DESIGN AND IMPLEMENTATION OF A SKILL DEVELOPMENT PROGRAM IN AI DRIVEN GENERATIVE ENGINEERING

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ABSTRACT
The application of Artificial Intelligence opens up completely new opportunities for the development of innovative products and systems. Computational design synthesis techniques such as generative design can be used to explore a design space with many potential solutions optimised for different objectives. By using CAD tools that deploy these techniques, designers no longer must limit themselves to the variation and simulation of a few parameters. Engineering designers using these tools can focus on evaluating and selecting the solution(s). The impact on the product development process, the handling of new techniques, methods, and the implementation for future product development and innovation activities results in an enormous need for training and further education of engineers.
This paper presents a comprehensive skill development programme for professionals and engineering students to provide the necessary skills (methodology and tools) in terms of Generative Engineering, design automation, and design optimisation. It includes an introduction to Generative Engineering as well as its foundations and software applications. The concept of the skill development programme is predominantly organised as eLearning divided into learning nuggets but is complemented by an additional practical part. The paper describes the approach employed in developing this program and highlights its outcomes. The teaching methodology and concept along with the focal teaching points are introduced. Subsequent optimisation measures and requirements are determined, which are based on the evaluation of the learning paths and nuggets carried by industry participants and their feedback. Finally, the potential of the suggestions for improvement and the resulting changes are discussed.

Keywords: Generative engineering education, skill development programme, generative design

1 INTRODUCTION
Progress in digital engineering tools has continuously changed the engineering design process. The shift from sketching on paper to CAD tools can be compared to the application of Artificial Intelligence (AI) in engineering design software tools (i.e. CAD) [1]. This shift for tools in terms of Generative Engineering, design automation, and design optimisation opens completely new opportunities for the development of innovative products and systems and changes the engineering design process. Even though Generative AI has been around for several years, it is still ahead of the plateau in the Gartner Hype Cycle for AI [2]. Especially Generative Design AI as an emerging technology is still in the Innovation Trigger area and indicates a steady increase in demand in the coming years. For the new emerging generation of CAD/CAE/Simulation toolsets a CAGR grow of greater than 15% during the forecast period 2024 – 2029 is expected [3, 4].Their machine learning capabilities suit the growing demand for advanced manufacturing with complex designs and the need to reduce size and mass of products while improving the performance. On the other hand, these tools impose a paradigm shift in product development like the shift from sketching over 2D-CAD drafting to 3D-CAD product modelling. Since this technology is quite newly introduced in CAD tools, engineering professionals have to be upskilled to leverage the potential impact on future product development and innovation activities in companies [5, 6]. The market for professional education in Generative Engineering and Design (GE&D) is primarily driven by software vendors, who a high focus on their own software capacity and capability. Comprehensive training programs that are more focused on methodical aspects than on specific software tools or features can be found at universities, if at all, and are only occasionally available for professionals. Therefore, a curriculum comprising different educational paths and learning

nuggets on these topics will be developed and integrated into skill development courses focused on professionals of different skill levels and technical specialisations but not excluding students on master level with background in engineering design. The results, the evaluation and the resulting changes are discussed in this paper.

2 STATE OF THE ART

2.1 Generative Engineering and Generative Design

For this paper Generative Engineering (GE) is the generic term for a number of concepts related to the change in product development, including e.g. generative design, design automation and design space exploration. Generative design is the most widely used term and is an algorithm-driven approach to automate the develop of products and finding solutions by not explicit create the geometry. Instead, the definition of constraints, boundary conditions, rules and procedures allow the computation of multiple feasible solutions (design space exploration) including the implicit generation of geometric models. The aim is to consciously create the opportunity to break down ingrained thought patterns so that solutions do not just emerge as a gradual development of existing patterns. In contrast to topology optimisation, the geometry does not have to be explicitly specified and further boundary conditions can be considered [6]. Therefore, the engineers and designers need to shift their skills from modelling the shape to define the boundary conditions and be educated to evaluate multiple solutions [7]. This leads to a shift in the way of thinking for generative designers and engineers [6, 8]. In traditional education this and the exploration of as well as dealing with the larger solution space are not part of the education [9]. Therefore, Li et al. (2021) [10] propose an Evolving Design Thinking Model to integrate the new 'Generative Design Thinking'. They highlight the need to ingrate the required design technologies (e.g. Parametric Design Tools, Topology Optimisation, Machine Learning, …) as well as the cognitive side in education to improve the education of generative designers.

2.2 Existing Learning Environments for Generative Engineering and Design

As the Gartner curve for emerging technologies already indicate the concept of Generative Design AI is quite new. Therefore, the landscape of training and education in this area is small to non-existing. Nonetheless a snapshot of the market situation and available skill development programs emphasises this. For this purpose, an "Internet Search Index Analysis (ISIA)" was conducted. There was a continuous increase in search phrases such as "Generative AI", "Generative Engineering" or "Design Automation" in purely numerical terms, at the same time these search queries were mostly related to the search for a definition or delimitation of the topics or were driven by other generative innovations, such as ChatGPT. Thus, they have little or no connection to the semantic field of "training and education" especially in engineering or CAD. While further training in classic CAD is offered by both software vendors and external companies, further training in generative design is primarily driven by software vendors. In the German-speaking area, very few training providers (around 13) were found that are dedicated to the topic of GE or related topics. Consideration the fact that the technology is in Phase 1 of the Gartner Hype Cycle underlines the results for the low number of available trainings.

3 CONCEPTS

An analysis of the existing learning environments for GE&D has shown that due to the relatively recent development of this approach in engineering, comprehensive training documentation is scarce or non-existent. In particular, the difference is that training is compared to CAD in general e.g., is provided primarily by the software vendors themselves. But since teaching of GE&D requires a change in mindset in addition to the pure software application, the need for independent curriculums is given. Therefore, the concept for this program does not specialise in a particular type of software, but rather focuses on methodology independent of software. The target groups come from different areas and develop different products with correspondingly different requirements in terms of knowledge. The concept of the skill development program is predominantly organised as eLearning divided into learning nuggets but is complemented by an additional hybrid practical part.

3.1 Teaching methods and framework

The eLearning teaching method are learning nuggets and paths. Learning nuggets are self-contained learning units that deal with a specific topic to improve certain skills (skill driven). These learning nuggets have a duration of 10 to 20 minutes and can contain text-based, video, or interactive content

(e.g. H5P). Each learning nugget is based on learning outcomes. The definition of Learning Outcomes is according to Bloom Taxonomy [11] for the learning nuggets as well as for the learning path. Several learning nuggets make up a learning path (competences driven). Each learning nugget and path end with an assessment. These online assessments are primarily based on multiple choice and other automatically graded Moodle question types like true/false, matching, a list of given answers as well as drag and drop to enable an automatic grading. Compared to free-text answers, the use of automatic evaluable questions poses a challenge to the evaluation of correspondingly higher competence. This is offset by the variety of question types to allow learners to continuously monitor their progress in asynchronous learning.
The scope for the experience of this program is to provide factual and theoretical knowledge in broad contexts to reach a range of cognitive and practical skills, including value judgement and sustainability. The framework for this concept includes the goal to achieve