of engineering education concepts proposed by Olin College of Engineering in the United States and are "engineering education" concepts worthy of reference.

It can be seen that building an embodied experience environment where students shift from passive to active—workshops—is one of the key tasks that new programs need to study and emphasize in depth. There is a close relationship between embodied teaching and engineering practice, which is an important component in constructing an interactive design learning process. To achieve this goal, we must first scientifically analyze and adjust the content of courses in mathematical and physical foundations, disciplinary foundations, professional foundations, and specialized courses set by the new major, focusing on the connection points between each course content and its embodied practice components. We should scientifically and organically integrate various practical components such as ideological and political practice, course practice, enterprise internships, project practice, scientific research training, and innovation and competitions into course teaching. Secondly, we need to establish on-campus workshops closely cooperating with enterprises, guided by project implementation, inviting enterprise mentors into the school, and establishing a beneficial university-enterprise cooperation model that takes teaching as the main line, workshops as carriers, students' active embodied practice, and enterprise benefits. On this basis, forming different "embodied modules" that fully run through the design training content from undergraduate to master's stages, while considering the teaching needs of cross-major and interdisciplinary intersections, is essential.

3 MECHANISM FOR ESTABLISHING THE "INTERACTIVE CONSTRUCTIVIST LEARNING PROCESS"

The "Interactive Constructivist Learning Process" emphasizes that students achieve the goal of embodied learning through the integration of observation, simulation, and dialogue, which first relies on the scientific proportioning of the curriculum system and the overall support of the cultivation plan. Under the backdrop of the rapid iteration of artificial intelligent technology, the construction of the

Intelligent Interaction Design major is gradually maturing through exploration. It fully leverages the technical advantages of engineering universities and the strong logical thinking abilities of students, highlighting a technology and creative core guided by design thinking. It constructs a professional cultivation mechanism where "Artificial Intelligence+" user experience serves as the base, and intelligent products, intelligent interaction, and digital space echo each other:

1. **Intelligent Interaction Direction**: Focuses on "using artificial intelligence technology to explore and gain insights into new design application scenarios, and exploring interaction forms under future human-machine collaboration."
2. **Intelligent Products**: Focuses on "software and hardware collaborative information product design; revolution and innovation of cloud design production methods."
3. **Digital Space**: Focuses on "productivity revolution and cultural digital experience empowered by extended/augmented reality technology."

These three directions not only inherit the traditional advantages of the major—user experience and human-computer interaction—but also cover potential future trends such as design application scenario exploration, cloud design, and cultural digital experiences. This constructs an overall framework for subsequent course chain development and touchpoint identification.

Based on the framework of the Intelligent Interaction Design major's cultivation plan, 47 related courses (including the graduation project) are divided into five course chains: ICT—Professional Course Chain, Design Thinking—Human-Machine Experience Course Chain, Intelligent Product Course Chain, Intelligent Interaction Course Chain, and Digital Space Course Chain. The first two chains are the foundation of the entire curriculum system, supporting the Intelligent Product, Intelligent Interaction, and Digital Space course chains from both ends of "AI+ (Artificial Intelligence Technology)" and "UX (User Experience Design)," which are also the three professional directions (see Table 1). Thus, the Intelligent Interaction Design major forms a cultivation approach of "artificial intelligence technology assisting scenario exploration and productivity revolution, and user experience design empowering creative practice."

Table 1. Course Chain of the Intelligent Interaction Design major

<table>
<tr><th colspan="3">ICT—ICT Professional Course Chain</th><th rowspan="17">Graduation Project （7/8）</th></tr>
<tr><td>ICT</td><td colspan="2">Introduction of ICT (1), Introduction to Computing and Program Design (2)，Introduction to Artificial Intelligence (2)</td></tr>
<tr><td rowspan="4">ICT professional</td><td colspan="2">Data Structures and Algorithms (2), Methods of Scientific Computing (2)</td></tr>
<tr><td colspan="2">Fundamentals of Machine Learning (3), Databases and Backend Applications (3)</td></tr>
<tr><td colspan="2">Computer Graphics (4), Deep Learning (4)</td></tr>
<tr><td colspan="2">Computer Vision (5), Natural Language Processing (5), ICT and Design (5)</td></tr>
<tr><th>Intelligent Product Course Chain</th><th>Intelligent Interaction Course Chain</th><th>Digital Space Course Chain</th></tr>
<tr><td>Design Graphics (3)</td><td>Digital Visual Communication Design (2)</td><td>Digital Scene Design (6)</td></tr>
<tr><td>Design Representation (3)</td><td>Web Interaction Design (3)</td><td>VR/AR Design (6)</td></tr>
<tr><td>Intelligent Open-source Hardware (4)</td><td>Fundamentals of Animation and Video (3)</td><td></td></tr>
<tr><td>Practice of Intelligent Open-source Hardware (4)</td><td>Interaction Design Prototyping (3)</td><td></td></tr>
<tr><td>3D Digital Modeling Design (4)</td><td>Mobile Interaction design (5)</td><td></td></tr>
<tr><td>Fundamentals of Design Engineering (4)</td><td>Web Application Development (5)</td><td></td></tr>
<tr><td>3D Intelligent Digital Creation (5)</td><td>Collaborative Design Practice (6)</td><td></td></tr>
<tr><td>Product Design Prototyping (5)</td><td></td><td></td></tr>
<tr><td>Design Semantics (5)</td><td></td><td></td></tr>
<tr><td>Intelligent Product Design with Human-Machine Integration (5)</td><td></td><td></td></tr>
</table>

Human-Machine Experience	Human Factors Engineering Experiment (4), Data Statistics and Analysis (4), Fundamentals of User Experience Evaluation (6), Product Experience Design (6)	
	Digital Image Processing (1), Composition Design (2), Infographics Design (2), Human Factors Engineering (4)	
Design Thinking	Design Psychology (5), Service Design (7)，Digital Photography (7)	
	Fundamentals of Interaction Design (1), Design Thinking (1), Design History (2)	
Design Thinking—Human-Machine Experience Course Chain		

* The semesters when the courses are offered are indicated in parentheses after the course names.

4 CONSTRUCTION OF UNIVERSITY-ENTERPRISE CO-CREATION WORKSHOPS

The structuring of course chains lays a solid foundation for in-depth university-enterprise cooperation. Although fully implementing industry-education integration in teaching practice to test the actual cultivation effect will take time, university-enterprise joint course workshops have been organized on a small scale from lower grades to higher grades, from "basic experience" to "result incubation," covering the Intelligent Product Course Chain, Intelligent Interaction Course Chain, and Digital Space Course Chain. Preliminary, it forms a 4-level "embodied modules" of design education – experiential basis, advanced learning, engineering embodiment and design implementation – sharing the similar thoughts with Olin College of Engineering (see Table 2). In practice, actual projects are introduced, and students are encouraged to team up with enterprise designers, fully integrating the industry experience of enterprise designers with students' creative enthusiasm. Through a mix of online and offline methods, a "dialogue-interactive" embodied co-creation atmosphere is created for teaching practice. The main collaborations include:

Table 2. "Embodied Modules"

Course Chain		Embodied Modules	Key Points
ICT—ICT Professional Course Chain		**experiential basis**	• Experience design process. • Reverse-analysis of design motivations. • Experimental improvements.
Intelligent Product Course Chain		**advanced learning**	• Problem solving ability. • Prototyping skills. • Connecting to market.
Intelligent Interaction Course Chain		**engineering embodiment**	• Deeply engagement of product development. • Embodied practice package of engineering. • Interdisciplinary Collaboration.
Digital Space Course Chain		**design implementation**	• Co-creation of university and enterprise. • Application of intellectual properties and design awards. • Design implementation and entrepreneurship.

4.1 Experiential Basis – Reverse Engineering Training Camp

The university and Beijing JIANG Design Studio jointly held a "Reverse Engineering Training Camp," foucsing on training students' basis of intellectual product design, and conducting physical disassembly, measurement, reverse analysis, improvement attempts, and 3D printing verification of mature products (see Figure 1). Leveraging the rich practical experience of enterprise designers, first-year university students are guided to experience product form, material, and color; understand structural design features and assembly principles; reverse-analyze product positioning and functional design motivations; and encourage students to rethink new application scenarios and carry out experimental improvements. This allows lower-grade students to experience the entire process of product design, cultivating good design habits and ways of thinking.

4.2 Advanced Learning: BUPT–Li-Ning University-Enterprise Joint Course

In 2024, combining the university-wide second-year general education course "Design Thinking," the Intelligent Interaction Design major's courses "Human Factors Engineering" and "Data Statistics and Analysis," cross-disciplinary design and development teams were organized. On one hand, using enterprise pre-research topics to connect the chain of user needs investigation, ergonomics analysis, circuit prototype development, and design solution exploration, training students from different majors in problem discovery and problem-solving abilities. On the other hand, enterprise designers convey industry knowledge to students in practice, completely changing the "behind closed doors" conceptual design training mode, and selecting projects with implementation potential to carry out in-depth R&D cooperation with enterprises.

4.3 Engineering Embodiment: BUPT– Thyseed Design Workshop

From 2022 to 2024, two intelligent product design workshops were jointly held with Thyseed, relying on six undergraduate courses belonging to the Intellectual Product Course Chain: "Design Semantics," "Design Representation," "Human Factors Engineering Experiment," "3D Digital Modeling Design," "Product Design Prototype," and "User Experience Evaluation Basics." Enterprise pre-research projects were introduced into the classroom, with frontline designers providing primary guidance throughout (see Figure 2). Students deeply engaged in the entire product development process from industry interpretation, needs decomposition, solution design, circuit development, human factors analysis, structural design, material and process, prototype assembly, peripheral design, to patent application, forming an "Intelligent Product Design" engineering embodied practice package. The workshop's works applied for a total of two invention patents, six utility model patents, and two design patents; won 16 competition awards including the Silver Award of the American MUSE Creative Awards, the European Product Design Award, and the Second Prize of the Milan International Design Week Chinese University Design Discipline Teachers and Students Excellent Works Exhibition.

Figure 1. lecture of the training camp

Figure 2. discussion of the design workshop

(4) Design Implementation: BUPT–Xinhua News Agency Joint Practice

From October 2023 to February 2024, BUPT and Xinhua News Agency's Technology Bureau conducted a cross-major and cross-grade joint course, creating AI-generated content (AIGC) animations/videos and H5 pages around the theme of "Spring Festival." A total of 11 tutors from both university and enterprise, and 99 students from majors including Internet and New Media, Intelligent Interaction Design, and Digital Media Art, jointly created eight short animations. Three of these works were launched on Xinhua News Agency's official platform during the 2024 Spring Festival, receiving over 4 million views. This joint course combined four courses: "Media Convergence" (Internet and New Media major course), "Design History" and "Digital Visual Communication Design" (Intelligent Interaction Design major courses), and "Creative Image Research" (Digital Media Art major course), attempting cross-major and cross-grade course linkage. It initially practiced the "Intelligent Interaction Design (AIGC)" progression from engineering embodiment to design implementation, and then to result incubation practice package, achieving good teaching effects in the field of digital space (see Figure 3).

(5) Design Implementation: BUPT–Ant Financial "Ant Design Joint Innovation Challenge"

Completely breaking professional and disciplinary boundaries and targeting the goal of teaching achievement incubation, Ant Financial, together with BUPT, Beijing Institute of Technology, and

Jiangnan University, held the “Joint Innovation Challenge.” Three tracks were set up around Ant Financial's business characteristics: “Green Claims,” “Ant Wealth,” and “Intelligent Service Innovation (Voice).” Relying on the undergraduate course “Professional Internship” (part of the “Joint Practice” course in the new training program), after the preliminary presentations, enterprise designers and students formed teams to deeply refine the design schemes. They repeatedly won international top design awards, including the 2024 Red Dot Design: Best of the Best Award, two 2024 iF Design Awards, the 2024 IDEA Finalist Award, and the 2023 Good Design Award, truly realizing the co-creation of future consumer scenarios between universities and enterprises (see Figure 4).

Figure 3 animation screen design assisted by AIGC

Figure 4. AntSure GreenPost Insurance

5 “EMBODIED CO-CREATION BETWEEN UNIVERSITY AND ENTERPRISE” DESIGN TALENT CULTIVATION MODEL

Through the redesign of the professional cultivation plan and the construction, exploration, and continuous improvement of co-creation workshops, leveraging resource advantages and long-term mechanisms, and engaging in deep cooperation with more top enterprises, we have explored relatively stable product design and training directions and developed interdisciplinary and cross-major integration projects. This has gradually formed a university-enterprise co-creation operation model characterized by teacher leadership, student self-management, flexible timing, and demonstrative effects.

Based on industry-education integration, by creating embodied practice environments corresponding to four modules and constructing a design talent cultivation model, we have not only overcome the limitations of traditional teaching systems by applying advanced cognitive education theories throughout the knowledge chain and progressive practice links but have also developed practical structures of “embodied modules” according to local conditions. Progressing from experitial basis, advanced learning, engineering embodiment to design implementation, we have enhanced students’ “craftsmanship spirit,” providing a new approach for aligning with industry leaders and cultivating high-quality young talents.

At the same time, by constructing a co-creation teaching model of industry-education integration, leveraging enterprise resources to link courses and practical teaching components, and building training camps and workshops to form hierarchical ability cultivation—where university teachers and enterprise mentors jointly guide training camps and co-create with students in subsequent advanced workshops—we enable students to adapt to the rapid changes in the demand for intelligent interaction design talents and interdisciplinary talents amid industrial upgrading and transformation, meeting the urgent need for shaping compound talents in the future.

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THE DESIGN AND ASSESSMENT OF AN AI INTERACTIVE INSTALLATION BASED ON IMAGE STYLE TRANSFER AND FACIAL RECOGNITION FOR CULTURAL HERITAGE LEARNING

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ABSTRACT
Artificial intelligence (AI) has proven to be an effective tool for the public sector in preserving, analyzing, managing, and presenting cultural heritage. However, little research has focused on the specific impact of AI on public engagement, particularly regarding cultural heritage learning. This article aims to investigate the impact of AI on the public's cultural heritage learning through the design and evaluation of an interactive installation that combines image style transfer and facial recognition technologies. We focused on assessing participants' performance in the cultural heritage learning process and learning outcomes in terms of behavior and knowledge through conversation analysis, interviews, and questionnaires. The results demonstrated that the interactive installation fostered user-generated learning dialogues across five main categories: Perceptual talk (30.60%), Strategic talk (24.89%), Connecting talk (16.40%), Conceptual talk (15.22%), and Affective talk (12.90%). Furthermore, it facilitated the acquisition of cultural heritage knowledge and behavior of sharing cultural heritage on offline and online platforms post-experiment.

Keywords: Artificial Intelligence, Cultural Heritage, Interactive Installation, Image Style Transfer, Facial Recognition

1 INTRODUCTION

Cultural heritage is a vital source of identity, creativity, and social cohesion for individuals and communities [1]. Professionals in the cultural heritage field have widely adopted technology to enhance the access, preservation, management, and communication of cultural heritage while ensuring interoperability and noninvasiveness. One effective method for achieving these goals is the use of AI. AI models can assist cultural heritage workers in preventing and repairing damage caused by natural disasters [2][3], processing and comprehending cultural heritage data more efficiently [4] [5] and generating more personalized and realistic data to increase public interest in cultural heritage [6] [7].
With the rapid development of deep learning networks, image style transfer has emerged as a promising technique for cultural heritage applications. Image style transfer is a technique that enables the transformation of original images into specific artistic styles and provides opportunities for artistic analysis and heritage development. For example, Dunhuang Academy uses image style transfer to make e-Heritage images more appealing by a mini program that lets users design their own scarves with dome elements [8]. Similarly, Zhang and Romainoor used image style transfer to create Pop art style New Year prints with high quality, enhancing the appeal of this cultural heritage among young people [9]. However, these applications still lack in-depth interaction with users, so we propose an innovative way of interaction.
Facial recognition technology is a non-contact and convenient technology, widely used in recognizing and analyzing various public datasets [10] which suits public cultural heritage domains. It can be applied to protect and manage cultural heritage by scanning visitors' faces for security and access purposes [11]. Some research also uses facial recognition to analyze facial features and explore human images and traits across cultures, regions and times [12]. However, despite significant advancements in AI applications for cultural heritage, research investigating their specific impact on the public, especially in terms of cultural heritage learning, is limited.

Public cultural heritage learning often takes place in informal environments such as museums, so this field is closely related to informal learning. Previous research has examined how technology affects museum learning outcomes using meta-analysis [13]. Some researchers have also focused on exploring the specific effects and evaluation of the application of virtual reality or augmented reality to cultural heritage [14][15]. However, there is limited research on the impact of AI on cultural heritage learning. In addition, evaluating learning outcomes in informal learning environments poses challenges within the educational community [16][17], because informal learning activities are characterized by autonomy and freedom, with learning outcomes emerging at various stages, encompassing diverse aspects such as knowledge, skills, attitudes, emotions, and behaviors [18]. Therefore, it is necessary to adopt more diverse evaluation methods to study the learning process and outcomes of cultural heritage.

This article aims to investigate the impact of AI on the public's cultural heritage learning process and outcomes through the design and evaluation of an interactive installation that combines image style transfer and facial recognition technologies. More specifically, based on the cultural heritage content (pattern features and cultural background) of this case and the pre-experiment result of the interactive installation (triggering dialogue), we choose to focus on the users' learning dialogue and thinking during the learning process, as well as their knowledge acquisition and sharing behavior in the learning outcomes. Therefore, our research questions are as follows:

Q1: How does an interactive installation that applies image style transfer and facial recognition technology affect the cultural heritage learning process?

Q2: How do participants perform in cultural heritage learning outcomes in terms of behavior and knowledge when using an interactive installation that applies image style transfer and facial recognition technology?

To answer the above research questions, we conducted experiments in a controlled laboratory setting by conversation analysis and interviews for learning process (Q1), and questionnaires for learning outcomes (Q2), and then captured data during the experience, after the experience, and two weeks following the conclusion of the experiment.

2 INTERACTIVE INSTALLATION DESIGN

2.1 Interactive installation description

The cultural heritage resources utilized in this case are derived from the Changsha kiln patterns. The Changsha kiln is a type of underglaze porcelain that exemplifies the achievements of Tang Dynasty porcelain-making technology. The kiln pioneered the decoration of ceramics with painting and inherited from the traditional ink and brush of Chinese calligraphy and painting while integrating exotic patterns, forming a unique system of expression that influenced later generations [19].

Figure 1. Changsha Kiln interactive installation

The Changsha Kiln interactive installation aims to provide visitors with a new cultural heritage experience by capturing visitors' facial expressions and displaying scene images filled with different styles of Changsha kiln patterns in real-time. The installation comprises a screen, camera, printer, mobile phone, and computer (Figure 1). When a visitor approaches the screen and is captured by the camera, the original scene image containing the user will be transformed into a specific Changsha kiln style image. At the same time, corresponding cultural heritage information will be displayed. The style of the scene image changes when the visitor tries different expressions. Additionally, the installation provides visitors with the opportunity to obtain a photo as a souvenir by pressing the "print" button on their mobile phones at a satisfactory moment.

2.2 Interactive installation design

The interactive installation design process mainly consists of three parts (Figure 2). To achieve scene stylization, it was necessary to determine suitable Changsha kiln patterns that would effectively communicate cultural heritage knowledge and yield good image style transfer results. To achieve this, we invited three experts to screen and classify over 1,000 different artistic styles of Changsha kiln patterns. We then tested different types of patterns for image style transfer and consequently selected four typical abstract Changsha kiln artistic style patterns (Figure 3).

To enable real-time image style transfer, we used a knowledge distillation technique to train a compact transformer-based network that mimics the style transfer capabilities of the larger Visual Geometry Group (VGG) network while significantly reducing computational demands. Knowledge distillation transfers knowledge from a large, pre-trained model (in this case, the VGG network) to a smaller model, preserving the stylistic details of the Changsha kiln patterns while allowing quick, real-time processing. This streamlined model ensures fluid user interaction, as style-transferred images are rendered almost instantly.

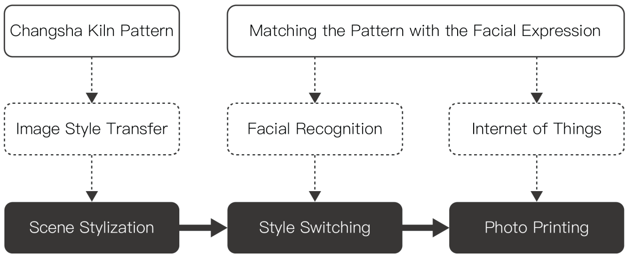

Figure 2. Design process

Figure 3. Four typical Changsha kiln patterns and corresponding four effects of image style migration

In terms of interactive design, we utilized facial recognition technology to enable the switching between different styles. To establish the correspondence between different expressions and different style patterns, we first selected four relatively common expressions from an existing expression library and then invited 30 participants to match different expressions with different style patterns based on their intuition. Test results showed that participants had a clear tendency as shown in Figure 4.

For facial recognition, we integrated the Dlib face detection framework due to its high accuracy and efficiency in facial feature extraction. Dlib's deep learning-based methods enable precise detection and tracking of facial landmarks with minimal latency, which is essential for smooth user interaction in real time. This framework was configured to recognize and categorize four common expressions, each mapped to a specific Changsha kiln style. When a user's expression is detected, the image classification network applies the corresponding style, enabling expression-based style transfer and enhancing the responsiveness of the interactive experience.

To enhance user engagement, the installation allows users to print their style-transferred images as keepsakes. Using Internet of Things (IoT) technology, we implemented a remote printing feature that enables users to activate a button on their mobile devices, which communicates with the installation's computer system to print style-transferred images from computer screenshots.

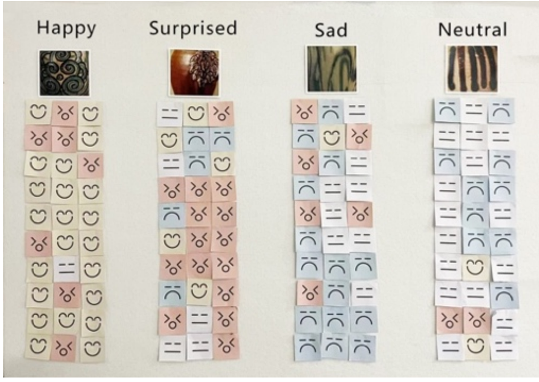

Figure 4. The result of matching facial expressions with patterns

3 INTERACTIVE INSTALLATION EVALUATION

3.1 Experimental methodology

Our research focuses on the learning process and outcomes of cultural heritage. For the learning process, we selected the method of conversation analysis to code and categorize recorded conversations based on Sue Allen's learning dialogue coding scheme, which combines socio-cultural and cognitive science perspectives, including five main categories of Perceptual talk, Strategic talk, Conceptual talk, Affective talk, and Connecting talk [20]. Furthermore, we conducted interviews to further elicit users' thoughts and feedback on the learning process.

We also assessed learning outcomes by distributing knowledge questionnaires before and after the experiment, which included questions on Changsha Kiln pattern recognition, cultural understanding, and self-reported learning. Finally, two weeks after the experiment, we distributed a follow-up questionnaire to explore related discussions and sharing behaviors to verify whether users discussed and shared their experience, the interactive installation, related technology, and Changsha kiln.

3.2 Experimental procedure

We conducted a laboratory experiment involving 24 university students aged 20-25, including 9 males and 15 females. Participants were grouped into threes to experience the interactive installation, and they knew each other beforehand. This technique aimed to simulate typical public visitation scenarios, such as those in museums and exhibitions, where small groups of two to three visitors explore and interact freely.

Prior to commencing the experiment, we distributed a knowledge questionnaire to evaluate participants' understanding of Changsha Kiln. Subsequently, we introduced the functions of the interactive device to each group and allowed them to take turns to experience it individually, followed by 3 people in the group experiencing it together. Assistance was provided where necessary, and all conversations between participants were recorded for analysis.

After the experience, participants completed the same knowledge questionnaire on Changsha kiln. We then conducted individual interviews to further obtain their feedback on the cultural heritage learning process. Finally, two weeks after the experiment, we administered a follow-up questionnaire.

4 RESULTS AND DISCUSSION

4.1 Cultural Heritage learning process

We collected audio recordings of the experience process from 24 participants who were divided into eight groups of three. We categorized the learning dialogues into five categories and calculated the average percentage of each type among all the learning dialogues (Figure 5). On average, each group produced 10 learning-related dialogues during the experiment.

Perceptual talk was the most prevalent type, accounting for 30.60% of the dialogues. This behavior involved identifying, naming, quoting, and describing features. For example, Participant 1a stated, "This color is a ceramic base"; and Participant 8a stated, "This effect is abstract."

Strategic talk, the second most common type (24.89%), involved how to use the installation or evaluating one's own or a partner's performance and behavior. For example, Participant 4b said, "I'm having a bit of a hard time getting this effect."

Connecting talk accounted for 16.40% of the dialogues and included life-connection, knowledge-connection, and Inter-installation connection. For example, Participant 2c said, "A visual work combining animals and flowers that I've seen online before" and Participant 7b: "I once went to the museum and saw the Changsha kiln pattern."

Conceptual talk accounted for 15.22% of the dialogues and related to the participant's cognition and interpretation of things they paid attention to. For instance, Participant 4a: "The effect with the green dots occurs when you make a smiling face."; Participant 5c "The pattern is supposed to come from on a jar."

Affective talk (12.90%) captured all emotional expressions, with most users pleasantly surprised by the experience. For example, Participant 6a: "My expression is just so cool"; Participant 6c: "Wow, this is a magic effect."

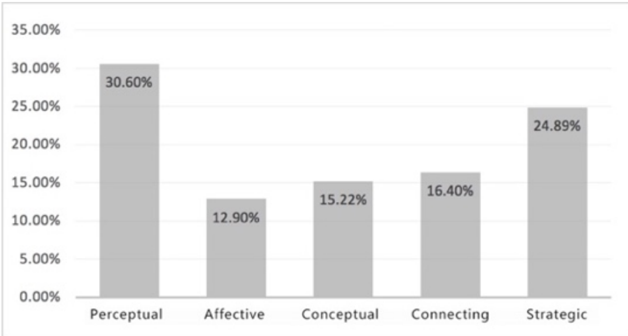

Figure 5. The average proportion of each category among all learning dialogues

Subsequently, interviews were conducted to further explore the participants' learning process. The facial recognition interaction method was found to be interesting, and participants enjoyed trying out different expressions to generate stylized images. Moreover, this method provided sustained engagement by encouraging people to try out all cultural heritage pattern effects instead of exiting after experiencing one or two effects. In addition, this method actively promoted discussion among participants. For example, they may comment on their own/peer's behavior or share experiences of making expressions. However, only a few people expressed discomfort with making too many facial expressions in public. Overall, the novelty and challenge of this interaction motivated the experiencers to keep completing the task.

The image style transfer technique also motivated participants to actively discuss the experience, the cultural heritage, or the technique effects. Participants mentioned that "this reminds me of a photo I took with my friends"; "these technique effects are like the facial effects that are very popular on TikTok". In addition, questions were asked: "Are these effects specific to the Changsha kiln patterns?"; " Could other patterns of porcelain achieve similar effects? ". Finally, some suggested that a stronger stylized effect could be created, while others preferred a softer effect.

The above analysis leads to the conclusion that the entire experience actively prompted users to engage in learning dialogues, most of which focused on the interactive installation and personal experiences. However, regarding cultural heritage, this installation triggered the participants' attention to Changsha Kiln patterns and some associations on patterning features but lacked complex cultural reasoning. For example: although we provided textual knowledge about artistic characteristics and craftsmanship of Changsha kiln, most participants did not read it carefully, and there was no discussion of the content. This may be because participants were more interested in exploring the novel and challenging facial recognition interaction than in learning about the historical and cultural background of Changsha kiln. This suggests a need to balance the engagement and educational aspects of interactive installations for cultural heritage.

4.2 Cultural heritage learning outcomes

For the knowledge dimension, we conducted statistical analysis on the Changsha Kiln knowledge questionnaire scores administered before and after the experiment, revealing that the participants' average score increased by 15.53%, with pattern recognition improving by 12.12% and cultural understanding by 3.41%. These findings highlight the significance of the interactive installation in facilitating cultural heritage learning, with more prominent effects observed in intuitive pattern recognition. Additionally, most participants reported an increase in their understanding of Changsha Kiln through self-report, particularly those with less prior knowledge.

For the behaviors dimension, analysis of questionnaires issued two weeks after the experiment revealed that most participants engaged in related discussions and sharing activities. Specifically, 79.17% discussed related topics, with 66.67% sharing their experience, 41.67% discussing the interactive installation, 33.33% discussing related technology, and 16.67% discussing topics related to Changsha Kiln (Figure 6). In addition, 25% of participants shared related topics on personal social media, with 16.67% sharing their experience, 8.33% sharing knowledge about Changsha Kiln, and 4.17% sharing information about the interactive installation and related technology (Figure 7). These findings indicate that participants share cultural heritage consciously or unconsciously to some extent. Although people may not directly discuss complex or professional knowledge, interactive experiences closely related to personal experience create opportunities for discussing and sharing cultural heritage.

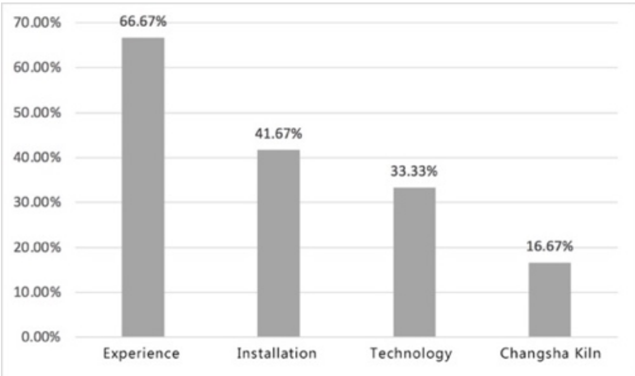

Figure 6. Proportion of discussions

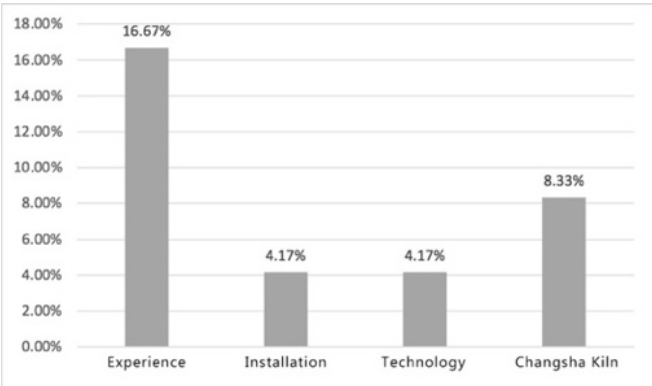

Figure 7. Proportion of social network sharing

5 CONCLUSIONS

This article explores the effectiveness of AI applications in the cultural heritage learning process and outcomes for the public through the design and evaluation of an interactive installation that utilizes image style transfer and facial recognition technology. The results demonstrate that the installation effectively promotes participants to engage in relevant learning dialogues during the experience, covering five categories: Perceptual talk (30.60%), Strategic talk (24.89%), Connecting talk (16.40%), Conceptual talk (15.22%), and Affective talk (12.90%). As for learning outcomes, we found that it improved participants' knowledge of Changsha kiln and stimulated them to actively discuss and share this experience, relevant technologies, or cultural heritage knowledge, indicating the positive impact of the installation on promoting cultural heritage post-experiment.

In conclusion, our research demonstrates that AI technologies such as facial recognition and image style transfer are effective tools for cultural heritage learning. The interactive method of facial expression provides sustained engagement and encourages participants to try out different cultural heritage pattern

effects while discussing their behavior and sharing experiences. Similarly, the image style transfer technique motivates participants to actively discuss the experience, cultural heritage, and technique effects.
We identified a limitation in conveying deeper cultural content, as some users overlooked key textual information. To address this, we recommend enhancing knowledge delivery through audio playback or staff-led guidance [21]. Providing incentives, such as knowledge-based rewards, could also boost engagement with the content [22]. Regardless of the approach taken, designers should prioritize the primary objective of enhancing understanding of cultural heritage.
While this study shows promising results, the absence of a control group limits our findings. Including a control group in future research would provide a clearer baseline for assessing the installation's impact on learning outcomes, thereby strengthening the reliability of our conclusions.

ACKNOWLEDGMENTS

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A CASE STUDY OF APPLYING THE EXPERIENCE STRATEGY FRAMEWORK FOR BUSINESS TRANSFORMATION IN THE ERA OF EXPERIENCE ECONOMY

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ABSTRACT
This paper presents a case study of the Experience Strategy Framework (XSF) applied to a business transformation project within the experience economy. The XSF integrates key dimensions—people, experience, brand, and organization—to guide holistic, experience-oriented strategies that align business goals with customer needs. This study highlights how the XSF can address complex business challenges through a dynamic, relationship-based approach by detailing the rebranding of a leading home furnishings company in Taiwan. The case study demonstrates the framework's ability to overcome siloed business functions, enhance customer engagement, and provide a foundation for long-term competitiveness. Furthermore, the study underscores the evolving nature of the XSF as it adapts to new industry practices, making it a valuable tool for academic research and professional application.

Keywords: Experience Strategy Framework, Experience Management, Brand Experience, Customer Engagement, User-Centered Design, Organizational Strategy, Experience-Driven Business.

1 INTRODUCTION

In today's experience-driven economy, the influence of customer experience on business competitiveness has become increasingly evident [1][2]. As a result, industries are prioritizing the enhancement of customer experience to create added value [3]. Brand experience, which emerges from interactions between companies and consumers, relies on the effective translation of brand values into tangible actions [4]. However, research highlights a gap between organizations' customer experience strategies and their brand values, indicating a disconnect in their experience strategies [5].

This study posits that organizations must adopt a proactive approach to experience design in order to enhance competitiveness and brand value, by gaining a better understanding of users' preferences and perceptions of service experiences. We introduce the concept of the Experience Strategy Framework (XSF) [6]. The XSF emphasizes critical elements for organizations that rely on experience to drive business value. Using design-in-practice research, this paper presents an experience strategy-based approach to brand experience design, illustrating the advantages of adopting a macroscopic view of experience within a business context.

1.1 Background

This paper on experience strategy represents the culmination of ongoing activities, including academic research, consulting projects with clients, documented case studies, published books, journal and conference publications, conference presentations, workshops, professional education, and both undergraduate and postgraduate courses. Additionally, the authors have held regular weekly meetings to exchange ideas derived from pedagogical and practical experiences. Two activities, in particular, have significantly contributed to the research and development of experience strategy: industry design projects with paid clients and educational courses in both professional and academic environments. With each activity, the definitions and frameworks of experience strategy have been iterated, evolved, and refined.

The research and development of experience strategy leveraged case studies from TANG Consulting, one of China's leading experience strategy, design, and management consultancies. These case studies included projects with Amway, Xiao Guan Tea, China Merchants Bank, WM Motor, and Starbucks. The case studies have been documented in the book *X Thinking: Building Better Brands in the Age of Experienc*e, as well as its Chinese edition. Subsequently, the proposed experience strategy was applied to TANG's new client projects, including an international skincare startup, a leading global sports footwear and apparel company, and a leading global luxury automotive manufacturer. Additionally, it was implemented at HOLA, a leading retailer of home furnishings and household merchandise in Taiwan. This paper uses the HOLA case study to illustrate some of the latest developments in experience strategy and the Experience Strategy Framework (XSF).

In addition to design projects, the authors applied the XSF concepts to professional education training programs for TANG employees and university courses in Taiwan and Shanghai. In 2019, a comprehensive X Thinking training program was delivered to over 120 design researchers, strategists, and designers. This program enhanced the consistency and quality of the consultancy's experience research, strategy, and design practices across the organization. In 2020, an advanced Experience Strategy training program was developed and delivered to TANG's top 30 consultants.

Elements of experience strategy have also been incorporated into university courses at various levels, including undergraduate, postgraduate, and professional education. Notable courses include the "User Experience Design and X Thinking" course for graduate students at Tongji University's College of Innovation and Design, a graduate-level course in "User Research" at Beijing Normal University's Master's in Applied Psychology in User Experience, the "User-oriented Innovation Design" course at Taiwan University of Science and Technology, and the "Service Design Innovation" course at The University of Hong Kong for the Institute for China Business.

The authors have published the evolving state of experience strategy in various forms, including trade publications, trade books, an academic journal paper, and an academic conference paper. Lai [7] initially defines experience strategy as an "omni-touchpoint approach (meaning all touchpoints working together) to create a holistic experience for customers" by "strategically defining and creating the situations where brands can influence users' thoughts, feelings, and meanings toward your brand." Huang & Lai [8] describe an eXperience Strategy as a mid-term to long-term strategic and tactical plan for the development of brand eXperiences to achieve business objectives. It helps brands envision the ideal eXperience people would like the brand to deliver, identify the touchpoints that deliver such an eXperience, and prioritize the business activities required to realize the vision, aligning the eXperience with the brand value proposition.

An eXperience Strategy aligns every touchpoint, from customer engagement to employee interactions. It is comprehensive, incorporating both expectations and perceptions. It involves the interconnected activities of personas and scenarios to identify their jobs-to-be-done, aligning with the brand value proposition and contributing to business growth. Lai & Tang [9] further elaborate on the elements, methods, and process of experience strategy: Experience strategy encompasses the interconnected nature of enterprise capabilities, the brand value proposition, holistic experiences across experience domains, and customer lifetime relationships, all of which support informed decision-making for long-term competitiveness in the experience economy. The process of eXperience Strategy should include the positioning, planning, and operation of the brand, as well as analyses of experience and users, to fully understand the spectrum of experience from both the company's and the users' perspectives. The methods of experience strategy include the analysis of industry competitiveness, brand value, user perception, stakeholder priorities, and XPI. The core elements of experience strategy are the corporation, the brand, experience domains, and people.

In a recent conference paper [6], the authors document the development of experience strategy through its different phases of transformation, from user experience to strategy, where each new phase of development created opportunities for designers and strategists to deliver more value to clients. The four phases of UX transformation move from UX (the design of digital experiences), to experience design (the design of holistic experiences), to experience strategy (the design of the dynamic link between users and the brand), to experience management (the quantification of experience), and finally to experience-driven transformation (strategic consultation for organizational transformation to achieve desired customer-centric and experience-driven objectives).

1.2 Research problem

Despite the numerous publications mentioned above, we observed a lack of a clear definition of the Experience Strategy Framework (XSF), which has evolved through its application in different contexts. Therefore, this paper aims to clarify the definition of the XSF and establish a foundation for future academic research and industry practice. The objectives are twofold: first, to elaborate on the core elements of the XSF with the underlying rationale, and second, to present a case study that implemented the framework to further illustrate its possible applications in both academic and professional settings.

2 THE DEFINITIONS OF THE ELEMENTS OF EXPERIENCE STRATEGY

2.1 Experience Strategy

In the experience economy, customers' needs go beyond external branding to include internal value alignment. When selecting customized services, they prioritize brands that resonate with their beliefs, evaluating them through diverse touchpoints such as product usage, staff interactions, physical environments, digital platforms, and communication channels. Brands must actively design experiences across these dimensions to foster satisfaction and identity. As customer needs grow more complex, design management has shifted toward optimizing processes, strategies, and decision-making [10].

The customer journey forms the backbone of the experience economy, where brand interactions mature into lasting memories. These experiences, influenced by individual perceptions, can be analyzed on micro and macro levels [11]. Micro-level experiences focus on engagement with specific touchpoints, while macro-level experiences encompass the broader customer journey, building loyalty and enhancing brand value over time.

To address these dimensions, "experience management" has emerged as a key focus for industries [12][13][14][15][16][17]. By digitizing and concretizing experience design, organizations develop systems to evaluate effectiveness and inform strategic decisions. Tools like Qualtrics' Experience Management (XM) identify gaps, prioritize actions, and foster action-oriented cultures, helping integrate experience management into business strategies.

Customer journeys, however, are shaped by multiple departments within organizations, often resulting in inconsistencies. To deliver cohesive experiences, many companies now translate brand strategies into experience strategies through focused design initiatives. This process ensures alignment across departments and strengthens customer engagement.
Experience strategy, rooted in practical design and business case studies, has evolved into an innovation framework for organizations, advancing design performance and experience management. However, academic research has largely focused on customer experience without exploring how design transforms brand strategies into actionable experience strategies and design principles [18][19][20][21].

Modern design research should bridge these gaps, helping enterprises implement strategies through products, services, environments, and communications. The results would help identify opportunities for innovation, optimize service journeys, refine touchpoints, and deliver customer experience to deliver brand value. However, current frameworks need more scalability and integration for experience design management and theoretical models dynamically connecting people, experiences, brands, and businesses. This study proposes a research agenda for experience design management to meet these challenges.

2.2 The Revised Experience Strategy in this Study

The proposed experience strategy is a holistic and sustainable balance between the dynamic relationships among the business, its consumers, and the experiences that the business projects and consumers perceive. It helps companies make strategic decisions by understanding and interpreting both business dynamics and customer behaviors. It involves the deliberate selection of touchpoints to bring a brand to life and provide a strategic advantage over competitors. This approach aims to enhance long-term competitiveness in the experience economy.

At the core of experience strategy is the Holistic Experience Model, which focuses on the connections between brands and consumers through experiences, as shown in Figure 1. This model emphasizes that people primarily perceive a brand's value through the experiences it offers.

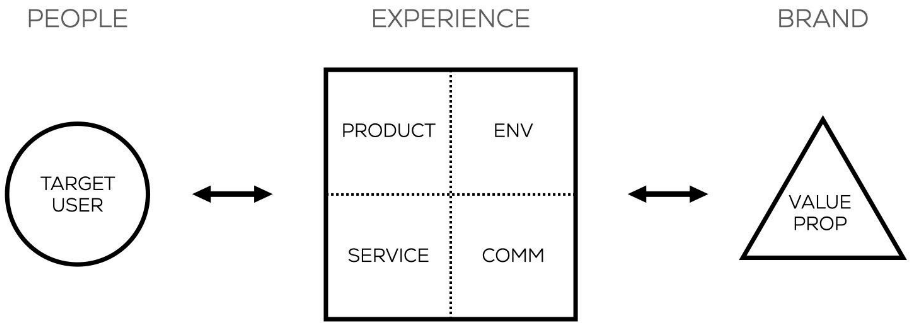

Figure 1. Holistic eXperience Model

Brands and consumers connect through experiences. Brands create value through touchpoints across four key Domains of eXperience, which also enable consumers to perceive this value.

The Domains of eXperience were originally inspired by brand practitioner Wally Olins's Four Vectors of Brand Tangibility and have evolved over the years [22]. The word "domain" was chosen because each domain requires a distinct set of knowledge, skills, mediums, and tools to design, implement, and operate. The original versions of the Domains of eXperience, as defined in both the Chinese and English editions of the *X Thinking* book, included four domains: offerings, communications, environments, and behaviors.

However, over time, the four domains have evolved for the following reasons: Initially, only products and services were considered offerings. However, after working in the real estate and intellectual property industries, it became clear that environments and communications are also forms of offerings. Additionally, user research revealed that consumers discuss services more frequently than they talk about behaviors.

Today, the Domains of eXperience have evolved to include products, services, environments, and communications, as shown in Figure 2.

Products are physical or digital artifacts that users acquire to own permanently. They are typically characterized by being produced by the company, owned by the user after purchase or acquisition, and evaluated through usage and its design to accomplish specific tasks or fulfill certain needs. Products can be physical (like a car) or digital (like software).

Services are activities or benefits that a brand provides, which are experienced temporarily. They are often characterized by being produced and owned by the company, accessed by the user but not owned, and evaluated through the quality of interaction (including customer service, user interface, and content quality). Services can be physical (like laundry and dry cleaning) or digital (like streaming services).
Environments are physical or digital spaces designed by a brand to facilitate user interactions, activities, and experiences. They are characterized by being produced by the company, accessed by the user for short or long durations, and evaluated through supported activities and design elements. Environments can be physical (like brick-and-mortar stores or hotels) or digital (like e-commerce sites or virtual worlds).

Communications refer to the exchange of information between a brand and its users, as well as among users themselves. They are characterized by being produced by both the company and users, accessed by both the user and the brand, and evaluated through engagement and relevance. Communications can be physical (like signage), digital (like social media posts), or in-person (like events).

	PRODUCTS	SERVICES	ENVIRONMENTS	COMMUNICATIONS
DEFINITION	Tangible or digital artifacts that users acquire to own permanently.	Activities or benefits that a brand provides, which are experienced temporarily.	Physical or digital spaces designed by a brand to facilitate and enhance user interactions, activities, and experiences.	The exchange of information between a brand and its users, and among users themselves.
PRODUCTION	The company	The company	The company	The company and the users
ACCESS	The user after purchase or acquisition	The user but not owned	The user for short or long durations of time	The user and the brand
FORM	Physical (like a car) or digital (like software)	Digital (like streaming services) or physical (like laundry services)	Physical (like stores, hotels) or digital (like e-commerce sites, virtual worlds)	Physical (like signage), digital (like social media posts), or in-person (like events)
EXPRIENCE FACTORS	Utility derived from use, designed to accomplish specific tasks or fulfill needs	Interaction quality	Supported activities and design elements	Engagement and relevance

Figure 2. Domains of eXperience

2.2 Experience Strategy Framework

Over time, as client projects shifted in scope from design to strategy, the Holistic Experience Model has evolved and expanded into the Experience Strategy Framework. While the people and experience components of the Holistic Experience Model remained unchanged, focusing solely on the brand was insufficient for holistically representing the business dimensions of experience strategy. As a result, the organization was added to the original framework to address strategic issues that are dynamically linked to achieving a holistic and sustainable balance between the business, its consumers, and the experiences the business projects and consumers perceive.

The Experience Strategy Framework provides a structure for holistically considering the dynamic relationships between an organization’s structure and capabilities, brand value proposition, holistic experiences, and customer relationships. The application of the Experience Strategy Framework in research and design practice enables organizations to adapt to rapidly changing markets and deliver exceptional experiences across multiple touchpoints, ultimately achieving business objectives.

The Experience Strategy Framework consists of four dimensions: people, experience, brand, and organization, as shown in Figure 3.

People addresses the question, “WHO are we serving?” To evaluate an organization in this dimension, examine the users, represented by their personas, jobs-to-be-done, needs, and user asset value.

Experience addresses the question, “WHERE, WHEN, and HOW do we serve them?” To evaluate an organization in this dimension, examine the solutions across the customer journey and the four Domains of eXperience.

Brand addresses the question, “WHAT do people think of us?” To evaluate an organization in this dimension, examine the brand value proposition, brand positioning, and brand personality.

Organization is the newest addition to the Experience Strategy Framework. It refers to the entity responsible for the brand and experience. While most industry projects work with for-profit and non-profit corporations, the term “organization” was chosen to include governments and non-governmental organizations (NGOs) to which the Experience Strategy Framework has been applied. The organization dimension addresses the question, “HOW do we operate?” To evaluate an organization in this dimension, examine its structure, capabilities, and processes.

These dimensions are dynamically linked, where changes in one dimension impact the components of the other dimensions.

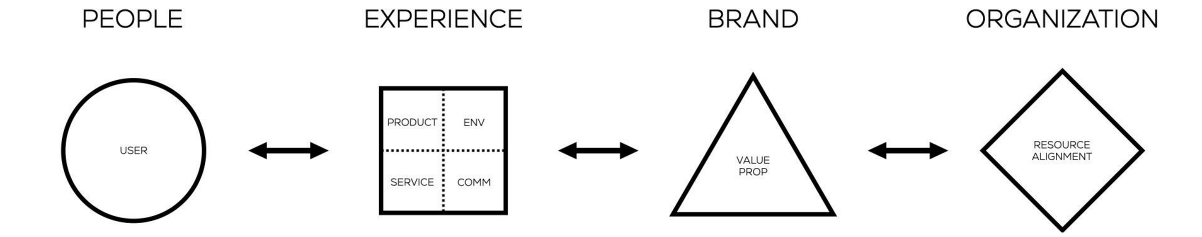

Figure 3. Experience Strategy Framework

3 IMPLEMENTING THE EXPERIENCE STRATEGY FRAMEWORK

3.1 Case Study

This section presents a case study that demonstrates the application of the Experience Strategy Framework (XSF) in redesigning an organization's overall experience strategy to address a specific business challenge. The case study aims to provide a detailed understanding of the process and its outcomes, offering insights for future implementations of the framework. Conducted from an action research perspective, the study involved researchers actively participating as members of the design team, offering an insider's view of the project.

The case study focuses on a leading home furnishings company in Taiwan, known for its 25 retail locations and expertise in trim design products and home decoration consulting services. The project aimed to rebrand the company through an experience strategy, enhancing its brand value and fostering stronger connections with younger consumers.

Primary data were collected through observations, semi-structured interviews, and materials from seminars. Over a nine-month period, the team held 13 meetings and conducted five co-creation workshops. Feedback and questions were documented throughout the collaboration, and 13 interviews with key personnel were conducted post-project. These data provided a basis for evaluating the impact of XSF on the company and its potential for broader application. The experience-oriented rebranding process was divided into three distinct phases.

3.2 Phase 1: Define the Personas and the organizational goal

The first phase focused on defining both ends of the XSF—personas and organizational goals—to establish the initial target for the experience strategy. Quality-of-life trends in Taiwan and in-depth interviews with potential users were analyzed to create personas. A workshop involving 30 employees from various departments was conducted to validate the selection of personas and to identify their needs and expectations. Open discussions and voting helped align customer groups with the company's business goals.

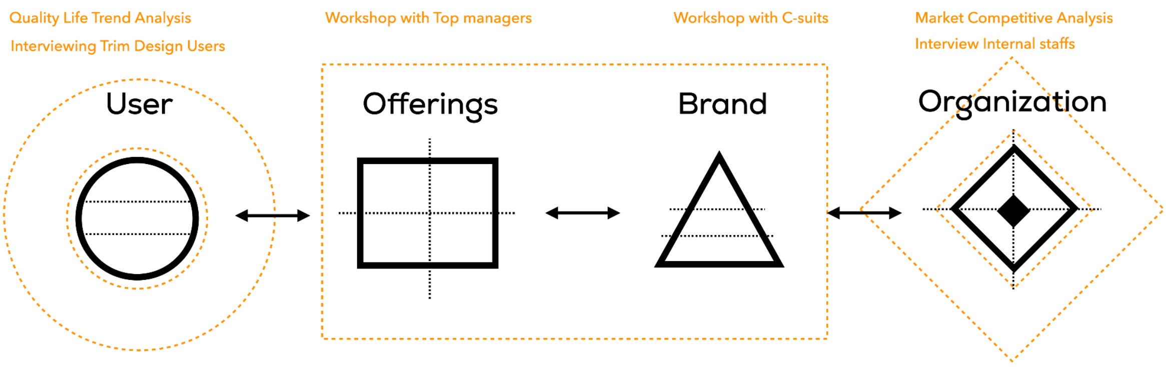

Figure 4. The process to apply experience strategy framework in the case study

Additionally, consumer and corporate competitiveness analyses and interviews with C-suite executives and top management informed the organizational goals, as shown in Figure 4. An experience strategy session with 40 top managers and a Brand Values Workshop with the C-suite further refined the company's direction. These sessions fostered consensus on target customer impressions, potential needs, brand personality, and key attributes, culminating in finalizing the company's experience strategy.

3.3 Phase 2: Connecting Expected Experience to Brand Value

The second phase involved conducting an experience walkthrough using the SPEC framework (Space, Product, Environment, and Communication) to evaluate the current state of the customer experience provided by the company. This process identified key touchpoints in the customer journey and clarified guiding experience principles. These principles were aligned with the brand's personality and attributes defined in the first phase. The team established a strong foundation for designing and implementing the overall experience strategy by integrating customer expectations with brand projections.

3.4 Phase 3: Experience Design and Program Execution

The final phase focused on brainstorming ideas aligned with the experience principles defined earlier. An experience design workshop was conducted with essential personnel from various departments, including both design and non-design backgrounds, who were directly responsible for shaping the customer experience. Participants contributed ideas related to store services, category-specific design, and marketing. These ideas were iteratively refined based on shared experiences and practical considerations. At the conclusion of the project, an execution plan was collectively developed to ensure each idea contributed to the overarching experience strategy.

3.5 The Benefits of Using XFS in the Case Study

The case study revealed three key benefits of using the Experience Strategy Framework (XSF):

Practical and Executable Results: The XSF process facilitated the creation of practical and actionable outcomes for each element within the framework. Interview findings showed that personas, experience principles, and brand values developed during the process were applied within the company even after the project concluded. For instance, employees across various departments began using personas in their daily discussions to assess service quality and design decisions. The study also highlighted that these results were more practical and cohesive than previous individual user studies or rebranding projects. Notably, the XSF outcomes unified employees from different departments, aligning them around shared target audiences and brand objectives.

Fostering an Iterative Spirit: The XSF process encouraged an iterative approach within the company. Participants were motivated to explore, test, and refine ideas to meet personas' jobs-to-be-done and align with brand values through workshops held at various process stages. Unlike rigid, process-driven frameworks, the relationship-oriented nature of XSF allowed for dynamic evaluations of ideas based on how they impacted the relationships between its core elements. This ongoing reflection on personas and brand values made the company more proactive in enhancing experiences.

Breaking Down Silos: The XSF process fostered dynamic connections among different departments, helping to avoid siloed operations. However, the primary focus was on rebranding, the XSF structure effectively defined and connected relationships between traditionally isolated business units. This integrative approach enabled departments to maintain alignment in their activities. Interviews revealed that the XSF was a valuable employee communication tool, reinforcing interdepartmental collaboration.

In conclusion, the case study demonstrated that the XSF preserves the relationships central to a solid experience strategy. It provides a foundation for future planning and allows the organization to adapt to external changes by modifying and iterating on new XSF scenarios. The findings highlight the strength of the XSF's dynamic relationships between its core elements, operating effectively at both macro and micro levels.

4 FUTURE STUDY OF THE XSF APPLICATIONS

The Experience Strategy Framework (XSF) offers a high-level structure for strategists, designers, and organizations to analyze and position the various elements and relationships between consumers and the organization during the early, ambiguous stages of the design process.

Once the experience strategy is defined, designers use the XSF as a framework to guide the design of each Domain of eXperience—products, services, environments, and communications—ensuring the brand delivers and users perceive an ideal experience. An ideal experience occurs when there is significant alignment between customer goals and business objectives. This process culminates in the detailed design and implementation of products, services, environments, and communications. The natural evolution of the XSF is Experience Management (XM), which extends its application. While experience strategy focuses on defining balanced relationships and experience design on execution, experience management focuses on measuring the outcomes of that execution.

Experience management is a discipline, approach, competency, and process that enables organizations to monitor, analyze, and act on experience data to enhance customer experiences. Experience data encompasses individuals' interactions with and perceptions of a brand's products, services, environments, and communications. This data can be collected from diverse sources, including user feedback, social media platforms, website analytics, customer support interactions, and sensor data in physical environments. Common methods for evaluating experiences include the Net Promoter Score (NPS) and Customer Satisfaction (CSAT).

The Experience Strategy Framework logically extends to validating the selected strategy and design execution using the same structure upon which they were built. We have already integrated the core elements of the XSF—people, experience, and brand—into TANG's XM solution and its Brand eXperience Index in practice. Future research should focus on further integrating XM and XSF to create robust growth mechanisms for experience-oriented businesses.

5 CONCLUSION

This paper proposed the Experience Strategy Framework (XSF) as a transformative tool for business adaptation in the experience economy with our previous papers and case studies. The case study demonstrated the framework's ability to integrate key dimensions—people, experience, brand, and organization—into cohesive, experience-driven strategies. The findings highlight the critical importance of aligning customer perceptions, brand values, and organizational processes to create meaningful, competitive brand and customer experiences.

From the case study, we conclude benefits of the XSF include:

1. **Holistic Approach to Experience Strategy**: The XSF establishes a comprehensive structure that connects customer needs, brand identity, and organizational capabilities. By emphasizing dynamic relationships among these elements, it enables businesses to achieve sustained competitiveness.
2. **Application Across Multiple Dimensions**: The framework encompasses four domains of experience—products, services, environments, and communications—facilitating the design and implementation of customer-centric strategies across diverse touchpoints.
3. **Strategic Business Transformation**: The study demonstrates how the XSF aids in breaking down organizational silos, aligning cross-departmental objectives, and adapting to evolving market demands. This approach enhances customer engagement and strengthens connections with key demographics, such as younger audiences.

The paper emphasizes the dual value of XSF for researchers and practitioners, providing a structured approach to bridge existing gaps in design and management frameworks. However, it recognizes that the evolution of experience strategy is ongoing. As design and experience management roles continue to expand in the industry, researchers and practitioners must iteratively refine and adapt the framework to meet emerging needs. While this version of the XSF is neither definitive nor exhaustive, it serves as a foundational starting point for leveraging experiences to drive business success. Future advancements in case studies and practices will contribute to the framework's evolution, ensuring its relevance in the ever-changing landscape of the experience economy.

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EMOTIONAL DESIGN IN SMARTPHONES: CRAFTING FUTURE DIGITAL EXPERIENCES

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ABSTRACT
Design and emotions have a strong correlation and are interdependent. Emotional design is a domain in design that centers around creating design that evoke emotions, which in turn generate positive and delightful user experiences. Since Donald Norman's pioneering work, emotional design has become integral to product and service design. With expanding focus on digital products and experiences, it is crucial to reexamine emotional design in this context and explore its future values. In this paper, the authors aim to explore the emotional design aspects of future digital experiences focusing on Gen Z, how they use smartphones, their perceptions, new meanings and emotional values associated with smartphones. The theoretical focus is on emotional design aspects to discover insights for future development of digital experiences enabled by the interface of smartphones. With the methodology of Research through Design (RtD) approach, this paper investigates both theoretical and practical knowledge, based on a case of Project-Based Learning (PBL) in a Master's Design Management course in an Indian design school. The study explores upcoming emotional aspects for designing new digital experiences in the future, in collaboration with an Asian smartphone company. The results reveal that for Generation Z, the smartphone exists in two metaphorical levels; one is "phone-as-a-companion" and second "phone-as-a-transformer". Furthermore, a framework of emotional design for digital experience is prototypically proposed. The framework can contribute both theoretical and practical point of view for creating future values of smartphone experiences.

Keywords: Emotional Design, Digital Experience, Metaverse of Things (MoT), Research through Design (RtD), Generation Z

1: INTRODUCTION

There is a strong relationship between design and emotions. Since Desmet [1] and Norman's [2] research theories regarding the aspects of emotion and design were pioneered, various studies on emotion design and emotional design were rapidly explored under the same umbrella of design and emotion; a topic that became an important one in the field of design during the last decades [3]. Meanwhile, in the last few decades, the scope of design in both academia and practices increasingly covers digital products and experiences [4]. Therefore, emotional design also has to be seen in this changed context. It is crucial for designers, companies, and design scholars to explore the current meaning of emotional design and discover future values in terms of the emotional aspects of digital products and experiences. In a world where products, services, and experiences are becoming increasingly digital, how can we capture what an emotional digital experience is? How can emotional design contribute to digital experiences? All of these concerns are worth investigating and exploring to give a better understanding of the topic regarding emotional design and digital experience.

1.1. Emotion and Design

The concept of "emotion," first introduced by Plato [5], was later highlighted by Darwin [6] as a crucial factor in shaping social behaviours such as communication, forming a basis for his evolutionary theory. Dewey [7] built on this by suggesting that emotion is influenced by experience, not merely a response to external stimuli. Since the 1970s, emotion has been explored across various disciplines, including psychology, philosophy, sociology, and economics [8].

In design studies, researchers have developed theories and methodologies to understand how emotions impact design. Ho and Siu [8] categorized design and emotion studies into three approaches: "user/consumer-driven," "designer-driven," and the "relationship among users/consumers, designers, and design outcomes." The "user/consumer-driven" approach emphasizes understanding user experiences to improve design [9]. The "designer-driven" approach focuses on how external changes influence designers' goals and emotional responses [10], [11]. The third approach highlights communication between users and designers through design outcomes [12], [13]. Mapping these approaches is fundamental for situating specific research within the broader field of emotion and design studies.

1.2 Emotional Design and Digital Experience

As digital technologies become integral to daily life, most products and experiences are now technology-enabled, impacting psychological well-being and emotions. For instance, Kushlev and Dunn [14] showed that frequent email checks via smartphones increase stress, while Misra et al. [15] found that the mere presence of a mobile phone reduces the quality of face-to-face interactions. Given the pervasive presence of digital technology, designing experiences that consider their emotional and well-being impacts is increasingly crucial.

Leung [4] notes that the "art" of digital experience design extends beyond usability, encompassing emotional and atmospheric elements such as attraction, seduction, and engagement. These intangible aspects are difficult to define or quantify, requiring insights from other disciplines experienced in designing holistic experiences. Peters et al. [16] highlight a knowledge gap in designing technology that supports well-being, despite the potential for technology to be consciously developed to enhance or regulate emotions. Therefore, exploring emotional aspects in digital experiences is essential, but the lack of methodologies and practical knowledge must be addressed in both academic and practical contexts. Empathy is a critical tool for bridging this gap, providing a holistic, human-centered approach to understanding and identifying users' latent needs.

1.3. Focus of the research: Emotional design for digital experience of smartphone for Generation Z

To address this issue, this paper aims to explore the emotional design aspects of future digital experiences, focusing on Generation Z and their use, perceptions, and new meanings and emotional values associated with smartphones. One trend that is common to Generation Z in all of the Asian countries is the influence of technology on their lives and behavior. It is clear that the members of Generation Z in Asia are not only digital natives but have grown up in a world of both social media and mobile technology [17]. Especially in India, with a population of 472 million, Generation Z in India is the largest in the world [18]. According to Hameed and Mathur [18], members of Generation Z in India show common behaviors and preferences with their counterparts around the world. Additionally, members of Generation Z in India have clear opinions and ideas of how youth can contribute to a developing nation like India. Therefore, by focusing on Generation Z, especially those in India, we will be able to gain future insights about the emotional design of digital experiences through interpreting weak signals of the future of digital experience [19].

There are three main targets of the research. First, it investigates what emotion smartphones bring to generation Z and what they want from smartphones in the future. Second, based on the first set of insights, we derive two hypothetical scenarios about what future smartphones should look like with respect to emotional design. Third, we formulated an emotional design framework for digital experiences as a theoretical model for the prototype. This research aims to contribute to knowledge generation mainly in the categories of "user/consumer-driven approach" based on the categorization by Ho and Siu [8].

2: METHODOLOGY

Owing to the constructive design research as a way of Research through Design (RtD) approach, this paper investigates both theoretical and practical knowledge. A design challenge of creating "emotional design framework for digital experience in smartphone" was the setting of the research, where an industry-collaborative Project-Based-Learning (PBL) in design management program at the Master's level in an Indian design school. Collaborating with an Asian smartphone company, this study explores upcoming emotional aspects for designing new digital experiences in the future.

2.1. Project-Based-Learning (PBL): Creating an “emotional design framework for digital experience

To explore the emotional design aspects of future digital experiences, a Project-Based Learning (PBL) [20] was conducted in a design management program at the master’s level in an Indian design school. Project-Based Learning is a pedagogical approach in higher education in order for students to learn cutting-edge academic topics within real-world practice [21]. Project-Based Learning is a student-centered form of instruction that is based on three constructivist principles: learning is context-specific, learners are involved actively in the learning process and they achieve their goals through social interactions and the sharing of knowledge and understanding. It is considered to be a particular type of inquiry-based learning where the context of learning is provided through authentic questions and problems within real-world practices that lead to meaningful learning experiences [21]. Therefore, by collaborating with a leading Asian smartphone company, the research was planned and conducted for the purpose of exploration of emotional design aspects for future digital experiences especially on smartphone.

As the basic conditions of the project, an industry-academia collaborative project was conducted as an educational course under the design management master’s program at the MIT Institute of Design (MIT ID) in India. The project was coordinated by the faculty of design management and a leading Asian smartphone company, in which four students and two teachers and three mentors from the company participated. 50 students as interview collaborators also participated. The design project theme was creating an “emotional design framework for digital experience” which can clarify what is the “plausible” level of emotional experiences in digital experience for the smartphone. In order to achieve this goal, the focus of investigation set on understanding generation Z’s way of usage and perceptions regarding smartphones to see the future in weak signals [19]. The timeline of the project was planned of three phases with a duration of 13 weeks.

2.2. Research through Design (RtD)

Relying on constructive design research as a way of Research through Design (RtD) approach [22], this research investigates both theoretical and practical knowledge. According to Stappers and Giaccardi [22], RtD indicates design activities that play a formative role in the generation of knowledge, in other words “Doing design as a part of doing research”. As most academic publications about RtD focus on the prototype, The designing act of creating prototypes is in itself a potential generator of knowledge (if only its insights do not disappear into the prototype, but are fed back into the disciplinary and cross-disciplinary platforms that can fit these insights into the growth of theory) [22]. Based on the definition of prototype by Houde and Hill [23], prototype is defined as “any representation of a design idea, regardless of medium”. Here, we are considering a framework as the end product, and have applied the design process to create the required solution.

Therefore, through generating a prototypical framework of emotional design for digital experience as a visual representation of design outcome, this research pursues to generate a piece of knowledge in the identified research gap between emotional design and digital experience.

Data was collected through two different formats. Firstly, secondary and primary research data during the project which were collected by the students’ participants. Secondly, the final outcome of the emotional design framework, which is the generated prototype.

3. RESULTS

First, the research yielded several insights into what emotion smartphones bring to generation Z and what they want from it in the future. As basic insights, eight emotional dimensions were synthesized through a study of how the digital experience of a smartphone is emotionally charged for Generation Z. The desires they expect from future smartphones were also analyzed and integrated into the five sensory aspects. Second, based on the first insights, two hypothetical scenarios were derived. The students generated two metaphorical concepts; one is the "smartphone-as-a-companion" and the other is the "smartphone-as-a-transformer." In both cases, different types of Generation Z's emotional needs could be realized by the smartphone. Third, based on these insights and hypotheses, a prototypical framework of emotional design for digital experiences was formed. This framework is prototyped with the aim of creating a piece of knowledge about emotional design for digital experiences, with reference to the theoretical background of emotion and consciousness [24], [25]. In particular, in the broader context of emotional design, it is intended to contribute to the "user/consumer-driven approach" [8].

3.1. Insights

First, we gained findings into what emotions smartphones bring to Generation Z and what they want from smartphones in the future. These findings were synthesized through extensive desktop research (secondary research) focusing on how emotional design affects Generation Z today, and workshops and surveys (primary research) to better understand the emotional interests of 50 students in MIT ID who are Generation Z when it comes to smartphones.

3.1.1. What emotion does smartphone bring to generation Z

During the PBL, students explored the fundamental emotions smartphones evoke in Generation Z through primary and secondary research. They identified triggers that lead to emotions and synthesized eight emotional principles based on patterns observed in users' conscious and unconscious experiences: control, familiarity, serendipity, reward, closure, nostalgia, assurance, and attachment.

1. **Control** can be described as an ability to perform a task according to your preferences. Smartphones enable multitasking easily, however, each task should be allowed by preferable gestures, actions and settings that leads to a high emotional level of control. This principle exercises the degree of control smartphones allow the user and is important to establish to enhance user's privacy.
2. **Familiarity** is a sense of relatedness to the real world scenarios and objects. Even with digital interfaces, qualities that stimulate familiar real-world textures and sensory perceptions can enhance emotional utility. An easy-to-use and learn interface also generates familiarity and plays an important part during new developments in smartphones like software updates. For example, phone wallpapers themes form a sense of familiarity to the phone due to the user constantly seeing the particular setting.
3. **Serendipity** is a sense of exploring new things that lead to an unexpected positive reaction. The digital interface of the smartphone is perceived by Generation Z as a doorway to a new world, and the accidental discovery of an experience never seen or experienced before evokes an emotional experience of serendipity and adds new dimensions to the emotional relationship and attachment of humans to smartphones.
4. **Rewarding** is a productive feeling and achievement. When an action is accomplished through a smartphone, having appropriate feedback is important to enhance feelings of being rewarded. For example, having different feedback for each layer of multi-layered tasks can appropriately enhance feelings of fulfillment.
5. **Closure** is a sense of completion. When a task is completed, being able to clearly see that it has been completed is very important for emotional utility. A smartphone's appropriate feedback results in providing the user a feeling of contentedness.
6. **Nostalgia** is "emotional" take me back. This emotion is derived from the historical memories that are stuck in the smartphone. The connections with family members who live far away and various friends and acquaintances you have met over the years are stored in your smartphone. For example, albums from the past can heighten feelings of nostalgia.
7. **Assurance** means affirmation and guarantee. In the digital experience on smartphones, many actions are performed for the first time. Therefore, a clear and understandable explanation of what the results of a certain action will be will help to dispel the user's apprehension and increase the feeling of assurance; providing a guarantee for every action or gesture. For example, informing the user whether the action they are performing is in the right direction or not is critical as is to guide the user throughout their journey.
8. **Attachment** triggers the connection with other people and objects. The connectivity to the world that is achieved through the phone triggers this emotion as smartphones are the primary means to connect with people and other things particularly for Generation Z. For example, images on the home and standby screens are important for enhancing attachment. Another example, is the call log which gives the users the ability to connect with their family, friends and others in mere seconds, increasing attachment to the phone. The ability to change frequently used applications to one's preferred colors and settings will further increase attachment.

These principles serve as fundamental guidelines, aligned with sensory triggers and cognitive processes. In designing digital products, they can be applied to assess emotional design throughout the user journey and act as a checklist to ensure designs are holistic and integrated. This approach influences brand perception, purchase decisions, and user retention, enhancing digital experiences with a human-centered focus.

3.1.2. What generation Z want from smartphones in the future

Through in-depth observation and interaction with Generation Z participants, we gained insights into their needs and visualized future smartphone scenarios. Understanding their emotions and levels of self-awareness offered deeper insights into their preferences and the image they want to project. Our analysis focuses on the emotional design of future smartphones based on the five senses, summarized into four categories: touch, hearing, sight, and futuristic senses (smell and taste).

The close relationship between the senses and emotions presents opportunities for developing emotional smartphone experiences. Knowing that users engage multiple senses (touch, hearing, sight) simultaneously during communication enhances psychological and emotional connections. In addition to exploring these prevalent senses, designing future digital experiences that incorporate taste and smell shows significant potential for creating advanced scenarios.

3.2. Hypothetical scenarios

Second, based on the above insights into future smartphones, two hypothetical scenarios were derived. These hypothetical scenarios are intended to provide conceptual and archetypal hypotheses for the future meaning of smartphones [26]. Smartphones exist at two metaphorical levels: the "smartphone-as-a-companion" and the "smartphone-as-a transformer." In both cases, different types of Generation Z's emotional needs are met by the smartphone.

3.2.1: Smartphone-as-a-companion

The first hypothetical scenario is "smartphone-as-a-companion". This hypothetical scenario explores the direction of seeking a more core sense of security and comfort, such as healing and attachment to smartphones. The detailed scenario was developed as follows.

"Humans are biologically predisposed to form attachments, extending even to non-human and inanimate objects. Attachment styles affect not only relationships with others but also with objects like smartphones. For Generation Z, phones are more than simple devices; they are companions integral to their lives. Young people display attachment behaviors such as proximity-seeking and separation stress, influenced by their attachment style. Those with higher attachment anxiety are more likely to rely on their phones for constant connection. Generation Z views their phones as companions, providing emotional comfort and fulfilling various needs throughout their day."

3.2.2 : Smartphone-as-a-transformer

The second hypothetical scenario is that of a smartphone-as-a-transformer. This hypothetical scenario is based on the premise of constant technological evolution, and the rethinking of the smartphone from a more emotional aspect, given that its functionality will continue to evolve in multiple dimensions in the future.

"With advancing technology, cell phones have replaced and rendered many physical items obsolete, such as radios, music players, books, wallets, maps, calculators, and scanners, transforming them into applications accessible with a few taps. Essentially, the cell phone functions as a transformer.
In our user survey, respondents expressed desires beyond emotional needs, envisioning smartphones facilitating various futuristic activities like transportation, knowledge embedding, and digital twins. Technological advancements will further expand the role of smartphones as transformers, integrating AR spaces that blend digital and physical realities, and evolving Metaverse experiences. As smartphones extend reality and perform human-like functions, users may develop deeper emotional attachments to them."

These two hypothetical scenarios were exploratively constructed as directions for future smartphone ideas. These scenarios are based on the analysis of India's Generation Z in envisioning future smartphones and are hypothetical narratives for examining the emotional design of smartphones.

3. 3. Framework: Emotional Design for Digital Experience

Third, based on these findings and hypotheses, a hypothetical emotional design framework for digital experiences was formed. In constructing the prototypical framework, we referenced several academic theoretical frameworks on emotion and consciousness. The first is a categorical distinction between emotion and consciousness [25]. They argue that emotion consists of an emotional state (functional aspects, including emotional response) as well as feelings (the conscious experience of the emotion), and that consciousness consists of level (e.g. coma, vegetative state and wakefulness) and content (what it is we are conscious of). Freud's classical theory of consciousness was also referred [24], [27]. According to Freud, consciousness consists of three stages; conscious mind, preconscious mind, and unconscious mind. The conscious mind consists of all the mental processes of which we are aware. The preconscious mind Contains thoughts and feelings that a person is not currently aware of, but which can easily be brought to consciousness. And the unconscious mind comprises mental processes that are inaccessible to consciousness but that influences judgments, feelings, or behavior. Based on these two theoretical backgrounds, a prototypical framework for emotion design of digital experience was proposed, by considering the eight aspects of emotion obtained from the desk research and primary research conducted in this study (Figure 1).

This circular prototype framework consists of two parts: the eight emotional aspects and the three levels of depth of awareness aspects. The eight emotional aspects represent the emotional desires of Generation Z regarding smartphones explored in this PBL research. The depth of these aspects was set up so that they could be evaluated on three levels of awareness. This framework allows us to evaluate the emotional aspects of the digital experience regarding smartphones according to each scene, which in turn allows us to improve the design regarding the emotional aspects.

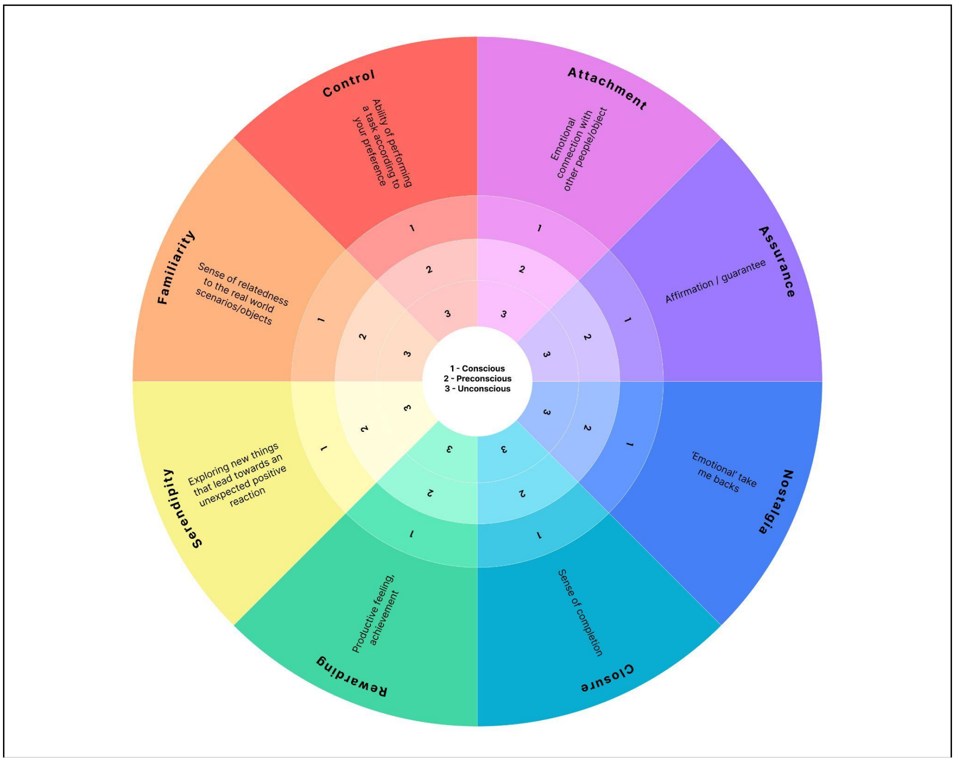

Figure 1. A prototypical framework of emotional design for digital experience

In fact, one case study was set up and evaluated. The students created an example customer journey map of setting up a new wallpaper screen for a smartphone and evaluated it by Generation Z users (Figure 2). In the customer journey map, the pain points of the target users were identified, and based on the emotional principles and awareness level that triggered them, they were marked on the framework as

appropriate. For instance, when the users decide the wallpaper image, they feel a sort of anxious feeling about what the result would be. Touch & sight are the senses at play providing input for the triggers. The emotional principles of “assurance” and “rewarding” have been triggered -assurance was an unconscious trigger, and rewarding was conscious trigger in the action. This allows for a deeper understanding of what emotions are triggered and can be enhanced to provide better human-centered design solutions. Based on the assessment, the level of awareness is plotted and visualized in this framework (Figure 3).
Based on this principle, a framework for determining the level of consciousness emotion was developed and a prototype framework was proposed by the student. This framework was identified as a more attractive and organic way to analyze and quantify emotions.

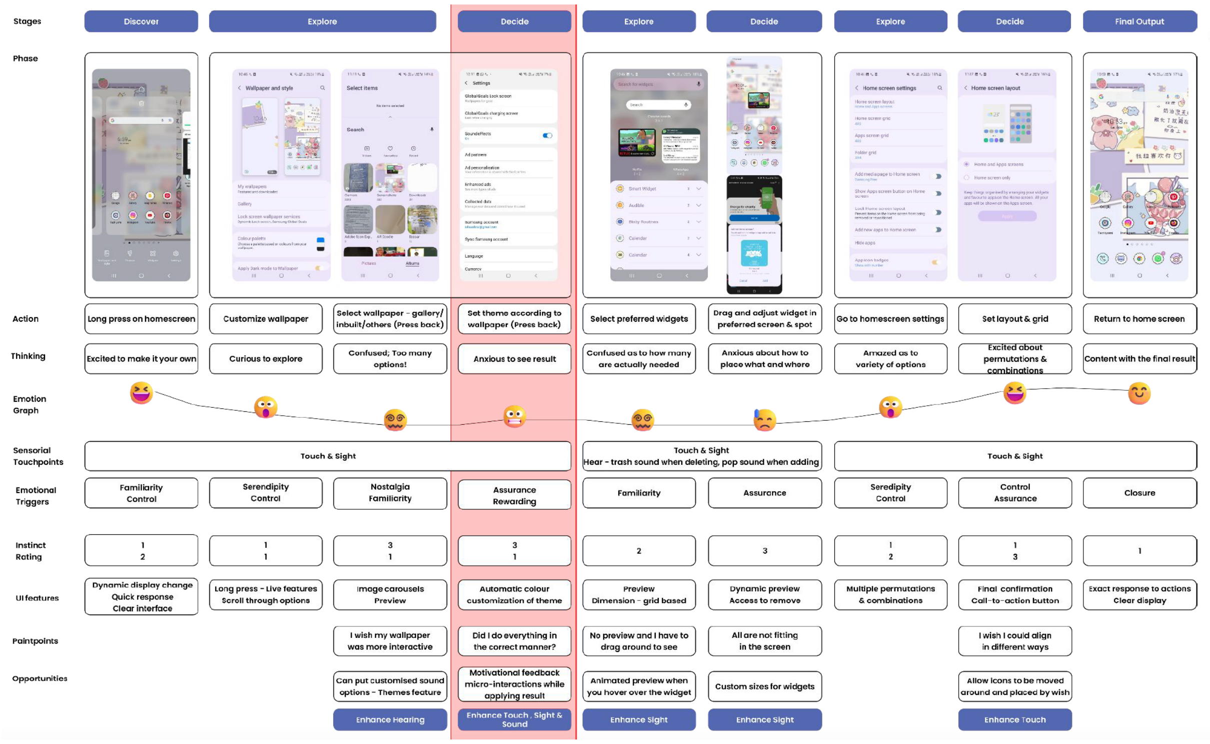

Figure 2. An evaluation of the framework with a customer journey

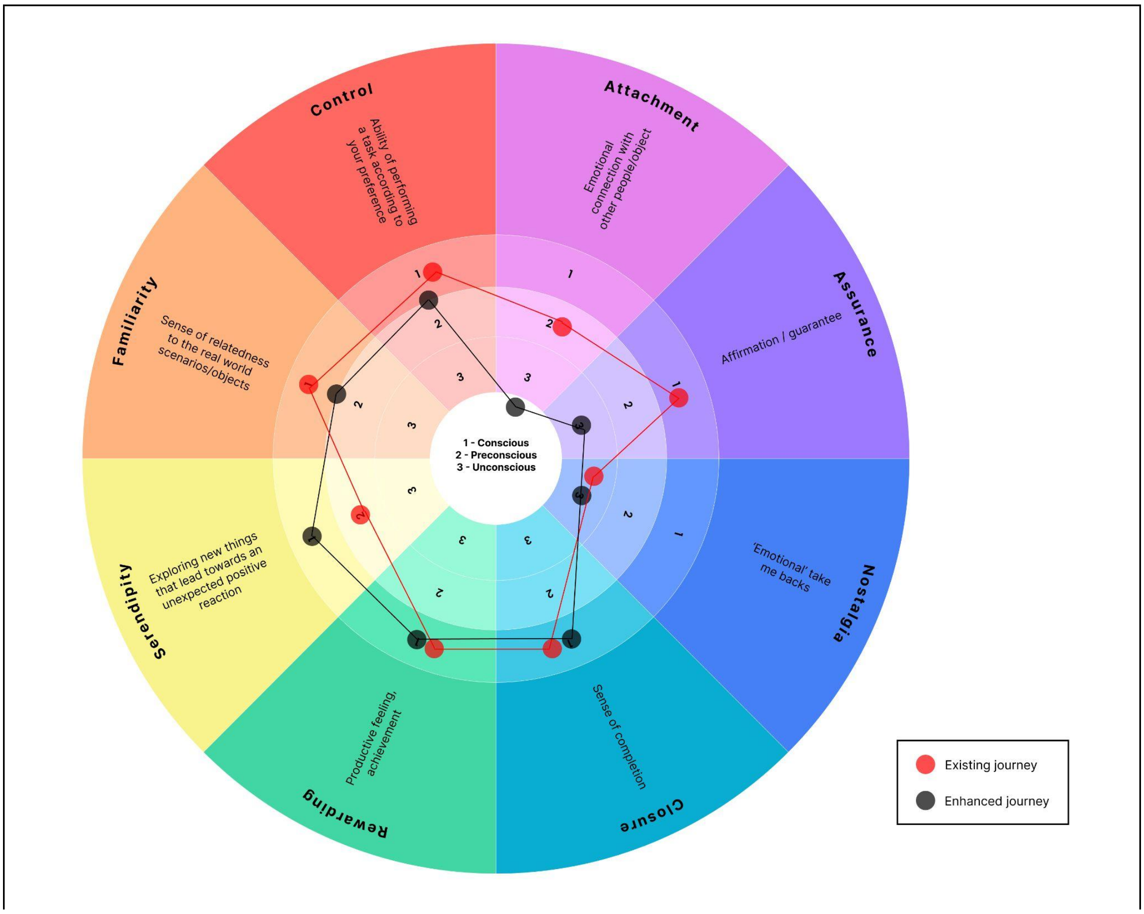

Figure 3. A result of evaluation of a customer journey

4. DISCUSSION AND CONCLUSION

This paper addresses an upcoming but as yet unexplored research gap between emotional design and digital experience design. Through a constructive method of Research through Design, based on a case of Project-Based Learning (PBL) in an Indian design school, this study tackled three focal issues. First, we gained some insights into what emotion smartphones bring to Generation Z and what they want from them in the future. For Generation Z, smartphones are an inseparable part of their lifestyle and an extension of themselves. They are an extension of themselves. Smartphones are also like a therapist, a charger, and a portal to family and friends. Second, based on the above findings and insights, we derived two hypothetical scenarios: making the smartphone a companion and transforming the smartphone. These hypotheses are intended to provide conceptual and archetypal hypotheses for the future meaning of smartphones [26]. Finally, from all the research and user studies conducted to date, we constructed and proposed an affective framework for determining emotions at the level of consciousness, using established affective principles. Since emotions, being intangible, are difficult to map, emotion maps proved to be a more attractive and organic way to analyze and quantify emotions.

This paper contributes to both design education and future research. First, it makes a piecemeal knowledge contribution with respect to the identified research gap: affective design and digital experiences. As digital technology becomes a necessary foundation for our society, business, and daily life, it is important to build on the practical and academic contributions of design on human emotions. Second, through the practice of Project Based Learning in industry-academia collaborations, design education has contributed to providing suggestions for the future. In particular, we found that PBL in industry-academia collaboration in university education is one of the best methods to explore weak signals [19] and scenarios [26] of how Generation Z perceives the current situation and hopes for the future with regard to certain products and services such as smartphones. Third, the results clearly show that design education can not only train future professionals in the field of design management, but also provide them with better opportunities to propose the future [28].

It should be noted that this study has several limitations. First, methodologically speaking, it relies on a single case study, the Research Through Design (RtD) project. Therefore, this study should be widely implemented by other different methodologies and scopes. For example, a case study of real-world practice on aspects of emotional design in digital experiences would provide a deeper and more practical understanding of this topic. In addition, the vast amount of theoretical knowledge on digital experience and emotional design still exists independently and would provide meaningful suggestions and research directions for both academia and practice. Second, the limitations of the hypothetical framework itself that has been produced need to be pointed out. It is a limited framework, based on the theoretical model of Tsuchiya and Adolphs [25] and Freud [24], [27], but piloted on the eight affective dimensions explored in this PBL. While we may have been able to demonstrate a certain possibility of constructing a theoretical model of Emotional Design through the PBL approach, with reference to theories of emotion and consciousness, the practicality of the model itself and the strengthening of its theoretical background will require further academic and practical However, it must be emphasized that further academic and practical research is needed to strengthen the practicality of the model itself and its theoretical background. It should be emphasized that this is only a limited framework produced within the educational course of PBL.

It is worthwhile to describe possible future research topics related to the research areas of Emotional design and Digital Experience identified by this study. First, it is important to reexamine the broader topic of emotional design from the perspective of digital experience. This study focuses on "user/consumer-driven research" of emotional design of digital experiences [8]. Therefore, as Ho and Siu [8] categorize, other broad areas of emotional design, such as "designer-driven research" and "user/consumer-designer relationships through design outcomes and other means," would be worth further study. Second, with respect to Emotional Design, a focus on the differences with respect to Real Experience and Digital Experience. Third, Emotional design within digital spaces such as the metaverse would be an interesting topic. How realistic emotions can be created in a metaverse space will require progress in design research in various fields.

Finally, as digital experience has become an important experience domain worldwide, we expect that many cross-disciplinary studies on emotional design and digital experience will be raised in the coming decades.

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UNDERSTANDING EMERGING MATERIALS AND THEIR INTEGRATION PATTERNS FOR DESIGNING NEW PRODUCTS WITH ENHANCED EXPERIENTIAL VALUE

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ABSTRACT
Material-driven design is a novel approach to product design, starting with a thorough understanding of the materials. The traditional design process determines materials at later stages. Materials have played a crucial role in research and practice, offering direction for applications aligned with the product's design and enhancing the product manufacturing process. Material research provides novel materials as superior substitutes for conventional ones and seeks the designers' collaboration to further their development. However, conventional applications have primarily used these materials. From an experience-value standpoint, the functional and experiential attributes of the materials may profoundly influence the overall design of a product. Nevertheless, design literature has not adequately addressed experiences with and for these materials, indicating that designers' objectives do not fully encompass their applications and integration in product design. This study aimed to first identify emerging materials that hold significant potential for product design. Secondly, it acquired a comprehensive understanding of these materials through a design ideation workshop with designers and subsequent interviews with material scientists. Third, we utilized the insights from these activities to conduct a concept design experiment with design participants. The aim was to explore the integration of these materials and the experiences they may elicit in product design concepts. The results provided valuable insights into understanding emerging materials and their integration patterns in new product designs, enhancing the product's experiential value and functional aspects in an envisioned scenario.

Keywords: Material integration, experiential value, material understanding, emerging materials, concept design

1 INTRODUCTION

Generally, the design process begins with a problem-driven or need-driven approach for a product design and considers material selection in the detail design stage [1]. Designers consider the technical characteristics of a material in a product to support its application, but they often overlook the experiences that a material may evoke [2]. Material-driven design (MDD) is a novel approach that begins with a thorough understanding of materials, both technically and experientially. It then identifies the optimal situational whole in which the material is most suitable for a product. This approach has enabled designers to leverage the experiential attributes of materials and identify integration possibilities with other materials [3]. This approach can enhance the significance and worth of materials, surpassing those with a single use and limited potential for innovative exploration. Design researchers recommend leveraging the properties of new materials to stimulate innovation and create new opportunities for artistic interaction within products and environments [4]. The use of novel or unused materials can produce innovative product forms and aesthetic experiences, underscoring the need for developing materials or manufacturing processes to actualize product concepts [5]. Consequently, it is imperative for designers to understand the characteristics of materials, their sourcing methods, processing methods, and types, as they are essential to the design process. Design practitioners have demonstrated the feasibility of implementing various aspects of material experience, whether in a general context or a more specific context on aesthetic and functional aspects. Some of these experiences are the expressive sensorial atlas [6], the multi-dimensional materials charts [7], the meaning-driven materials selection [8], the color atlas [9], design with Wabi-Sabi [10], the textile atlas [11], the aesthetics of tactual experience [12], and materials and emotion [13]. Moreover, Howes et al. [14] discovered the effects of material sounds and tastes on users' experiences of products. Chapman [15] investigated the emotional connections with materials in relation to durability and long-lasting experiences. Despite previous attempts to understand existing materials for their aesthetic, functional, and experiential features [16, 2-4], there is still a gap in understanding and integrating new emerging materials with their multiple experiential features. Adding to this, several design researchers argue that in practice, designers often lack proper familiarity with the potential applications of materials and their experiential characterization [17, 18, 4]. This study aimed to identify key emerging materials, explore their potential aesthetic and functional features, and understand material integration patterns. The purpose of the integration patterns is to propose new design concepts with experiential value, which encompass aesthetic (sensorial), interpretive, affective, and performative experiences within a situational whole, based on envisioned scenarios. We conducted several visits to two local science and technology institutes to observe and understand potential materials with novel characteristics that can have multiple applications in product design. Our preliminary observations and engagements with material researchers enabled us to identify key emerging materials with particular applicability in their domains. However, we could not use these materials in the design, even for experiment purposes. Despite the potential benefits, the materials' applications remain challenging due to the lack of a fully developed sample for technical and experiential characterization and the absence of a formal process for transforming a product concept into reality. As Rognoli [6] argued, designers are the ones who define the expressive and affective aspects of a product experience. In the absence of actual material samples, designers may conceptualize the experience utilizing alternative materials that possess similar sensorial qualities and physical properties [3]. We conducted an ideation workshop with designers to analyze the possibilities of the materials used in the design process, assess their limitations, and explore their potential applications in the product design [4]. Subsequently, we conducted interviews with material researchers to further reinforce the findings from the workshop. We used our existing understanding of the materials to conduct a concept design experiment with 10 postgraduate design students, with the aim to identify material integration patterns and their connection to specific experiential aspects, emphasizing that functionality is a prerequisite for a proposed product design concept. Furthermore, the experiment aimed to validate our design activities by identifying key emerging materials, understanding them based on limited available knowledge, and devising meaningful integrations into product design concepts that evoke valuable experiences. This study presents potential research directions for designers focusing on material-based design thinking. The study aims to gain new insights into the effectiveness of material-driven design methods for diverse product design expeditions, resulting in innovative product design experiences. Furthermore, this study provides valuable insights for material researchers, aiding in the advancement of materials in development. This, in turn, enhances their utility, value, and versatility in product design, thereby eliciting enhanced experiential characteristics and ensuring their effectiveness and worth in intended applications.

2 RESEARCH APPROACH

Before commencing the main study, we first visited numerous materials science labs to discover emerging materials for multiple design applications. These materials include thermoelectric generating (TE) paint, printed batteries, electric energy-storing paint, 3D printable microorganisms, and 3D photochromic soft photonic crystals. Material researchers wanted to find further uses for these materials. Therefore, we investigated these materials' intended uses to better understand their characteristics and applicability in product design. The researchers developed TE paint for furnaces, industrial boilers, and other heat-loss equipment. Current thermoelectric generators turn heat into electricity. These generators are flat 3D modules; thus, only a tiny section touches a circular furnace surface, wasting thermal energy. In contrast, TE paint clings to any surface like conventional paint, minimizing gaps and converting heat energy into electricity. This allows us to analyze the usability of TE paint, identify new applications for its unique qualities, and engage in design discussions. It is useful and attractive to paint since it generates power via heat and works on numerous surfaces. After successful visits to materials science labs, we reviewed literature to identify new materials with multiple aesthetic and functional properties for product design. We added these new materials to our list and learned more about their aesthetic and functional properties.

Second, we conducted a design ideation workshop where we provided a list of key emerging materials to the design participants without using the MDD method—a method to understand and design for material experiences in product design [3]. In particular, the workshop aimed to understand the obstacles that hinder product design processes, preventing designers from leveraging emerging materials with multiple properties that contribute to the aesthetic (sensorial), interpretive, affective, and performative experiences of a product. We found that designers lack knowledge about potential applications of emerging materials for product design; their creativity is limited due to their inability to deviate from established product design solutions. Moreover, the current product design scope limits their ability to explore beyond traditional product design processes. Therefore, we delved into the constraints of understanding these materials during the design process while also identifying envisioning potential applications of the key emerging materials in future product designs.

Third, we conducted interviews with material researchers to gain insights into emerging materials and to learn about the design possibilities and future uses of these materials. Having listened to both design participants and material experts, we articulated the potential integration of specific materials to create unique experiences in product design.

Finally, we conducted a concept design experiment, drawing inspiration from the previously mentioned activities. The aim was to incorporate new materials into product design and allow participants to leverage emerging materials to design products with improved aesthetic and functional experiences. We incorporated the MDD method into the experiment to introduce the participants to a specific material-based design process. This can allow them to understand the materials through their experiential features and produce new design concepts.

2.1 Design participants

We recruited 10 design participants, including seven females and three males, with ages ranging from 25 to 30 years, for the concept design experiment. They were postgraduate students majoring in product and industrial design at a local design institute. Participants had more than two years of prior experience in product design and had the ability to handle complex design tasks. This study received approval from the institutional review board (IRB) of our institute with reference number HSEARS20221103006. Figure 1 shows participants design activities and the design environment.

Figure 1. A participant design activity and the design environment

2.2 Design tasks

In order to educate the design participants about emerging materials, we gave them a catalog based on the results of the ideation workshop and interviews. We then asked the participants to utilize the unique technical and experiential characteristics of the materials in the catalog. Additionally, we asked them to design new product concepts, enhance existing products, or create a system that combines both functional and experiential components. We introduced the participants to the MDD method for experiential characterization on four distinct levels, which is an essential component of designing for experiences. This introductory part also served as a task to understand the process, which employs a conversational strategy to accommodate uncertainties [19]. We also conducted a brief exercise to familiarize the participants with the main task, which involved assigning experiences to individual materials and their contribution to the overall experiences of a product in a situational context. After ensuring their understanding, we handed over the design brief, and a material catalog, which included information about the technical and experiential characteristics of all identified materials. Before proceeding, participants had the opportunity to ask questions about the task. The design brief stated that the main task was to either design a concept for a product or system or devise a solution to improve the aesthetic features or functional experience of an existing product using the materials available in the catalog.

2.3 Experiment setup and measures

We conducted the experiments in a meeting room free from external distractions. We provided each participant with all the conventional tools necessary for sketching their design concepts, including a sketch pad, pencils, sharpener, eraser, ruler, and sticky notes. We allowed them to use the provided tools to express their concepts. The invigilator observed the participants' design activities, took notes continuously, and informed them that the process would take two hours. There were no restrictions during the concept design process. After the design activities, participants were required to fill out a self-reflective form while verbalizing the reason for certain responses and explaining their design concepts. Subsequently, based on the notes taken during the concept design process and the self-reflective form, we conducted a retrospective interview to gain further insights into the decision-making process and envision the experiential and functional aspects that constitute the participants final concepts.

2.4 Data collection and analysis

The participants filled out a self-reflective form and explained their design concepts and how they envisioned them for the intended user at four distinct levels of experience. We conducted retrospective interviews based on the insights gained from idea generation with inspiration, the application of emerging materials, the intended user's experiential evaluation, and the usefulness and novelty of the application. We quantitatively analyzed all the data from the self-reflective form to identify only those product concepts that demonstrate a sufficient understanding of how materials and products function in the envisioned scenarios. We achieved this by counting the number of experiences that each participant wrote down on their paper. An increased number of experience counts indicates that the participant had a deep understanding of the experiential aspect of the materials. Additionally, the product they proposed had a high experiential value, indicating more thought put into the concept. Conversely, those with fewer experience counts suggest that the participant either had a poor understanding of the experiential aspect of the materials and product or, even if they had a good understanding, their proposed concept product had a low experiential value, leading to the exclusion of their concepts. We examined the verbal protocol data recorded during the concept design experiment. For each successful concept, we asked the participant to describe the envisioned scenario and the experiences they thought the product would provide for the intended users on four levels: aesthetic (sensorial), interpretive, affective, and performative [2]. In order to extract valuable insights based on material understanding, we transcribed the interview data for qualitative analysis. We then generated a coding scheme and categorized the transcribed data into themes and subthemes. The following elements formed the foundation of the coding scheme:

- Basic decision-making process–the process of basic decision-making involves inspiration, integration consideration, product selection, and anticipating the expected outcome.
- Product experience–how will the user experience the product in the proposed environment and over time?
- Evaluation based on functional and experiential novelty–how they perceive their product as a valuable addition and a novel use of emerging materials.

3 RESULTS

3.1 Overall concept designs

The design participants envisioned products in an experiential manner based on the materials. The concept design experiment directly links the understanding of experiences elicited by the product with the understanding of material, which in turn relies on the identification of emerging materials. Based on the total experience counts provided by each participant in the self-reflective forms, we analyzed a total of 10 concept designs and only concepts with experience counts higher than the average across all levels of experiential value were considered for further study. Among them, the VR gaming suit, companion seat, health monitoring vest for the elderly, and stuff toy were selected for further study.

3.2 Selected concept designs

3.2.1 VR Gamming suit

The VR gaming suit is a concept that utilizes wearables on body joints to record muscle movement and replicate it in a virtual world environment. Body heat self-powers these sensors, requiring only raw stimuli signals to reach the main device. The headset has a 3D electrochromic soft photonic crystal display, ranging from transparency to full color, allowing users to interact with people in the immediate environment without taking off the headset. This allows for AR and VR in the same system, unlike other headsets like HoloLens, which only works for AR/XR applications. While other headsets such as Oculus, Meta Quest, and Apple Vision Pro can create fully virtual environments, they only offer pseudo-real XR in their later versions. The dynamic chromic property of 3D electrochromic soft photonic crystals enables the creation of a fully opaque VR environment and XR, which can be augmented with the real environment, thereby enhancing natural and direct interaction. Movement-based interaction is more natural with wearables than handheld remotes, and AI models can detect hand movements for certain controls. The concept also proposes a more artistic approach to processing, using a flexible R2R printed circuit that extends along the neck.

In sensorial experience, the material of this gaming suit will be flexible and soft for comfort, and it will be visible with the lights inside the glasses. It can also be transparent in ambient mode for interaction with the surrounding environment. The interpretive experience will completely transform the in-game interaction, making it a futuristic product. Its valuable materials will undoubtedly enable these advancements over traditional VR sets. The affective experience should instantly evoke a sense of coolness due to the headset's transparency feature, the ability to turn back to a fully colored screen to return to the virtual environment in a game or other VR experience, and the natural movement sensed by the other parts and replicated accordingly in the virtual game world. In the performative experience, the new layout will draw attention and stimulate game exploration. This could potentially motivate them to spread the word to their friends. They may ask about the sensing components' materials and the headset's creative circuitry. Curiosity may lead consumers to try competing items to duplicate this amazing experience.

3.2.2 Companion Seat

The companion seat concept is a flexible and transformable seating option that combines a friend-like object with various seating options. It is designed with a flexible composition layer that incorporates segments of electrochromic, photochromic, electromorphic, and photonic crystals. This layer reacts to electric, light, and pressure signals, changing color and texture accordingly. This creates a multisensory interaction between the user and the product and the environment around it. The product's colors are indeterminate and live-like, setting it apart from other products with built-in reactions controlled by computational models. Its reactivity to light results in chromic and morphic properties throughout the surface. Even if the user is not around or using the product, it remains receptive and reactive to its immediate environment. The transition from one color to another is non-binary, taking its natural time depending on the intensity of the lighting environment. These features make the user think about the environment for the companion seat even after leaving the space, potentially finding it in a different form depending on any odd changes in the environment.

In sensorial experience, people will perceive it as a soft, flexible round bag, similar to a beanbag, with color-changing properties. It will be sensitive to the lighting environment due to its photochromic/morphic materials, which will change color and texture based on the lighting conditions. Its size will be large enough to accommodate a person. In interpretive experience, it would be a very comfortable place to sit on, very friendly, expressive in a colorful way, and a warm, cozy, and soft thing to have around. In affective experience, it can react to its immediate environment without a human user, so it may not be in the same color and texture as before, which will interest the user in the material/surface and the memory foam will provide comfort. In performative experience, the memory foam and flexibility of the form allow the product to be perceived in various shapes, allowing the user to sit on it, use it as a supporting rest, or even stand or lean on it if we build a specific fixture with it to aid in standing. This allows for a welcoming exploration of different forms.

3.2.3 Health Monitoring Vest

A health monitoring vest is a wearable piece of clothing with flexible pressure sensors and a layer of TE paint for temperature sensing. It is connected to a server that connects it to potential stakeholders, such as caretakers of the elderly, who can stay informed about their health. This vest can empower the elderly and allow them to perform their jobs without worrying about their health. The vest's scalability makes it ideal for health monitoring in hospitals, eliminating the need for frequent visits by doctors. It can also be integrated with an AI model to provide doctors with information about a patient's recovery progress and identify emergency situations. This device is more suitable for wards where EMG electrodes are not suitable or needed, as it does not restrict normal movement. The vest is compared to a smartwatch, which is limited to the wrist and monitors confined variables. Conventional clothing like this vest can have a greater impact on health monitoring than specialized equipment, which may impose restrictions and create a sense of constant monitoring. However, the participant expressed uncertainty about the manageability of implementing conventional clothing, its durability, and the importance of considering comfort when wearing it.

In sensorial experience, from a sensory perspective, this vest should be soft, similar to any other fabric-based wearable. It should also fit snugly to enable the embedded sensors to detect bodily movement, feel warm to the touch, and potentially be blue or green in color if it is intended for hospital use. In interpretive experience, since it is a simple piece of clothing, the elderly should perceive it as something new, unique, and high-tech. Therefore, it should be lightweight and comfortable to wear at all times. In affective experience, for the elderly, receiving care from their son/daughter will be a delightful experience, while for the caretakers, being able to stay connected while away and ensure their elders' safety will bring a sense of relief. It may seem strange that a simple piece of clothing can monitor these things, but it will also serve a very functional purpose. In performative experience, in the long run, this will facilitate an active lifestyle for both the elders and the caretaker, as they will feel more connected to each other and find it easier to go out and away at times. The elders will feel special when they wear fancy, light, and unique clothing, which can empower them to spend time with themselves without worry.

3.2.4 Stuff toy

The product concept is a lifelike toy with 3D electrochromic soft photonic crystals that display different colors based on the pressure applied when hugged. This chromic property is powered by a printed battery that stores the charge from TE Paint generated by body heat/warmth. When the user hugs the toy, it converts the heat energy from the human body into electric energy, which powers the pressure-sensitive chromic property of the 3D soft photonic crystals. This concept resonates with the concept of emotional energy transfer when two loved ones hug each other. Hugging the toy increases its expressiveness by responding in the form of colors. However, it will not show any colors or be very colorful, indicating an emotional gap. Regular hugging is necessary to keep the toy energetic. This product represents a significant departure from conventional stuff toys that lack responsiveness to emotional acts. While some toys incorporate embedded music and lights, they typically respond in a binary or overly controlled manner, making them neither truly alive nor evoking a deeper sense of emotional attachment.

In sensorial experience, stuff toys need to have the sensory experience at the highest level for people to assume they have them, so this one will be cute-looking, smooth, and soft-surfaced, so it will be visually very appealing. In interpretive experience, it will be a cute thing to have; cute is a singular word that can collectively represent the blend of friendly, cozy, comfortable, and a factor of warmth in aesthetics and experience. In affective experience, the small (not tiny) form factor will make it easy to carry and keep close, the soft and rounded material will make the user feel comfortable, and hugging the stuff toy will relieve stress and show colors in the hug while charging the battery with body heat. Therefore, the process empowers both the user and the object, making it feel alive. In performative experience, the affective experience suggests that hugging and keeping the toy around can create an addictive sense of belonging and friendliness, leading people to keep it around and even bring it to bed. This practice not only keeps the toy alive but also alleviates stress for the user.

3.3 Results of thematic analysis

3.3.1 Inspiration for the product

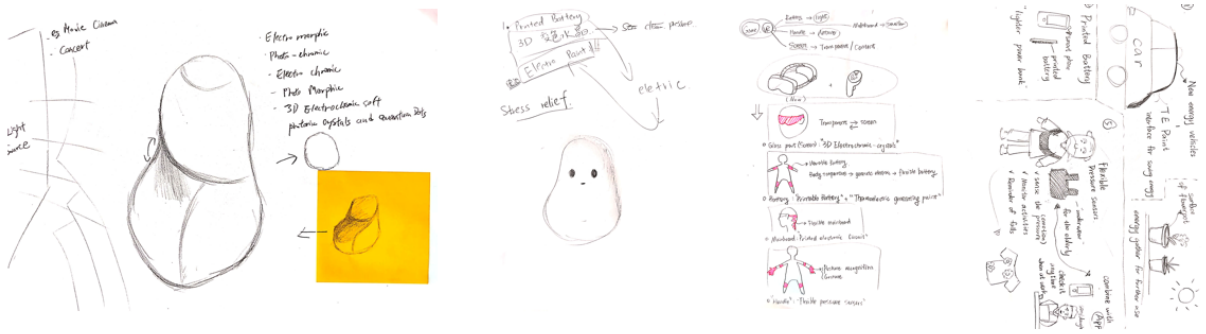
Two basic patterns were observed for inspiration: firstly, the process starts with a personal fascination, aiming to incorporate various materials into the objects of interest. Secondly, the focus shifts to the materials themselves, with the aim of identifying more effective applications. Three of the four successful concepts began with materials, and their unique properties triggered objects of personal interest or products they had previously experienced. However, only one concept—stuff toys—started from their personal interest in stuff toys, focusing on the materials' flexibility of application, which resonated with the toys' flexible behavior. At some level, this was also triggered by the unique property of the materials: flexibility of application. Later, the participant attempted to integrate the in-depth properties of the materials to enhance the object experience at different levels.

3.3.2 Envisioning experiential depth

It is fascinating to observe the patterns that emerge from this theme of envisioning the end user with the product. Two basic themes stand out here: Firstly, they serve as inspired or improved versions of existing products, and second, aspirational or innovative new products. All the successful product choices were derived from direct experience with similar products, such as VR gaming suits, stuff toys, and companion seats, or from their role as primary stakeholders in a specific problem, such as the health monitoring vest; even the later product was based on conventional clothing. They were able to better envision the end user's experience with the product due to the accessibility of the product's merits and demerits, which enabled them to understand current user sentiment and identify potential enhancements to improve the experience. They themselves had been the primary users of those existing products, so they were primary stakeholders in the former process to assess the experience in depth. Interestingly, all other product concepts that could not score experientially high enough as described by the participants were much more novel/new/innovative in nature, like bamboo rollable computers and cooking assistants, so it must have been hard to envision a user for products that did not exist before in a version close to the envisioned one.

3.3.3 Patterns of integration

Participants were free to integrate the materials in any way that best fit their concept. The integration patterns included incorporating these materials into IOT products, such as those connected to mobile applications or another server, general-purpose products like cooking aids, and entertainment items like toys. Here, two themes were emerged: the first was integration, supported by a computational model, and the second was integration within and as an analog medium. The first concept pertains to the integration of emerging materials, where a computational model either processes or stores data or responds instantly to external stimuli. The latter concept refers to a more natural integration of materials, known as analogue, where the material experience relies on its inherent behavior in response to specific external stimuli, independent of any computational model's control. It is worth mentioning that half of the concepts were based on a computational model: the VR gaming suit and the health monitoring vest. The materials acting as sensors would collect data, which would then be processed by the computational model, whereas the other two—the companion seat and the stuff toy—had the materials integrated to behave in their natural orientation. Interestingly, the later ones reported that their concepts exhibited behaviors akin to those of living things. The participants concept design sketches are presented in Figure 2 as an example.



Companion seat　　Stuff toy　　VR gaming suit　　Health monitoring vest

Figure 2. Participants' design sketches

4 CONCLUSIONS

This study aimed to apply the knowledge design participants gained about key emerging materials to develop potential product design concepts that leverage these materials' unique qualities to enhance the overall product experience. Previously, there was no definitive study demonstrating the feasibility of understanding and integrating materials for product design concepts. Engineering designers often synthesize materials based on proposed uses. This research established a foundation for designers to explore materials and integrate them into product designs. It can enhance product experiences and enable material makers to develop materials with a wider range of functional and experiential applications beyond mere specific functions. We initially evaluated the concept designs using a quantitative assessment of the participants' understanding of the process, focusing on the experiential value of their design concepts. We then conducted a qualitative analysis of the design concepts, focusing on those who had a thorough understanding of the process and material experiences. We focused on the themes of integrating emerging materials into new or existing products and exploring the types of experiences these materials bring to the final product design concepts. We discovered an intriguing method of utilizing materials as analog mediums to generate experiences based on their inherent behaviors rather than relying on a computational model for control. Despite the novelty and aspirational nature of the design concepts produced by design participants, there was a noticeable lack of confidence in them. Furthermore, we discovered themes of interactive experiences that evoked a sense of life, stemming from specific personal encounters and relying on the fusion of various materials to create a product that embodies life within a given context. These characteristics align with those previously discussed by Hobye and Ranten [20], Barati et al. [21], and Petreca et al. [22]. However, while these studies based their personal assumptions on the term "alive" for the product and processes, this study also provided empirical evidence for the existence of live experiences. We found a significant subjective difference in the way participants reported their work, based on their personal understanding of the levels of experiences. Some participants reported deeper experiences than others, which could potentially yield more value. Therefore, a more thorough and equitable evaluation is necessary to guide the future extension of this practice in a meaningful direction. Our future research will first expand this sample to gather more robust evidence about the designerly way of integrating these materials. Additionally, our aim is to gather actual material samples to explore the potential of integrating these materials as analog mediums to create naturally occurring experiences. Finally, our intention is to explore the integration of these materials with other materials to create a situational whole that interacts and exists in a lifelike manner. Subsequently, we aim to obtain expert evaluation and user testing of functional prototypes, as recommended by researchers for such aspirational product integrations. The current study has elucidated the process of understanding emerging materials to develop their integration patterns for product design concepts, taking into account the experience visions these materials convey, which can be incorporated into a final product in a variety of scenarios. We showcased our design activities, which aim to enhance the understanding of materials by integrating their technical properties and experiential qualities with the intended users' perceptions. These activities indicate that when materials exhibit diverse experiential characteristics and their integration becomes a crucial aspect of the design process, the designer must first understand the material's attributes and explore its experiencing dimensions. Subsequently, they must integrate these elements to create a vision of the material's experience, which they can then transform into a tangible product that aligns with various envisioned scenarios.

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RESEARCH ON THE DYNAMIC BSORM IMPACT PATHWAYS OF SENSE OF POWER IN CO-DESIGN

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ABSTRACT

Given the inherent characteristics and current state of co-design, the issue of power imbalance has become increasingly evident. This paper elucidates the impact pathways within co-design through qualitative research methods, and explores the potential role of the sense of power in addressing power imbalances. By examining four design workshops from Ant Group's "Lifestyle Research for Chinese Young People," this study identifies five key factors contributing to variations in individual sense of power: social status, knowledge level, resource control, self-positioning, and contextual background. Additionally, it outlines the dynamic BSORM paths that emerge from the interaction of different power perceptions within the collaborative process. The study further analyzes how fluctuations in sense of power at the individual, interpersonal, and organizational levels affect the overall outcomes of co-design. This research offers valuable insights for future quantitative studies on power dynamics in co-design, establishing a comprehensive framework for understanding the modifiable aspects of sense of power in this context.

Keywords: Sense of power, Co-design, Design workshop, Impact pathways

1 RESEARCH BACKGROUND

1.1 The problem of power imbalance in co-design is becoming apparent

Co-design refers to a process where participants from different disciplines, who are impacted by design decisions, share their knowledge relevant to the design content to become part of the decision-making process [1]. Typically, co-design activities are organized by one or more initiators with extensive design experience, guiding various stakeholders to collaborate.

Research suggests that the relationship between initiators and stakeholders in co-design involves the granting and receiving of power. However, both existing studies and practices have identified gradually emerging power issues in this context. First, the initiator holds and controls the majority of power, yet research indicates that this power is often excessive and its boundaries are poorly defined, especially in design decision-making [2]. Additionally, initiators tend to be constrained by existing power structures; for example, knowing stakeholders' social identities or knowledge levels in advance can limit the initiator's actions within the established power framework. Furthermore, initiators engage with individuals from multiple knowledge domains, making power delegation prone to misalignment or mismanagement. A more fundamental issue is the lack of design education and practice that addresses power dynamics, resulting in insufficient recognition of the importance of power [3].

Secondly, the majority of stakeholders are non-design professionals and lack the ability to translate their knowledge into design-specific knowledge, making them vulnerable to power marginalization, which diminishes their confidence and willingness to participate [4]. Furthermore, the temporary nature of co-design, coupled with unfamiliar interpersonal relationships between stakeholders, often leads to an imbalanced and unstable power structure, creating barriers and conflicts during the process of knowledge integration [5]. Additionally, stakeholders frequently have a lack of clarity regarding their roles in co-design, making it difficult for them to quickly adapt to the dynamic design process, which often results in them assuming a passive, bystander role [6].

1.2 Sense of power may become a breakthrough in solving the power imbalance

The initial power studies primarily focused on the macro-level aspects of sociology and political science and leaned towards qualitative research. Viewing power as a psychological cognitive variable has only emerged in the past 20-odd years, alongside the rise of social cognition research paradigms [7]. In the context of co-design, power can be understood as the ability of actors to influence outcomes, which is in line with the definition of power in psychology. Specifically, power in psychology is not actual power, but a sense of power. Sense of power can mediate the influence of all objective power. Sense of power cannot represent an individual's social status or actual power level [8], but it can affect the actual effect of power. At the same time, sense of power can turn power into a controllable psychological variable, which is both a relatively static and stable personal trait [9] and a situational variable [10]. In other words, even if individuals do not actually hold power, they may still develop a sense of power, and under the same conditions, the degree of power perception varies among different individuals; But when exposed to different situations, individuals may also experience subjective feelings of "great power" or "little power" due to environmental stimuli [11].

Based on this, it can be inferred that different stakeholders in co-design may possess varying initial sense of power due to personal characteristics within the given context. This initial power perception influences their ability to participate in co-design activities and ultimately affects the outcomes of the design process. For example, high-power individuals are more sincere in expressing suggestions [12] and tend to actively participate in competitive social interactions [13], while low-power individuals consider others' feelings more when making decisions and have more empathy [14]. It is evident that low and high power perceptions possess different practical advantages, necessitating regulation based on various tasks. Therefore, power perception enables the possibility of power regulation.

2 A FRAMEWORK OF IMPACT PATHWAYS FOR SENSE OF POWER IN CO-DESIGN

Co-design generally has a temporary nature, and the stakeholders involved have different initial sense of power, which reflects personal traits in this context. The 'self-construction hypothesis' proposed by Lee suggests that individuals in different states of power adopt different self-construction approaches. He found in the experiment that participants with high sense of power were more inclined to adopt independent self-construction methods, while participants with low sense of power tended to utilize more dependent self-construction methods [15], [16], [17]. Therefore, due to varying levels of power perception, individuals utilize different types of self-construction approaches, which can lead to differences in individual sense of power in co-design. The interaction of various environmental factors in co-design can also affect the self-construction effects of individuals with high or low sense of power. When entering a co-design scenario, the sense of power triggers situational attributes. As the organizational model and activities of the co-design evolve, this sense of power may shift. For instance, individuals with a consistently high sense of power may maintain this elevated level, influencing others' power perceptions and potentially causing a decline or instability in others' sense of power. Existing research shows that individuals with high power are less likely to empathize, often displaying disregard for others' feelings and giving less consideration to alternative perspectives [14], [18]. Additionally, the agentic-communal model suggests that individuals with a high sense of power focus more on self-expression, self-enhancement, and self-protection. In contrast, those with a low sense of power are more concerned with their relationships with others and are more likely to consider others' feelings when making decisions [19]. Consequently, shifts in stakeholders' sense of power influence their attitudes and behaviors in co-design, while the design process itself dynamically evolves in response to these varied behaviors, further impacting others' sense of power. This feedback loop ultimately affects the overall effectiveness of the co-design.

Based on the above, as illustrated in Figure 1, when stakeholders with different initial sense of power enter the relevant context of collaborative design, interactions and collisions occur between them due to the organizational model or activity content of collaborative design. This leads to changes in their sense of power, which in turn affects stakeholders' performance in collaborative design, creating a cyclical influence that ultimately impacts the outputs of collaborative design.

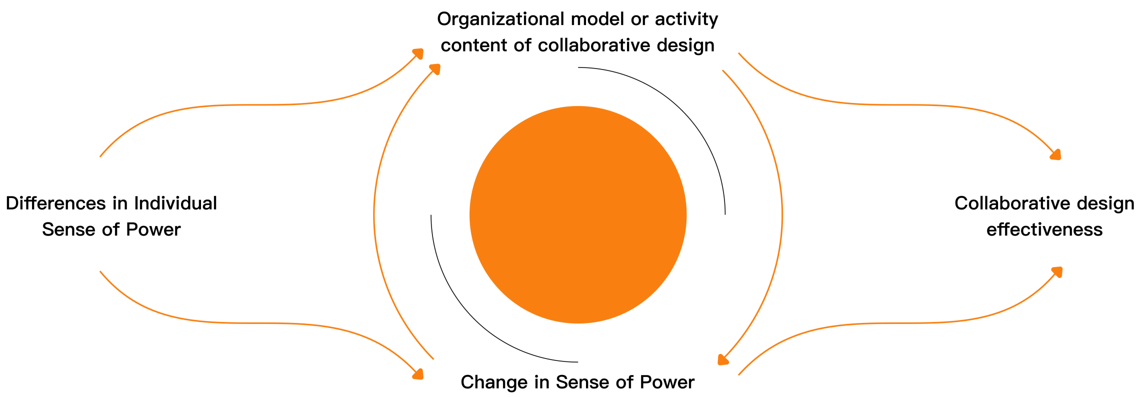

Figure 1. Diagram of The Framework of Impact Pathways for Sense of Power in Co-Design

3 ANALYZING THE INFLUENCE MECHANISM OF SENSE OF POWER USING DESIGN WORKSHOP AS AN EXAMPLE

Design workshops are one of the primary organizational formats for co-design. To clarify the impact pathways of the sense of power in co-design, this study focuses on the "Lifestyle Research for Chinese Young People" project. The project, organized by Ant Group, Tongji University, Guangdong University of Technology, and other institutions, was conducted from February to October 2024. Several design workshops were held at different stages of the project. This study focuses on four design workshops, where linguistic recordings and behavioral observations of participants are conducted. Through cross-validation and reflection on participants' language and behavior, the study identifies the representational meanings of their actions and speech. Subsequently, the information gathered from the workshops is integrated and analyzed to extract key features. Participants exhibiting prominent characteristics are selected for in-depth interviews, which further validate and refine these features. Finally, expert discussions are held to establish the final impact pathways. Table 1 provides details of the four workshops：

Table 1. Details of the Design Workshops

Design Workshops	Workshop Theme	Participants	Workshop Objectives	Workshop Organization Method
W1: Practical Workshop Location: Guangzhou, China	Co-creation Workshop for the Lifestyle Experiment Toolkit	Design experts, novice designers, and target users from various fields (including youth from first- and second-tier cities as well as youth from third- and fourth-tier county-level cities)	Based on the established framework for analyzing fundamental lifestyle patterns, we consolidate the life journeys of target users from various domains and utilize design-related methods to derive the form and components of the toolkit	The facilitator manages the process while design experts ensure information quality, guiding stakeholders in articulating their life contexts and offering suggestions for toolkit design
W2: Consensus-based Workshop Location: Shanghai, China	Lifestyle Characteristics and User Profiles of Chinese Young People	Representatives from four different universities in China, including design students, design instructors, and design experts	Conduct a common analysis of the information gathered from the four locations to distill the lifestyle characteristics and representative user profiles of Chinese youth	Design experts and representatives from various universities established the methods and criteria for information synthesis, guiding students from different regions to employ design thinking for feature extraction
W3: Training Workshop Location:	Training on Lifestyle System Research	Students from different grades and design majors in universities	Conduct teaching training on the newly developed innovative lifestyle system research	Students are randomly grouped and paired with teaching assistants for training in foundational knowledge

Tianjin, China; Xi'an, China	Methods	(including user research, industrial design, etc.), as well as design experts	method to validate the teaching effectiveness and feasibility of the new approach	and research methods
W4: Integrative Workshop Location: Shanghai, China	Exploring Potential Development Directions for Alipay Based on Young People's Lifestyles	Design experts, designers, representatives from Ant Group's product development team, and design students	Based on the lifestyle characteristics of Chinese young people, integrate their living needs with the service segments of Alipay to propose potential development directions for the platform	The designers present the concluding report, followed by R&D representatives who speak in a designated order to discuss their viewpoints, outline the necessary resources for development, and explore the feasibility of the proposed developments

3.1 The problem of power imbalance in co-design is becoming apparent

Generally, individuals tend to have a relatively fixed sense of power, which may fluctuate in different contexts. Through the observation and analysis of four workshops, it can be concluded that there are five reasons that contribute to individuals experiencing either a higher or lower sense of power in co-design:

3.1.1 Social status

In co-design, individuals with higher social status are characterized by greater familiarity within the temporarily assembled team and higher recognition from other stakeholders. This recognition enables them to receive more interpersonal support throughout various stages of co-design, particularly during decision-making. Consequently, individuals with higher social status tend to exhibit a stronger sense of power. The participants in W2 were largely recruited by or through design experts, and both design students and teachers demonstrated strong identification with these experts. Prior to W2, the design experts had already formed expectations or directions regarding the lifestyle characteristics and user profiles of young people distilled from the workshop. This made it easier for them to position themselves as facilitators or leaders, thus reinforcing their sense of power. Other participants, especially the design students, acted more as executors, responsible primarily for documentation and information verification. As a result, during verbal exchanges, design experts were frequently asked whether "a particular characteristic was accurately expressed" or prompted with affirming questions such as "I believe this characteristic is more appropriate, don't you think?" Spatially, design experts also tended to occupy central positions, as illustrated in Figure 2.

Figure 2. W2 Scenario Diagram

3.1.2 Knowledge level

In co-design, when social status is relatively equal, knowledge levels can influence an individual's sense of power. This is particularly evident when designers collaborate with non-designers. Designers, operating in their area of expertise, tend to display greater confidence and self-efficacy, while non-designers, lacking the ability to translate design concepts, often find themselves in situations where they only address minor, non-design-related questions. For instance, in W1, non-design participants, who were target users from various fields, rarely engaged in discussions during the concrete expression of life narratives. They only responded passively when asked specific questions, such as whether they exhibited certain behaviors or if a particular design element aligned with their understanding. Additionally, during the design of lifestyle experiment toolkits, while all parties participated equally, the suggestions from non-designers were less frequently adopted, as illustrated in Figure 3. Therefore, the level of design knowledge an individual possesses to some extent determines their ability to contribute to co-design. When their capabilities are not utilized or their input is not actively considered, their sense of power diminishes, and conversely, it increases when their contributions are acknowledged.

Figure 3. W1 Scenario Diagram

3.1.3 Resource control

In co-design, resource control refers to an individual's possession of various resources that can facilitate the implementation of design solutions, including human resources, land resources, and market resources. The output of these resources ultimately determines the value and feasibility of the design outcomes, leading individuals who control more resources to exhibit greater decision-making authority during the design payment phase. Even if they are not designers, these individuals can influence resource allocation based on their own interests or may possess stronger capabilities in project execution compared to designers. In other words, despite potentially having lower levels of design knowledge, the resources they control can afford them a significant sense of power in critical design stages. In W4, the speaking order was led by the R&D manager, followed by design experts, and finally the designers. The R&D manager and design experts, possessing Alipay's market and talent resources, exhibited a greater sense of power in decision-making regarding design direction. In contrast, designers, as the implementers of these resources, displayed more passive behavior, operating within the constraints of the available resources, which resulted in a lower sense of power.

3.1.4 Self-positioning

In co-design, self-positioning refers to how individuals perceive their own design roles, which encompasses their sense of control or autonomy over the design project, as well as their psychological state during the collaborative process. This self-positioning can predispose individuals to experience a heightened sense of power. For instance, in W2, design students from the same school exhibited varying degrees of control over the project based on their level of involvement. Students involved in the framework demonstrated a stronger sense of design responsibility and were more willing to engage with design experts regarding user details, reflecting a higher sense of power. Similarly, in W3, both design students and teaching assistants, although all design students, displayed differences in their sense of power due to their distinct roles in the co-design process. For example, the facilitator indicated that both design and non-design students needed to follow the teaching assistant's guidance when practicing lifestyle research methods. Consequently, students naturally sought advice from the teaching assistant and rarely questioned the instructions, exhibiting compliant behavior.

3.1.5 Contextual background

In co-design, cultural background refers to an individual's broader cultural context, separate from the design workshop itself, encompassing their work, educational, and social backgrounds. Individuals develop ingrained perceptions within their established contextual systems, and these perceptions influence their sense of power through comparisons with others. For example, in W3, students with more knowledge about lifestyle-related information would typically possess a higher sense of power. However, due to the higher recognition of other students' educational backgrounds, their willingness to express opinions was affected. They might use phrases like "I'm not sure" or "maybe," or even restrain their behavior to avoid communication, thus experiencing a lower sense of power.

3.2 BSORM: The dynamic changes of sense of power in co-design process

During the four design workshops, this study analyzed the participants' sense of power by examining their language, behavior, and interactions. The following are the types of changes in sense of power that may occur during the design workshop process, which can be understood by referring to Figure 4:

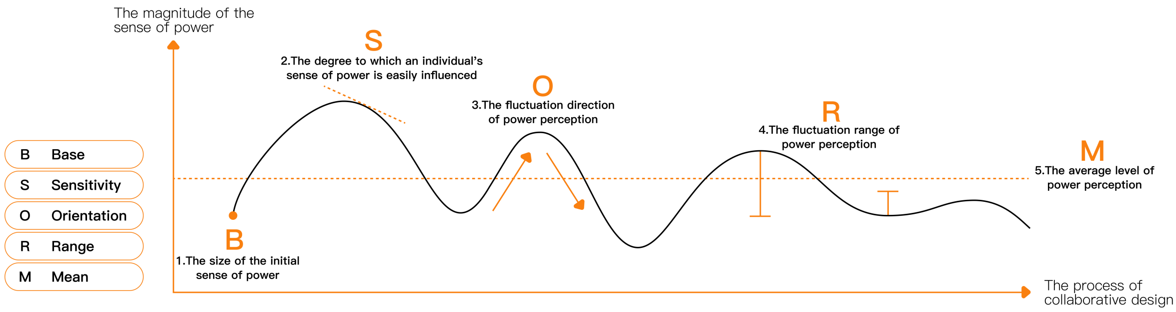

Figure 4. Types of Changes in Sense of Power Diagram

3.2.1 Base:The size of the initial sense of power

Before the formal commencement of each workshop, the facilitator typically introduces the identities of the participants. Each participant independently constructs the power structure of the workshop and assigns themselves a tentative position, thereby forming an initial sense of power. This initial sense remains stable until influencing factors emerge, leading to behaviors inconsistent with their sense of power, at this point, their sense of power begins to fluctuate.

3.2.2 Sensitivity:The degree to which an individual's sense of power is easily influenced

The extent to which an individual's sense of power is susceptible to influence is more closely related to personal traits. For instance, in W2, if both students' remarks are simultaneously challenged by the design expert, the more confident student is likely to give more affirmative responses, while the less confident student may tend to remain silent or interrupt, even if their internal responses to the issue are fundamentally similar. Therefore, in a co-design environment, even if individuals start with a similar sense of power, their susceptibility to influence differs, resulting in variations in their expressions during the co-design process.

3.2.3 Orientation：The fluctuation direction of power perception

An increase or decrease in an individual's sense of power can influence participants' performances, which is related to the stimuli provided by various contextual factors during the co-design process. For example, in W3, if an individual's viewpoint receives group affirmation, their sense of power will rise at that moment, leading them to repeat the viewpoint and seek further validation. Conversely, if an individual's remarks are ignored or refuted, their sense of power may decline, resulting in a tendency to cease speaking. Therefore, in co-design, different stimuli can potentially affect the direction of fluctuations in an individual's sense of power.

3.2.4 Range：The fluctuation range of power perception

The magnitude of fluctuations in an individual's sense of power represents the frequency or number of stimuli the individual experiences in co-design. When an individual receives continuous positive stimuli, the increase in their sense of power will be greater and last longer. Before the occurrence of negative stimuli, this can lead to observable behavioral differences at different stages. Therefore, during the co-design process, the sense of power will exert different influences on participants' behaviors at different stages, a phenomenon that occurs frequently in W1.

3.2.5 Mean：The average level of power perception

Even though various uncontrollable factors in co-design can cause fluctuations in an individual's sense of power, overall, participants with a higher average sense of power tend to exhibit differences in behavior compared to those with a lower average sense of power. For instance, participants with a higher average sense of power may show a decrease in their sense of power at certain points. However, their overall speaking style and frequency of participation in decision-making still differ from those with a lower average sense of power. For example, in W4, design experts and designers illustrate these contrasting behaviors.

3.3 The Influence of sense of power on individual performance in co-design

From the previous analysis, it can be seen that in co-design, individuals' sense of power will fluctuate, thereby affecting their ability to participate in co-design. Co-design is an activity about knowledge, so fluctuations in sense of power will affect the knowledge-related effectiveness of co-design. This article analyzes the performance differences of participants within and between groups during multi-line tasks in a workshop and clarifies the impact of sense of power on individual performance from three aspects: personal, interpersonal, and organizational.

3.3.1 Personal level

During the entire co-design process, individuals have two types of knowledge roles, namely knowledge providers and knowledge receivers. As knowledge providers, individuals contribute knowledge, and fluctuations in their sense of power can affect their attitudes, willingness, and behavior toward knowledge contribution. Specifically, individuals with a high sense of power demonstrate a higher sense of design efficacy and confidence in their knowledge output, while those with a low sense of power perceive their importance in co-design with the encouragement and recognition of others, thereby enhancing their desire to express themselves.

When acting as a knowledge recipient, individuals tend to adopt knowledge, and fluctuations in their sense of power can affect their attitudes, willingness, and behavior toward knowledge adoption. Specifically, individuals with a high sense of power may exhibit more prosocial behavior and be more open to the adoption of knowledge in certain situations, but they may also develop a rejection of external information due to the instability of their high-state sense of power; Low power individuals have higher empathy, are more tolerant of emotional information, and rely on external information for their own knowledge supplementation, thus exhibiting higher knowledge adoption.

3.3.2 Interpersonal level

Individuals engage in knowledge sharing through the output and input of knowledge among various parties in the co-design process, emphasizing the mode of knowledge interaction between individuals. The fluctuation of individual power will affect the motivation for knowledge sharing, and thus influence the attitudes and behaviors for knowledge sharing. Specifically, individuals with a high sense of power have a higher level of communication confidence in the process of knowledge interaction, especially in the decision-making stage, and therefore demonstrate a higher frequency of speaking and positive expression. However, individuals with a low sense of power may exhibit more spontaneous knowledge-sharing behaviors due to their high task dependency, or to avoid conflicts, they may split group tasks and avoid knowledge-sharing.

3.3.3 Organizational level

Whether it is knowledge adoption and contribution at the individual level or knowledge sharing at the interpersonal level, all of these factors ultimately influence knowledge conversion at the organizational level. The emphasis here is on the degree to which various forms of knowledge are transformed into design knowledge. Comparative analysis reveals that significant disparities in the sense of power within the same group can lead to polarization among participants, resulting in a clear division between a core discussion group and a peripheral group. In such cases, design knowledge occupies the highest domain, while opportunities for converting other types of knowledge diminish. Alternatively, frequent fluctuations in the sense of power can cause participants to remain in an unstable state, even leading to self-doubt, which destabilizes the overall collaborative model and results in fragmented or non-convergent knowledge conversion.

4 THE IMPACT PATHWAYS AND KEY FACTORS OF SENSE OF POWER IN CO-DESIGN

In summary, the impact mechanisms and key factors of the sense of power in co-design are illustrated in Figure 5. Individual differences in participants' sense of power stem from factors such as social status, knowledge level, resource control, self-positioning, and contextual background. These factors are interdependent; they may interact and vary in levels and combinations within individuals. Such inherent

characteristics influence both the initial sense of power experienced during co-design and its susceptibility to external influences. Additionally, within co-design, different organizational models and activity types continuously stimulate individuals' sense of power, leading to fluctuations of varying directions and magnitudes, which subsequently affect individual performance. This dynamic also influences the organizational methods and components of co-design. Overall differences and performance among individuals can be analyzed based on the average sense of power. Finally, the dynamic fluctuations of sense of power, trigger a chain reaction affecting knowledge contribution and adoption at the individual level, knowledge sharing at the interpersonal level, and ultimately knowledge conversion at the organizational level, thus influencing the overall effectiveness of co-design.
This study, from a theoretical perspective, employs qualitative research to analyze and deduce the degrees of influence and impact pathways among various factors in co-design. Subsequent quantitative research could further explore and validate these findings, offering clearer directions for studying the mechanisms and significance of the sense of power in co-design. Moreover, it introduces a new perspective for addressing power-related challenges in co-design contexts. From a practical perspective, assuming the manipulability of the sense of power, quantitative validation could help identify methods of manipulation, regulation scope, and related mechanisms in co-design scenarios. These findings could support the establishment of standardized organizational principles and guidelines, enhance education on power dynamics, and formalize training for co-design practices. Ultimately, such efforts aim to improve the overall effectiveness of co-design processes.

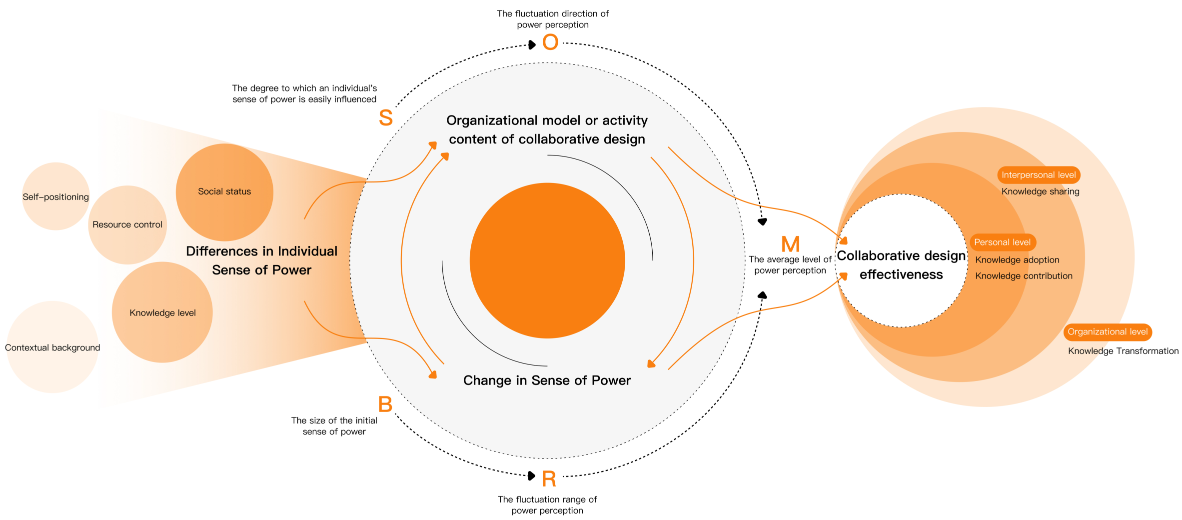

Figure 5. Diagram of the impact pathways and Key Factors of Sense of Power in co-design

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AI FOR CREATIVE DESIGN PROCESSES: ITS CURRENT STATE AND CHALLENGES

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ABSTRACT
This paper addresses a current technological status and issues of generative AI by applying an implementation example of using AI to the new design of an automobile part by metal die casting technology. This paper also indicated that it is difficult to eliminate erroneous output from an AI that has been fed unreliable data by using Attention technology by Transformer to infer and respond to frequently occurring descriptions from data fed into the AI. In order to reduce hallucination, it is possible to make inferences while considering statistical fluctuations and uncertainties that humans are not good at by using a foundation model that has learned only from in-house data that has full knowledge of the background of the data acquisition for inference. On the other hand, the issue of the need to incorporate hardware implementation into the system due to increased power consumption.

Keywords: Generative AI, AI Assisted Design, Foundation Model, In House Data, Inference

1 INTRODUCTION: THE RISE OF GENERATIVE AI AND CURRENT TRENDS

In November 2022, OpenAI made their generative AI, ChatGPT [1], available for free, marking 2023 as a year when the potential of AI gained widespread recognition. ChatGPT, which interacts as if it understands human language, raised expectations for increasing productivity in design. However, it also highlighted the problem of AI making mistakes when retrieving data, known as "hallucination." This occurs because generative AI learns from large databases based on frequency and context, but it cannot recognize its own errors.

At the same time, there were notable attempts to use AI in creative fields. For instance, an author of a novel that won the 170th Akutagawa Prize mentioned they used AI to assist in some parts of the creative process [2]. Similarly, software capable of generating artistic illustrations and turning them into videos gained popularity. In the JSME Design Engineering and Systems Department, research on the integration of AI in design is actively being reported [3]. In this context, we aim to summarize the current state and future outlook of how AI can be applied to the early stages of the creative process in design as of March 2024.

2 HISTORY OF GENERATIVE AI AND ITS POTENTIAL IN CREATIVE DESIGN

ChatGPT, a representative example of generative AI, is based on a large language model (LLM) [4]. It uses semi-supervised learning with efficient parallel algorithms, allowing it to generate high-quality outputs with minimal training. This enables AI to respond to natural, conversational instructions. However, product design is a process where manufacturers are held responsible for their outputs, making the application of generative AI still a developing area. The problem of hallucination arises because AI generates responses based on the frequency of data it has learned from, making it difficult to avoid errors when the input data is not reliable.

The underlying technology of generative AI, such as Transformers with an attention mechanism [5], shows that AI does not have logical thinking capabilities. It simply predicts what might appear most frequently based on the data it has read. There has been serious discussion about the rapid development of AI and whether it might become so advanced that it competes with humans, raising concerns about a potential future where robots with Artificial General Intelligence (AGI) pose risks to humanity. For example, OpenAI's board of directors expressed concerns about the rapid development of AI, advocating for slowing down progress and implementing regulations, which led to the temporary dismissal of CEO Samuel H. Altman [6]. However, Altman soon returned to his position, and his approach—accepting that generative AI still makes mistakes and that humans are much smarter—gained support.

Generative AI saw increasing use in creating literary works, artistic illustrations, videos, and music throughout 2023. In product design processes, there is potential for applying generative AI in areas where manufacturers are not directly responsible. For example, AI can be used to generate concepts for mechanical movements, discover combinations of ideas, or create visual prototypes for aesthetic purposes. Designers can then use these AI-generated suggestions to incorporate knowledge beyond their expertise, leading to a diverse range of ideas. When AI-generated ideas differ from the designer's idea, they can be used as valuable references, offering an effective way to enhance creativity.

3 OUTLOOK ON DESIGN METHODS THAT LEVERAGE AI

In the design engineering division of JSME, the concept of "design methods that leverage AI" has been proposed in technical roadmaps [7]. This paper tries to explore the possibilities of these methods based on the advances in generative AI seen in 2023.

For practical application of generative AI in design, reliable output is necessary. As of 2024, NVIDIA, a leading company in GPU design, reported a shift in AI processing from training large language models to performing inference (making predictions) [8]. This signals that the spotlight is beginning to shift to inference, where domain-specific models are trained using accurate and reliable data from companies and other organizations. LLM excels at obtaining responses based on reliable and solid data in areas that the designer or their organization does not have (but that are well known in a particular field), and this is thought to be an application where generative AI can truly demonstrate its capabilities. Examples of reliable and reliable large amounts of data include general ledgers and statements in financial statements, electronic medical records and prescriptions in medical care, statements in repairs and insurance, measurement data in maintenance diagnosis, and contracts in logistics. In the field of design, designs that utilize measurement data from devices owned by customers, data from manufacturing processes, actual feedback from lead users, and data obtained from equipment in use are conceivable. In the future, we can imagine a hallucination-free world by incorporating reliable, unique data to be referenced in design into a foundational model, and providing support with rapid output based on instructions in everyday language. Since generative AI operates on the logic of scale, it is possible to use generative AI to support decision-making in the upstream design stage, such as objectively supporting customer needs, ensuring marketability, and objectively verifying the validity of improved design proposals, especially in the design of products with many touchpoints with customers for which reliable data is easy to obtain (e.g., automobiles and smartphones).

4 AN EXAMPLE OF AI ASSISTED DESIGN AND MANUFACTURING METHOD 1: CASTING PROCESS

Figure 1 illustrates a foundational model for manufacturing automotive suspension parts through casting. The model incorporates real-world data, such as the temperature of molten steel during the casting process, the carbon and silicon content, the temperature at the time of pouring, and the elapsed time since magnesium bubbling. By training this model with reliable, measured data, statistical inference can be applied to reduce the occurrence of hallucinations. The diagram also highlights the models for materials, molds, and operators involved in the casting process.

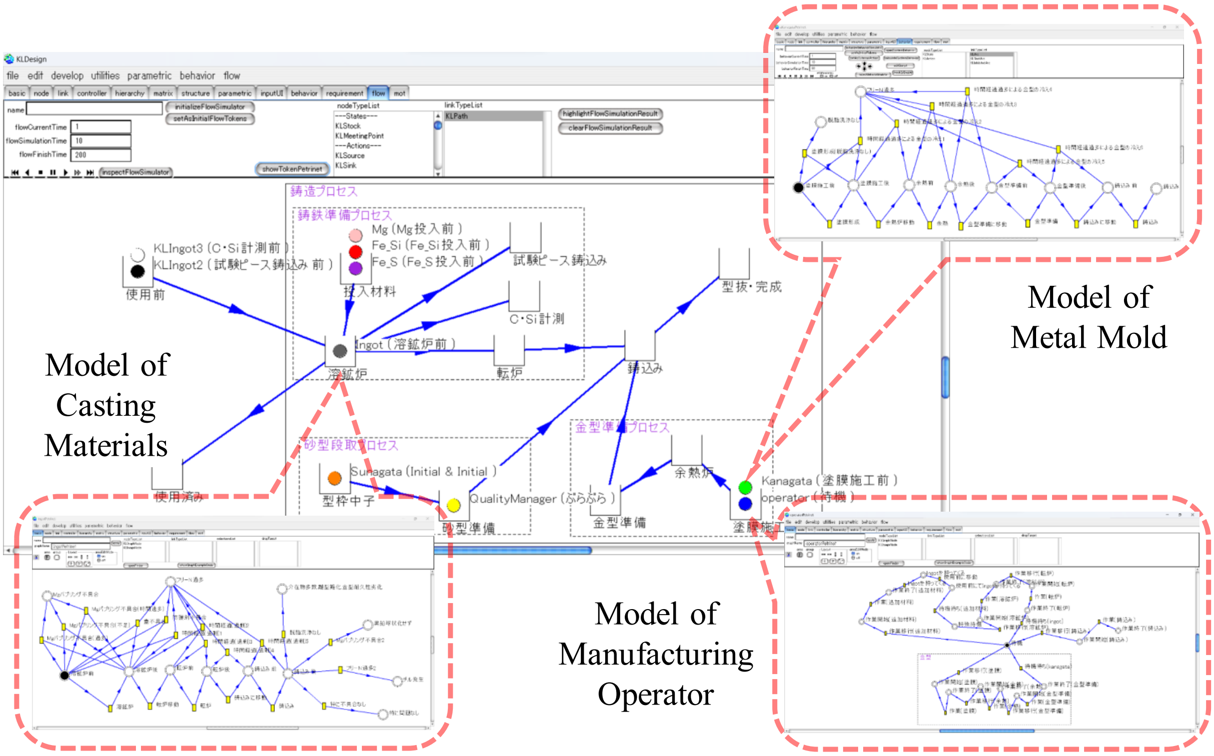

Figure 1. AI integrated manufacturing process of metal casting of automobile suspension component

5 AN IMPLEMENTATION OF AI ASSISTED DESIGN AND MANUFACTURING METHOD

Figure 2 shows the architecture of an inference system that uses AI in the casting process. Data collected by sensors during the process is stored in a data center on an AI server, where it undergoes parallel computation for training. The AI server consists of a learning section powered by GPUs and a memory storage unit (data center). The terminals used by operators in the casting process, referred to as AI edges, contain components that understand human language and locate relevant information based on user requests. By utilizing the language capabilities of generative AI, users can interact with the AI edge in their native language.

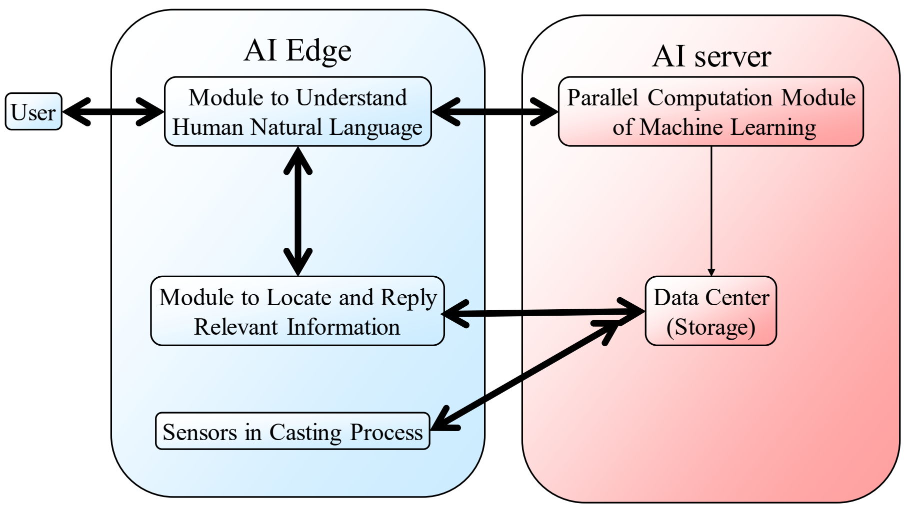

Figure 2. Server and Edge Configuration of the AI integrated manufacturing process of metal casting

6 DISCUSSION ON PROPOSED AI-ACCELERATED DESIGN METHOD

Based on these implementation and experiment study, this paper found an issue to consider which is the increasing power consumption of data centers filled with high-performance GPUs. By implementing AI as specialized semiconductor circuits, known as hardware acceleration or hard-wired technology, it is possible to perform tasks more efficiently and with less energy. This would enable the design of products with AI that operates locally on the user's device, rather than relying on centralized data centers.

7 CONCLUSION: AI AS A SIDEKICK OF THE CREATIVE DESIGN ENGINEER

In the second half of 2023, Gemini and Anthropic AI were released as generative AIs following ChatGPT, and competition between generative AIs began. The author was surprised that the usability of Anthropic A.I., which is supposed to be the latest, is comparable to that of the two leading companies, although there are differences in benchmarks. This suggests that the stage for providers of generative AI has moved from monopoly to competition, and further development through friendly competition between generative AIs is expected in the future.

This paper was written entirely by the author without using any generative AI, although such an era may be coming to an end. In fact, when the author entered this paper, including all references, into a generative AI and asked for its feedback, the generative AI gave the author specific comments on the following points: Are the cited references appropriate? Are the necessary technologies accurately explained? Are easy-to-understand concrete examples given? Are there any insights that are useful to design engineering experts? These were very helpful. In this way, this paper can foresee a future in which AI will play the role of a sidekick that is close to designers and immediately points out good points and areas for improvement, enhancing the creativity of designers. This paper would also like to note that AI is evolving very quickly and may become commonplace for future readers.

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APPLICATION STRATEGY ANALYSIS AND PRACTICAL SUGGESTIONS OF GENERATIVE AI IN SERVICE DESIGN

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ABSTRACT
A systematic literature review reveals that the role of AI tools in service design has been widely studied. Generative AI can significantly improve design efficiency in multiple stages of service design, specifically in service context, service demand insight, service design, and design execution. However, given the limitations of AI in emotional expression and complex decision-making, human participation in service design is still indispensable. In this context, the possible ways of AI-designer collaboration in each stage of service design are herein proposed, and future directions of research are put forward at the same time. It is asserted that a balance needs to be struck between efficiency and empathy and AI should serve as a complement instead of a replacement.

Keywords: Service Design, Service Demand Insight, Human-machine Collaboration, Design Innovation, Application Strategy

1 INTRODUCTION

Service design involves emotional needs and humanistic care and the globally wide development of artificial intelligence (AI) is significantly changing the way of service design and user experiences. Whether in health, retail, transportation or culture, AI technology has become the core driving force for innovation and optimization of services. Especially in the post-epidemic era, enterprises and institutions face tremendous digital transformation pressure. How to improve service quality, efficiency and user satisfaction through AI has become a key issue that needs to be urgently addressed. Based on this wide range of social needs, this study aims to explore how AI-driven service design can play a role in different stages of service design through systematic literature analysis and theoretical model construction, and put forward corresponding design strategies and application suggestions. To achieve the research objectives, this study has the following three specific objectives:

1. Analyze the specific stages in which generative artificial intelligence plays a role in the service design process. Clarify the specific application scenarios and action mechanisms of generative artificial intelligence in each stage.
2. Explore the advantages and limitations of artificial intelligence in different stages of service design. Analyze the advantages of generative artificial intelligence in a service context, demand insight, design generation and execution and at the same time explore its limitations in data accuracy, user experience, and design innovation.
3. Provide suggestions for service designers to integrate generative artificial intelligence into the design process. Based on literature analysis and practical cases, provide practical suggestions on effective application of generative artificial intelligence tools in the service design process so as to improve design efficiency and user experience.

2 LITERATURE SEARCH AND SCREENING

2.1 Research background and significance accessibility

The keywords ‘Generative AI’, ‘Service Design’, and ‘Human-AI Collaboration’ were combined with the help of Boolean operators to comprehensively cover relevant aspects of AI applications in service design. Databases include Web of Science, Google Scholar, IEEE Xplore, Springer, Scopus, etc., as well as industry reports and white papers, with a special focus on the application of generative AI in service design.

2.2 Search strategy

Boolean logic (AND, OR, NOT) is used to combine keywords and expand the search scope. Specifically, ‘Generative AI’ AND ‘Service Design’ were used to focus on AI applications in design contexts while ‘Human-AI Collaboration’ was included to ensure the coverage of collaborative design.

2.3 Literature screening and inclusion criteria

The screening process for the literature review was conducted in two stages to ensure the selection of high-quality and relevant studies.

In the first stage, a preliminary screening was performed based on titles and abstracts to identify studies in accordance with the following criteria: (1) published within the last five years, (2) peer-reviewed, and (3) focused on the application of AI within the service design process. This initial stage resulted in the identification of 66 potential documents.

In the second stage, a more detailed review of the full texts was conducted to further refine the selection based on relevance and quality. Articles were excluded if they were found to be (1) retracted, (2) not directly related to design fields, or (3) mentioned AI only in general terms as a prospective tool or approach without any specific applications within service design contexts. This second round screening ultimately led to a final set of 56 papers that are in line with our research objectives.

3 THEORETICAL AND MODEL BASIS OF LITERATURE ANALYSIS

3.1 Characteristics and principles of service design

Service design is a systematic, interdisciplinary approach that spans the entire process from understanding user needs to delivering final services, focusing on optimizing touchpoints and processes to enhance user experience [1]. It emphasizes being people-oriented, co-creative, holistic, visualized, and evidencing. These principles advocate for user-centeredness, stakeholder collaboration, a focus on the entire service journey, and the use of visual tools to simplify complex processes and convey service value. When combined with generative AI, these principles provide a framework where technology serves as a means to achieve design goals rather than overshadowing the human-centered approach.

3.2 Human-AI co-creation

The Human-AI Co-creation model points AI as a collaborative partner in the design process with its data processing and generative capabilities to support designers in creative generation and decision-making. [2] This collaboration works at different stages. The Human-AI Co-creation Model proposed by Wu et al. [3] categorizes the collaboration between AI and human designers into three stages: assistance, enhancement, and collaboration. In the assistance stage, AI supports decision-making while designers maintain full control over the outcomes. In the enhancement stage, AI actively contributes ideas and solutions to augment the design process. Finally, the collaboration stage represents a synergistic relationship where AI adapts based on designer preferences, enabling continuous co-creation and iterative refinement [3]. The collaborative effect between human creativity and AI’s analytical power allows designers to generate and refine design solutions timely with higher efficiency and greater innovation. In light of these theories, this study aims to investigate the integration of generative AI at different stages of service design and explore its practical applications and impact on the design process.

3.3 General strategic process model of service design

The model proposed by Zhang and Hu [4] is a foundational framework that outlines the strategic process of service design through four stages: service context, service demand insight, service design, and design execution (Figure 1). The model not only structures the service design process in a clear, user-centered progression but also emphasizes cross-disciplinary collaboration and continuous optimization to enhance user value. Its representation of the service design process—from initial market analysis to final execution—offers a comprehensive view that helps designers systematically address user needs at each stage. Additionally, by examining service design across time and type dimensions, the model provides both an analytical and organizational approach and enables designers to deconstruct and reconstruct service processes for innovation and management improvement. In this sense, this structured multidimensional approach may be conducive to the integration of AI into each phase.

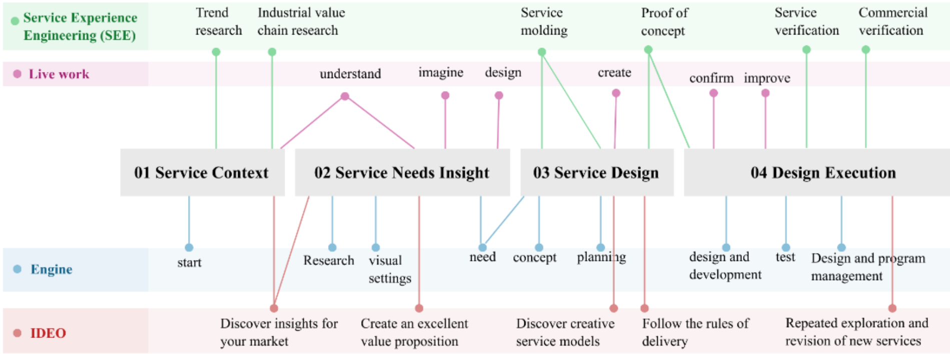

Figure 1. General strategic process of service design. From [4] with translation by the author.

4 MODEL-BASED LITERATURE CLASSIFICATION AND ANALYSIS

The above-mentioned model is used herein as a framework to classify literature and explore the application and intervention of artificial intelligence (AI) in various stages of service design. Specifically, the literature searched by keywords are divided into four stages in the model and then the way that AI promotes the service design process at each stage will be further analyzed.

4.1 Literature classification

As far as how AI supports the design process, the literature is classified as follows with the help of keywords in Table 1.

Table 1. Keywords to determine the stag

Service Context	Service Needs Insight	Service Design	Design Execution
• User profiling tools • Industry and market research tools (such as industry report analysis) • Trend analysis methods (such as market insight)	• User research methods (such as interview analysis) • Qualitative and quantitative analysis tools (such as demand matrix) • Data analysis tools	• Prototyping tools (such as Sketch, Figma) • Rapid iteration and generation tools • Concept verification tools (such as design simulator)	• Delivery optimization tools • Product testing and implementation tools • Final delivery methods (such as AI-assisted product deployment)

The four main stages of service design are service context analysis, service demand insight, service design, and design execution. With the support of AI, each stage can be greatly optimized especially in data processing, generating design plans, prediction and analysis. The following will analyze the specific role of AI in each stage.

4.2 Service context

Among the above-mentioned 56 papers, six are related to service context. Through data processing and predictive models, AI assists designers in understanding the complex macro environment, audience profiles and emerging trends by analyzing user data, behavior patterns, market dynamics, and socioeconomic factors. This capability allows for more efficient identification of key trends and potential opportunities in intricate service settings. For instance, Meesad and Mingkhwan (2024) discussed how AI integration in smart digital libraries enhances service personalization and automation,

allowing libraries to better adapt to evolving user expectations [5]. Similarly, Chun and Elkins (2023) introduced a framework for diachronic sentiment analysis using AI, demonstrating its potential to predict user needs while highlighting the risk that such AI-driven insights may overlook subtle user intentions [6]. Additionally, a study by Martin et al. (2021) explored the application of AI in analyzing consumer behavior across various industries, revealing that AI-driven analytics can uncover hidden patterns and preferences, thereby informing more targeted and effective service design strategies [7].
Beyond urban contexts, AI also shows potential in broader applications, such as rural public service systems. For instance, a study by the Alan Turing Institute explores the automation of resource allocation across various public sector domains, including healthcare and social welfare, highlighting AI's potential to optimize resource distribution in rural areas [8]. Additionally, research by Rahman et al. (2023) examines AI's role in optimizing resource allocation in agriculture through IoT integration, demonstrating its applicability in rural settings to improve efficiency and productivity [9]. Besides, AI’s failure to capture the complex social and cultural dynamics has also drawn scholarly attention. A study by Prabhakaran et al. (2022) highlights that AI technologies often embed the cultural values and practices of the countries where they are developed, leading to incongruencies when applied in diverse cultural contexts. This misalignment can result in homogenized solutions that fail to address unique, context-specific needs, thereby hindering the personalization of services [10]. Similarly, a study by Ananthram et al. (2024) investigates the Western cultural bias of large vision-language models, revealing that such biases can affect image understanding and interpretation, which is crucial for culturally sensitive AI applications [11].
In this stage, the collaboration aligns with the Embedding Mode, where AI functions as a supportive tool integrated into background research, allowing designers to focus on strategy and synthesis. Through leveraging the power of artificial intelligence in data analysis and pattern recognition, designers can effectively collect, filter, and analyze large amounts of relevant information, saving time while improving the accuracy and depth of insights. This process facilitates a more comprehensive grasp of the service environment, encompassing an in-depth examination of the research context, prevailing market trends, and user behavior, thereby establishing a robust foundation for formulating scientific and efficacious design strategies. Nevertheless, artificial intelligence frequently falls short in deciphering the intricate cultural and social subtleties that are paramount to attaining a holistic comprehension of the service environment. By integrating artificial intelligence with qualitative research techniques, such as anthropological studies, this shortcoming can be effectively mitigated.

4.3 Service demand insights

Thirteen papers center on service demand insights. Service demand insights are the process of identifying users’ core needs and pain points. At this stage, AI supports designers in digging deeper into user needs and classifying information through natural language processing, sentiment analysis, and big data analysis.
Bang Nguyen et al. (2021) used machine learning models to process a large number of user reviews in their sentiment analysis study of online food ordering services to identify user needs and emotional responses, thereby providing a basis for improving service design [12]. Similarly, Majid et al. (2024) explored the use of generative AI chatbots in understanding and guiding tourists’ sustainable travel behaviors [13]. Tools such as Uizard and Visily can process complex data flows to generate design specifications and problem definitions. By identifying hidden factors or potential conflicts, AI reduces human bias and enhances the logical consistency of problem definition.
In this stage, the collaborative mode is more inclined to the co-pilot mode. AI can provide designers with creative suggestions and insights into user needs, but the final decision and implementation remain in the hands of the designer. While AI can help reduce individual biases, qualitative methods, such as reflective subject analysis, show that subjectivity has unique value in revealing deep and subtle differences in human experience. Finding a balance between AI's objectivity and human judgment can generate richer, more meaningful, and highly context-relevant design insights.

4.4 Service design

Twenty-nine papers are about service design which involves innovative service solutions. The literature about this stage mainly discusses how to provide multiple options through AI to help designers quickly generate creative output and iterative optimization through algorithms and create links beyond human logic.

For instance, Huang et al. (2021) proposed a model that leverages the Semantic Web to facilitate creative service software development. This model is applied in two phases: requirement specification and service design. By employing semantic and visual cues, the model aids in bridging the knowledge gap between domain experts and software engineers, thereby improving the traceability of specifications and supporting machine processing [14]. This collaboration aligns with a co-pilot model, where AI generates multiple design options based on users' historical data, while designers refine and review the final output to ensure quality. This model is particularly valuable in the design generation stage, especially when speed and diversity are critical.

4.5 Design execution

The other eight papers are on design execution, where AI plays a crucial role in monitoring service delivery, assessing performance metrics, and providing optimization recommendations through predictive analytics and monitoring systems. Designers oversee these operations and intervene only when necessary. For example, the intelligent heart health monitoring platform proposed by Faust et al. (2020) monitors the heart rate and health status of patients through IoT and AI technology [15]. Similarly, Yu et al. (2024) showed that AI could optimize service integration through the service competition model and improve service quality in a competitive environment [16]. Maqtari et al. (2022) explored the role of IT governance in facilitating the integration of AI into accounting and auditing processes, emphasizing that robust governance frameworks enhance AI adoption, thereby improving transparency and accountability in service delivery [17]. Furthermore, Labadze et al. (2023) conducted a systematic literature review on the role of AI chatbots in education, demonstrating how these tools can transform support services, improve accessibility, and contribute to more efficient and effective learning environments [18].

At this stage, AI operates autonomously in an Agent Mode, optimizing the service delivery process through continuous observation and data analysis to maintain service effectiveness. This approach proves highly effective in dynamic environments such as medical monitoring or logistics optimization. AI-driven systems facilitate real-time adjustments, ensuring that services remain consistently aligned with evolving user needs throughout the delivery process.

4.6 Comments

A systematic literature review and case study reveal that the role of AI tools in service design has been widely studied and generative AI can significantly improve design efficiency in multiple stages of service design, especially in service context analysis, creative generation, and service optimization. It accelerates data processing, generates diverse design options, and refines outputs, thereby improving design quality and user experience. Meanwhile, it can be seen that although generative AI performs well in technical processing and logical analysis, its ability to deal with complex emotional needs and humanistic care is relatively limited.

Given the limitations of AI in emotional expression and complex decision-making, human participation in service design is still indispensable. Therefore, how AI and human design can collaborate in practice needs to be further discussed and explored.

5 POSSIBLE AI-DESIGNER COLLABORATION IN EACH STAGE

It is no doubt that AI can play a key role in technical and logical tasks, but in terms of humanistic expression and moral judgment, the dominance of service designers is irreplaceable. Song et al. (2024) emphasize that while AI excels in processing large datasets and generating solutions, the integration of human oversight is critical for ensuring ethical and contextually relevant outcomes [19]. Similarly, Milind et al. (2023) identify that AI tools are most effective in specific stages of engineering and design processes, such as generation and execution, while human involvement is indispensable for ensuring cultural and emotional resonance in design [20]

The current application landscape shows that the collaborative model of human-machine co-creation is highly feasible. Wu et al. (2021) categorize AI-human collaboration into three primary modes: Embedding Mode, where AI acts as a supportive tool integrated into workflows; Copilot Mode, where AI provides suggestions and assists in decision-making while humans retain control; and Agent Mode, where AI operates autonomously with human oversight only when necessary [3]. AI tools are most concentrated in the design generation and execution stages, where efficiency gains are critical, while human involvement remains strongest in context analysis and demand insights, emphasizing the need for a holistic and balanced collaboration. Designers must leverage the speed and precision of AI to manage tasks while ensuring the comprehensiveness of design results and user satisfaction through the control of emotions and ethics. In this context, tailored collaboration strategies are proposed to address the specific needs of designers at each stage of the service design process (Figure 2).

5.1 Context analysis

It is no doubt that AI can play a key role in technical and logical tasks, but in terms of humanistic expression and moral judgment, the dominance of service designers is irreplaceable.

The current application landscape shows that the collaborative model of human-machine co-creation is highly feasible. AI tools are most concentrated in the design generation and execution stages, where efficiency gains are critical, while human involvement remains strongest in context analysis and demand insights, emphasizing the need for a holistic and balanced collaboration. Designers must leverage the speed and precision of AI to manage tasks while ensuring the comprehensiveness of design results and user satisfaction through the control of emotions and ethics. In this context, the possible way of AI-designer collaboration in each stage of service design is proposed as follows.

5.2 Service design

In the stage of idea generation and prototyping, generative AI tools (e.g., Framer, Creatie) and user interaction simulation platforms enable the rapid generation of diverse design options and behavioral predictions, which is conducive to iterative prototype development. Designers should take full advantage of AI which can generate a large number of creative ideas in a short time and on this basis explore multiple possible design directions in the early stage and verify the feasibility of the solutions through rapid prototyping tests. Considering that it is difficult for AI to fully capture these multidimensional factors like emotions, intuition, and cultural background, it is necessary to combine AI with real user testing to validate AI-driven outputs against real-world user feedback, ensuring that the results are both contextually relevant and emotionally resonant. In the latter stage, participation and feedback from real users are needed to optimize and verify whether the AI-generated design meets the actual user needs and emotional experience.

5.3 Service demand insight

In this stage, with sentiment analysis platforms (such as Bang NLP), clustering algorithms and data visualization tools, AI can deeply explore user needs, pain points and behavior patterns. The initial insights generated by AI provide data support for designers, who then use their expertise to evaluate and contextualize these insights and balance data-driven objectivity with deep insights from human judgment. At this stage, designers need to collect and preprocess structured and unstructured data from questionnaires, user comments, and logs to ensure the reliability of AI output.

5.4 Service execution

Finally, in the process of service execution, designers should use AI tools to ensure the optimized implementation of design solutions and ensure the consistency and efficient delivery of multi-platform designs. Here, AI primarily operates in an autonomous mode and optimizes service processes while designers oversee the system to handle complex decisions and address ethical considerations. Meanwhile, designers continue to track the feedback data generated by AI after the project is delivered and make some necessary adjustments to ensure the consistency and effectiveness of the design solution in different application scenarios.

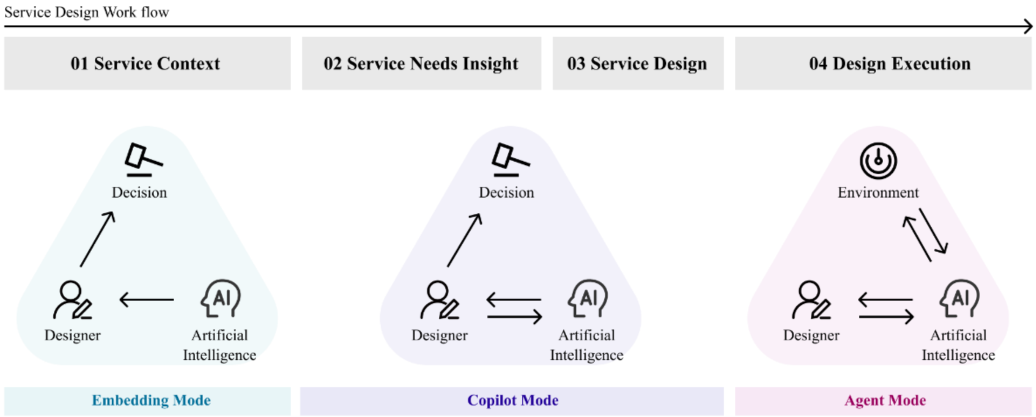

Figure 2. Three modes of AI-designer collaboration in the service design process. Drawn by the author.

6 FUTURE DIRECTIONS OF RESEARCH

The general strategic process of service design provides a clear framework for designers, but in actual applications, the differences in service objects and service contexts require designers to flexibly adjust the process so as to accurately respond to specific needs. A general tendency is that service design will not only be confined to the commercial field but also play a broader role in public services and social value creation. It is indisputable that AI-based service design research will further promote the continuous development of service design and provide designers with more intelligent design tools and strategies. Future research may be conducted in the following directions.

6.1 In-depth research on the co-creation model of AI and service design

Future research should further explore the collaboration between AI and designers in the service design process, especially the differentiated application in different service scenarios. The innovative application of service design requires the development of more sophisticated AI tools for specific industries and service needs. In addition, future research should continue to focus on how to balance the efficiency of AI and the limitations in creative tasks and explore the best collaborative model between AI and human designers in service design.

6.2 The role of AI in user feedback and emotional design

Future research should also pay more attention to the potential and challenges of AI in emotional design and user experience optimization. Although existing technologies can provide assistance in relatively simple emotion recognition and feedback processing, the application of AI still needs to be improved when it comes to more complex emotional expression and interpersonal interaction. How to effectively integrate AI into emotional design and make it complement the designer's intuition and creativity will be a direction worthy of in-depth exploration.

6.3 Cross-domain expansion and long-term impact

The rapid advancement of AI technology is reshaping the practice of service design. Future research should focus more on the long-term impact of these technological changes on the service design process and explore how AI technology can adapt to and reshape the process model of service design. In addition, service design projects in different fields may have different needs and characteristics. How to flexibly apply AI technology in different scenarios and formulate corresponding strategic processes are also important directions for future research.

7 CONCLUDING REMARKS

It is noteworthy that a balance needs to be struck between efficiency and empathy. For one thing, AI can play a leading role in such tasks as data processing, pattern recognition, and option generation with its high speed and precision. For another, designers need to take an active part in activities that require emotional intelligence, deep user understanding, and human-centered decision-making. AI can handle the mechanics while designers must bring empathy and cultural awareness to ensure the outcomes resonate with users.

It is asserted that AI should serve as a complement instead of a replacement. It is significant to view AI as a tool to augment human creativity and decision-making. With a human-centered, AI-driven collaboration, designers can focus on more strategic and nuanced tasks and make sure that the design process remains ethical, inclusive, and innovative. Although AI is in a position to enhance productivity, the human designer can never be replaced with its role in shaping the vision, addressing ethical concerns, and ensuring inclusivity. AI and human designers together can make design services both technically sound and emotionally impactful.

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A STUDY ON DESIGN ELEMENTS OF INTERACTIVE FACILITIES IN PUBLIC SPACES BASED ON CHILDREN'S PLAY BEHAVIOR

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ABSTRACT
This paper examines the activity behavior patterns of children in both older residential communities and modern urban communities, comparing the activity patterns and needs of children during their cognitive development. By exploring the connections between children's activities and spatial elements, the study extracts key environmental design elements based on children's observed behaviors. Additionally, during the pandemic, children's activities became more frequent but also more constrained within community spaces. Through a review of existing literature and analysis of firsthand data from surveyed environments, this research identifies commonalities and differences in children's activities across various spatial settings, outlining the essential design elements for creating child-friendly spaces. It also highlights the elements that detract from child-friendly and ecologically sensitive designs. This research endeavors to contribute to the conceptualization and design strategies regarding the creation of child-friendly spaces. It plays a catalytic role in facilitating the renewal and transformation of aged urban public spaces that fall short in catering to children's growth and development requirements. Moreover, it functions as a critical framework for designing child-friendly environments that effectively support children's development and well-being.

Keywords: Space Design, Child-friendly, Public Space, Facility Design

1 INTRODUCTION

With the advancement of urban modernization and the improvement of people's living standards, there have been significant changes in the activity patterns of children in cities, along with notable differences in the activity preferences and characteristics of children at different age levels. This has created new demands for spatial design. While children aged 3 to 5 engage in mainly simple and equipment-assisted activities with more sitting and standing games, those aged 6 to 8 are more active and restless, and children aged 9 to 12, being in a crucial cognitive growth phase, have a higher demand for puzzle games. Through qualitative research, the focus is on children aged 6 to 12 in this study as they are in a key growth and cognitive period [1]. Compared with the previous generation (around 1970s), the activity patterns and game varieties of modern children have gradually become monotonous. For example, scribbling with chalk, playing hide-and-seek, playing marbles, playing street baseball, stepping on seesaws, doodling on the ground, disassembling old baby carriages, climbing railings, etc. They can better feel sand, stones, sunlight and rain, but nowadays outdoor spaces leave them with nothing to do [2].

Outdoor spaces are an essential component of children's environments, profoundly influencing their development. A well-designed outdoor environment enhances children's sensory perception and provides valuable experiential opportunities [3]. These spaces mainly promote their physical and mental development in the following aspects: (1) Improve motor skills and tactile perception; (2) Promote children's understanding and cognition of the world; (3) Promote their ability to interact with others; (4) Develop moral qualities and personality characteristics [4].

Some poor designs in space also restrain children's activities, such as undulating roads, overly hard pavement, and uninteresting facilities. A study shows that improper application of plants in space has caused rhinitis in children. There are even cases showing that excessive screen time and sedentary behavior of children have also led to symptoms such as childhood obesity [5]. If outdoor spaces are not attractive enough for children's activities, then it will inevitably increase sedentary time and time spent on video games. On a deeper level, to a certain extent, it contributes to problems such as childhood obesity, social barriers, and mental health problems. Therefore, children's activity spaces need to be adapted to children's cognitive growth.

Although theories of human-environment interaction in public space design provide significant reference value for spatial planning [6], children's spaces often lack sufficient attention and detailed considerations. While emphasizing the significance of functional configurations and visual appeal in promoting children's physical and mental development, some scholars contend that children often adopt passive roles in spatial interactions [7].

A study integrates literature on urban green spaces, child-friendly cities and environments, and children's infrastructure, proposing the concept of Child Green Infrastructure (CGI). It emphasizes the need for more equitable, inclusive, and participatory approaches [8]. In addition, a study on kindergarten space design indicates that three critical dimensions are essential for children's spatial design: human-to-human interaction, human-to-object interaction, and human-to-environment interaction [9]. Furthermore, cognitive psychology provides essential guidance in understanding children's needs [10], enabling the design of environments that align with their psychological traits and behavioral patterns. For instance, preschool spaces should prioritize exploration and interaction, while adolescent spaces should address social and privacy needs [11]. Additionally, the integration of design thinking principles further refines the approach to designing children's spaces [12]. These insights offer a valuable foundation for constructing frameworks tailored to child-friendly public spaces.

However, participatory design strategies and framework is especially crucial. Further research on children's public spaces should focus on children's autonomous, play-oriented behaviors that frequently occur in these environments. Children's activities in spaces represent dynamic human-environment interactions, requiring designers to move beyond merely addressing physical functions to consider carefully crafted and rationalized user experiences. Drawing from the five elements of interaction design—users, actions, tools, goals, and contexts—designers should integrate children's developmental research to better understand their spatial perceptions and preferences [13].

This study investigates children's behavioral patterns and provides insights for creating optimal activity spaces. It aims to assist designers in comprehending children's motivations and preferences in play, thereby exploring novel approaches to child-friendly space design. For children, enhanced environments promote outdoor activities and fulfill cognitive and developmental needs through active spaces. For designers, developing spatial strategies from the perspective of children's activities helps update urban public spaces, fostering human-centered, child-friendly environments.

The objective of this research is to compare children's behavioral patterns across different community environments, specifically between spaces with high activity levels and those in aging communities with limited child-friendly features. It examines the types, frequencies, and preferences of children's activities in these environments, exploring how spatial elements influence children's interactions, play, and socialization. This paper aims to establish a catalog of spatial elements favored by modern urban children, describe spatial features that attract them, and explore fundamental principles for designing child-friendly environments. Emphasizing the long-term applicability and effectiveness of these principles, the study offers valuable insights for urban renewal and the design of children's facilities.

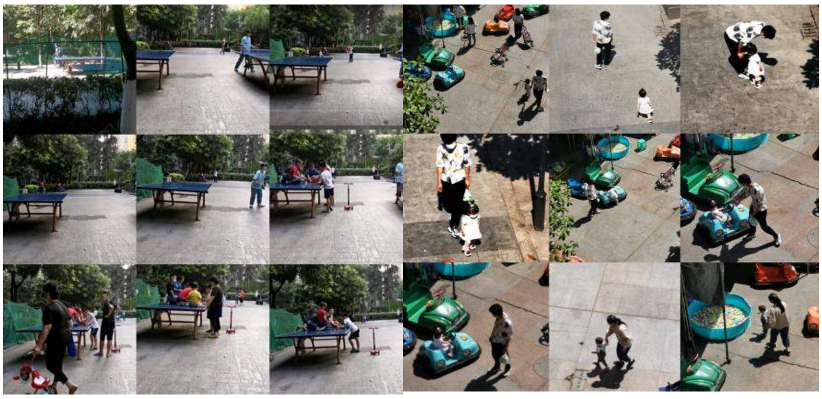
2 METHODS

This research aims to derive insights from the comparison of time and space. Through qualitative and quantitative analysis, two typical public spaces lacking child-friendly design, one old and one new, are selected and investigated. The activity spaces in a modern community in Chongqing (lacking facilities but with more children's activities) and an old-fashioned community in Chongqing (with imperfect facilities and relatively less play space) were compared and studied. The study uses a combination of research methods, including time-lapse photography (Figure 1), fixed-point observation, marking characteristics, and activity classification, based on public space research theory [14]. At the same time, the sample spaces mainly have the following standards: (1) Located within the research area; (2) Located at the intersection of major traffic routes such as residential areas; (3) Public areas. Subsequently, the morphological indices of these spaces are then measured, and children's activity patterns are recorded.

The specific process of the research method is as follows: First, the study selects eight objective indicators in four aspects related to space: site area, green coverage rate, number of seats, pergola coverage rate [15], color diversity within sight, and surrounding greening rate [16] (Table 1). These indicators are convenient to measure and have a great correlation with children's activities. After investigation and measurement, the data of each sample space is summarized and analyzed. Methods such as interviews, preliminary investigations, on-site surveys, questionnaires, literature analysis, and data analysis are used to discover site problems and propose design visions and strategies.

Table 1: Percentage of objective indicators of the spatial form of a sample A and Sample B

Sample	**Space Composition**		**Facility Configuration**		**Landscape Characteristics**	
	Site area	Green coverage rate	Seat area	Pergola coverage rate	Hard pavement	Waterscape area
Sample A: modern community space	1	32.4%	0.57%	4.7%	60.2%	2.2%
Sample B: an old-fashioned community	1	11.7%	0.15%	1%	58.9%	area 1.7%



(A) (B)

Figure 1. Time-lapse photography. (A) Community Space Ping Pong Table.

(B) Community Commercial Street Playground Facilities.

Within a continuous period of one month, the study combined with the spatiotemporal relationship of the site, has continuously observed children’s daily behaviors in the selected sample spaces, and record continuously for no less than 7 hours. To accurately document children’s daily lives, this study adopts an approach that allows for a clear observation of their activities and cognition while seamlessly integrating with spatial dynamics. During the recording process, both the observers and the recording equipment are positioned to minimize interference with the children’s activities and avoid drawing their attention. Time-lapse records are taken to make a study on activity frequencies at different times of the day. Classify the surveyed children (Table 2) and record the frequency of each activity type.

Table 2: Coding and interpretation of children’s behaviors

Type	**Coding**	**Interpretation**
Interpretation Leisure activities	Buying things	Selecting goods, making payments, and getting change at neighboring supermarkets or small stores.
	Playing with pets	Petting, amusing, feeding, and playing with pets.
	Eating or drinking	Literal meaning
	Conversing	Two-way communication.
Chasing games	Chasing games	Chasing and playing around. Generally, the person who loses a game chases other player.
	Throwing sandbags	(Stones, cloth toys, hats, etc. can all serve as sandbags). Confirm the target through throwing sandbags and conduct forward and backward chasing and catching.
	Machine gun games	Using toy versions of toy guns, some with plastic bullets and some with laser guns.
Tabletop toys	Playing cards	Spreading out cards on a table or on the ground in groups of three to five and playing according to the rules of game cards and collecting.
	Assembling toys	Spreading out model parts on a table and several children assemble them together.
	Playing house	(mostly for girls) Simulated business games and simulated talking and imitating forms with dolls.
	Playing table tennis	Literal meaning
Cycling	Cycling activities	Slapping game, In the form of guessing fists or black and white matching among two or more children, the loser accepts the punishment of being slapped on the hand.
	Riding a skateboard	(Children's skateboards are of different types, mostly two-wheeled skateboards with handrails, and there are also single-wheeled and styles without handrails).
	Riding a bicycle	Literal meaning
Sport	Dancing	Literal meaning
	Hopscotch	Drawing grids on the ground with chalk and playing games.

	Long jump	Literal meaning
	Skipping rope	Literal meaning
	Flying a kite	Literal meaning
Reading		Literal meaning
Playing with mobile phones		Literal meaning
Passing by		Passing through the space without stopping (just passing through here to go to another place without other activities).

3 RESULTS

3.1 Probability of occurrence of different behaviors

Through observation and questionnaires, in the two sample spaces, most children are aged 6-12, while the proportions of those aged 3-6 and 12-16 are only 17% and 28% respectively (Figure 2). Thus, middle and low-aged children are determined as the main research objects. Among them, the activity frequency of children is mainly activities such as playing cards, riding toy cars, playing with toys, and gathering to play video games. The activity time of children is mostly around 1 to 2 hours. From a spatiotemporal relationship, their playtime is mostly after dinner, concentrated and regular, and activities increase on weekends and on sunny days. Subsequently, children's activity data is sorted out according to time-lapse photography and photos.

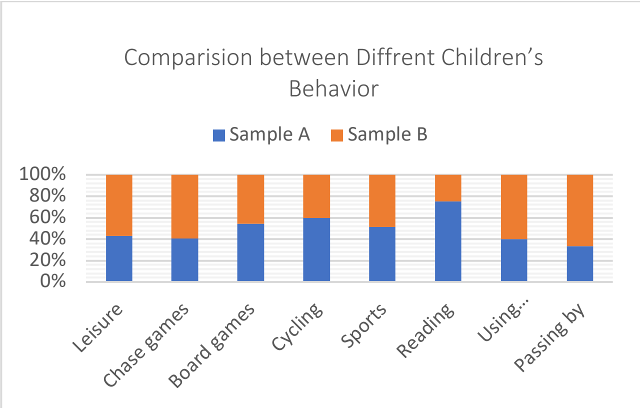


Figure 2. Frequency of Occurrence of Children's Behaviors. The frequency of sample A is calculated as sample A / (sample A + sample B), and the frequency of sample B is calculated as sample B / (sample A + sample B).

According to *Life Between Buildings* [17], longer outdoor stays are typically observed in vibrant residential areas and urban spaces. Based on behavioral surveys, this study analyzes the types of behaviors exhibited by children in these spaces and the frequency of their occurrence. Using "conversing" as an example, the study combines spatial form index data to explore the impact of spatial configuration on the frequency of children's activities.

Among them, the main activities with high frequency are the following categories: chess and card games, cycling, and sports activities. These activities are strongly correlated. Although behaviors such as chasing or onlooking occur less frequently, when they do, they tend to last longer and draw in additional children. The results show that when designing child-friendly spaces, priority should be given to meeting the activity needs with high probability of occurrence. In this study, the occurrence frequencies of "skateboarding," "dancing to music," "chasing," "passing by," and "playing musical instruments and singing" in the two sample spaces are higher than other behaviors and are worthy of consideration.

3.2 Impact of spatial form on children's behavior

Based on the analysis results, this study deeply explored the "chasing game". Through sample comparison, it was found that in the two spatial form indicators, the width of the adjacent street and the number of seats significantly affect the frequency of the "chasing game" among children in the public space. The activity space used by children has an uneven spatiotemporal distribution. In public space A with a large area, conversations are more likely to occur. The wider the adjacent street, the stronger the sense of openness. It can be inferred that the sense of openness of the public space may affect the frequency of children's chasing games.

There are more seats and spaces for people to rest in sample A than in sample B. In terms of activities, reading and tabletop games are also significantly more than in sample B. Thus, it shows that the number of seats and tables has an impact on the frequency of children's conversations and reading. More plans for sitting down to relax and chat increase the possibility of communication. Tables provide a platform for children to place game toys. Therefore, a reduction in the number of tables and chairs will have a negative effect on the frequency of conversations.

Children have diverse activity methods and complex behavior patterns [18]. Children's amusement facilities are difficult to meet children's activity needs. In the space, entertainment facilities are the carriers of children's outdoor entertainment. Children are interested in some "wild" corners, such as long ladders, flower bed corners, slopes, etc., but use traditional and stereotyped amusement facilities less frequently. It can be concluded that landscape planning needs to be coordinated with children's facilities.

In the landscape, especially the improper configuration of plants, such as sparse plants and shrubs, there are potential safety hazards for children's activities. In terms of the combination of landscape and space, the planting of flowers and the like will attract children more. The shade of big trees also makes children more active. Small-scale landscape spaces are more charming. The proportion of green space area is relatively high, but children's activities rarely involve it, which is obvious in both residential areas. The reason is that on the one hand, because the green space is a restricted activity type, reasons such as uneven ground make it difficult for dynamic activities favored by children such as bicycles and scooters to pass through this space [19].

3.3 Children are more active in communities with better facilities and landscapes

There is a certain sense of disorder and safety threat in the activities, and it is more obvious in sample A. In the comparison of old and new communities, children's activities are more frequent in communities where the elderly are active. This finding is in line with the positive and negative effect processes: the occurrence of activities is due to the occurrence of activities [17]. Children's activities are intervened by parents to different degrees and are related to the activities of the elderly. In the negative effect process, on the contrary, a bad environment reduces children's activities and increases children's dependence on virtual games, and may also exacerbate children's emotional disorders and autistic tendencies.

3.4 Consideration of safe distance in facility design

Under the suspension of classes due to the epidemic, it did not lead to a large fluctuation in the activity volume of children in the residential area. Insufficient and poor activity venues in the residential area are the main constraining factors. The residential area environment guides the choice of children's activity types. Under the epidemic, a safe distance is consciously maintained in activities [20], and overly crowded or aggregated activities are dispersed. The view that "activity venues should be kept at a distance" under the epidemic is a common consideration factor in our space design.

4 SOLUTIONS

4.1 The perspective of behavioral observation in space

In general, the children's behaviors and environmental cognition, as shaped by the epidemic, reflect patterns that have universal applicability. There are fewer children's activities in old communities with poor environments, which are closely related to environmental factors such as children's amusement facilities, landscape configuration, space safety, and space negative effects. By studying children's activity patterns - the activities with the largest proportion are card games and cycling, improving unfavorable and friendly designed public spaces-narrow areas and excessive hard pavement. For beneficial spaces, analyze the proportion of elements - high greening rate and low-lying landscapes can more conform to children's game patterns, summarize spatial elements, and are also applicable to the design of children's activity spaces during the epidemic closure period and after the lifting of the closure.

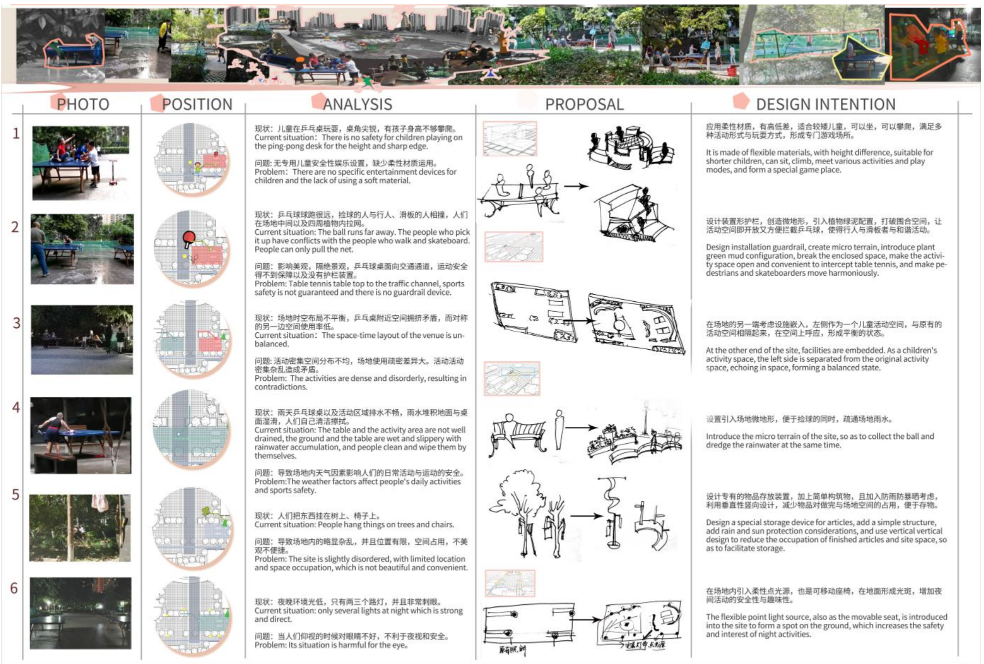


Figure 3. Children's space improvement design proposal

The proposal for the improvement of child-friendly spaces summarized in this study is put forward based on the observational perspective of children's behaviors (Figure 3). Through analyzing the positions of their behaviors in the space as well as the current situation and existing problems of the space, a new design proposal based on behavioral observation is presented. This framework encompasses the design inspirations (intentions). It evolves from "Photo position and nice Proposal" to "design intentions".

The Double Diamond Model consists of four stages (Figure 4), namely "Discover", "Define", "Develop", and "Deliver". During the "Discover" stage, in the research on children's spatial behaviors, in addition to conventional methods, social observation and interview-based research on spaces with high children's activity levels are added. From the perspective of planar space, the relationship between behaviors and spatial elements is analyzed to construct an observational mechanism, which is a refinement and expansion of the traditional "Discover" stage. In the "Define" stage, core problems, requirements, and goals are clarified based on the preliminary information to determine the design direction. In the "Develop" stage, various design schemes are conceived by utilizing relevant materials according to the determined direction to improve the design. In the "Deliver" stage, the design schemes are evaluated and screened, the optimal one is selected and further refined to ensure the feasibility and practicality of the design implementation.

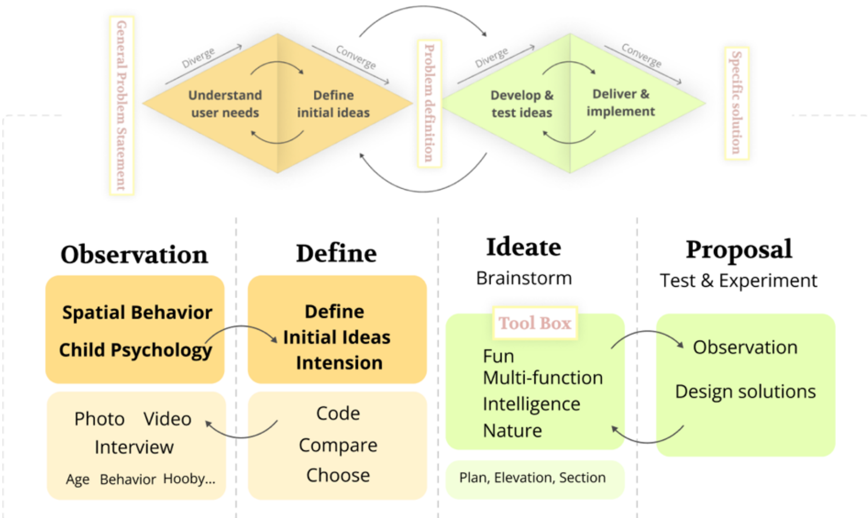


Figure 4. Double Diamond Design Process for Designing Child-friendly Spaces

Through the close integration with elements such as children's behavioral observation, the design process becomes more scientific and targeted, serving the goal of improving child-friendly spaces. Meanwhile, Photo observation is combined with user interviews and other aspects, and the "position" part is associated with user journey maps and the like. The new strategy disassembles and analyzes from multiple dimensions, enriches and improves the flattened design schemes, and its preliminary work corresponds to the sketching and other links in the design thinking process.

4.2 Design with More Functional Elements through the "Toolbox"

Based on the conclusions of research and observation, this study has put forward a toolbox strategy centered around children's activity elements, which expands from four dimensions, namely Fun, Intelligence, Multi-function, and Nature, aiming to enrich the application of design elements in the design of children's spaces.

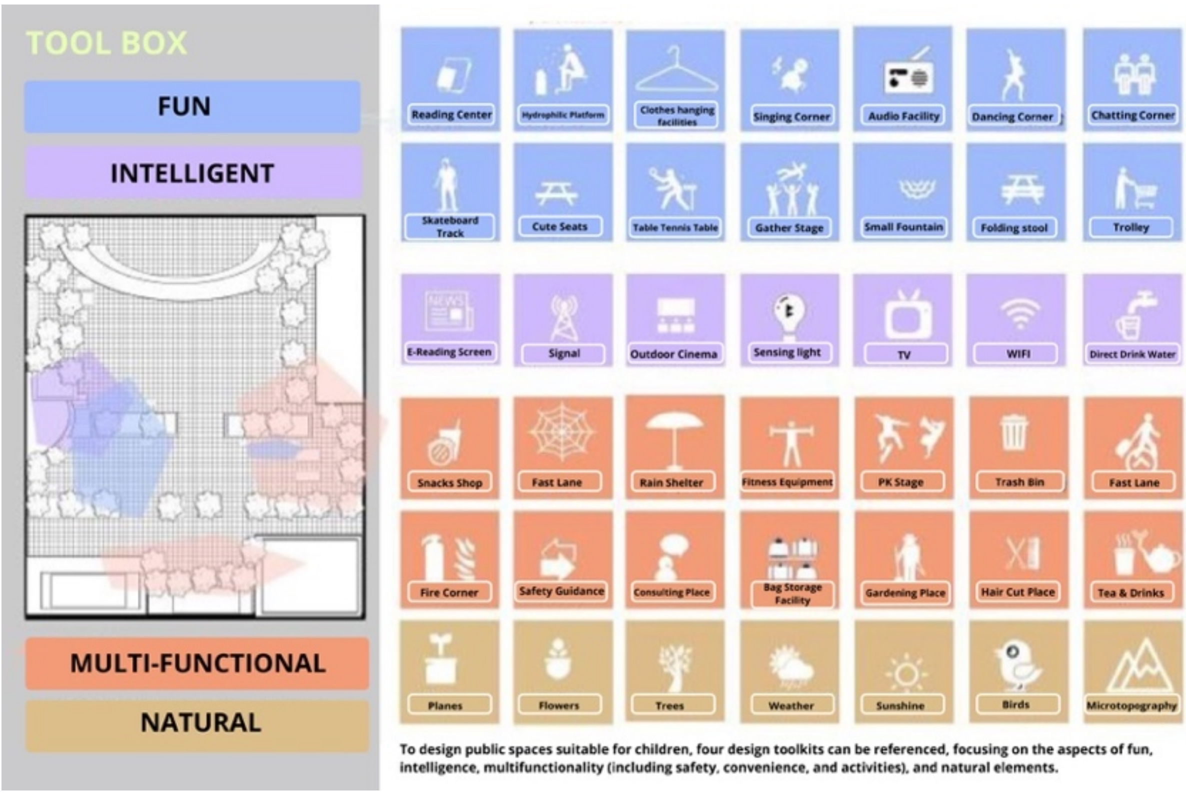


Figure 5. Newly added toolbox of children's activity elements

Based on the conclusions of research and observation, this study proposes a strategy of a toolbox for children's activity elements, which expands from four dimensions, namely "fun", "intelligence", "multi-function", and "nature" (Figure 5), increasing the application of different elements of design content in the design of children's spaces. In terms of interesting settings, the toolbox includes elements such as reading corners, waterfront platforms, singing corners, music flash mob stages, skateboarding areas, table tennis areas, folding stools, and various exclusive devices for children, aiming to stimulate children's interests and enhance the attractiveness of the spaces. From the perspective of intelligence, the toolbox incorporates technical devices like electronic reading areas, wireless network coverage, outdoor film screening systems, and intelligent lighting devices, with the expectation of providing children with a more convenient and modern user experience. In the realm of multifunctionality, the toolbox presents numerous innovative designs that address children's needs. For example, there are small pavilions with both rain shelter and resting functions, fitness facility parks equipped with guardrails, intelligent trash cans, fire hydrants, emergency passages, chatting areas, and storage racks, etc. These add diverse usage scenarios to children's activity spaces and achieve functional integration.

4.3 Specific Solutions

4.3.1 Improve Children's Amusement Facilities

To cultivate child-friendly public spaces, the diversification of children's amusement facilities should be prioritized alongside the integration of spatial installation art. Innovative installations and landscape arrangements can enrich these spaces, while the design process must be informed by a scientific understanding of children's cognitive and developmental stages. By tailoring spatial design to their age-specific needs, public spaces can support children's educational and sensory development.

A systematic analysis of children's sensory experiences is essential for effectively organizing artistic resources, with attention to the application of color [21]. Rather than relying on adult-oriented rational planning, designs should stimulate children's color perception, utilizing artistic installations and thoughtful material choices to encourage active participation. Flexible materials and low-saturation, soft color palettes can foster outdoor installations that blend functionality with imaginative, childlike qualities, enhancing both engagement and educational value. Designers should integrate more functional elements into the space to broaden the variety and possibilities of children's activities, thereby providing a richer range of experiences and interactive opportunities.

4.3.2 Enhance the Integration of the Elderly and Children in the Space.

Enhancing the design of environmental spaces that cater to both the elderly and children is crucial. In children's activity areas, it is important to consider their group travel patterns and family-accompaniment modes by creating opportunities for positive interactive engagement. Designing play areas for children should be complemented with adjacent activity spaces for parents, promoting shared experiences. Efficient utilization of the site is necessary, ensuring an even distribution of activities across time and space. For instance, alongside children's play zones, integrating flower bed seating and accessible water features for the elderly can provide comfortable resting areas. Such two-way interaction design not only enhances the positive impact of the space but also fosters vibrancy, encouraging greater participation and enriching the overall spatial experience.

4.3.3 Differentiate Space Design according to Children of Different Age Groups.

As indicated by literature research and observation results above, there are significant differences in the activity patterns of children of different ages, and their growth and cognitive needs also vary. Therefore, while children are playing, it is necessary to introduce phased and different forms of recreational activities. When it comes to space design, designers can create areas for popular science enlightenment, leisure and relaxation, sports activities, natural experiences, etc., which respectively correspond to various needs of children such as leisure, entertainment, sports, and cognition. Through such an approach, it may be possible to bring order to children's activities, enabling them to play without disturbing each other and allowing children of all ages to enjoy themselves harmoniously together.

4.3.4 Make Children's Spaces Ecological and Immersive

Make full use of natural elements to stimulate exploration interests and create an ecological and immersive environment for children's spaces. Plant low shrubs in the site, design landscape gardens, and rationally match color relationships according to the landscape changes in four seasons to create an immersive landscape environment and create "wildness" and "liveliness" in residential areas for children to explore and play in. For example, as pointed out in the case [22], forest kindergartens designed through planting gardens connect children and nature. As Jane Jacobs said that children's outdoor activities accumulate [23]. They have a greater sense of liveliness and freedom in their requirements for space.

5 CONCLUSION

In the design of children's environments, it is essential to adopt a holistic approach. As William Whyte aptly noted, elements such as sunlight, fresh air, accessible refreshments, and seating arrangements are fundamental to creating engaging spaces [24]. Public spaces, by nature, are intended for universal participation, necessitating a comprehensive consideration of all elements and stakeholders within the targeted area.

Combined with the characteristics and needs of children's activities exposed under the epidemic situation, by introducing child-friendly environmental factors, design safe and comfortable activity methods to improve the living environment. Designers need to construct more humanized and attractive child-friendly spaces for them [25]. The research results of this experiment on the relationship between spatial form and children's behavior can be used as learning data on the relationship between children's activity behavior and space under the epidemic situation and applicable under the normalized epidemic situation, providing design references. Moreover, the experimental findings on the impact of spatial configurations on children's behavior provide critical insights for informing decision-making logic in the design process. Designers should leverage these results as a foundation for systematically observing and analyzing children's behavioral patterns within various environments, while accommodating their evolving cognitive and developmental trajectories. Such an approach can lead to the refinement and optimization of existing child-friendly public space design frameworks.

In conclusion, by synthesizing research on children's psychological development, cognitive behavioral patterns, and interaction design theories, a more systematic and comprehensive design methodology can be established. This integrated framework offers robust theoretical underpinnings and practical strategies for advancing the design of future child-friendly public spaces.

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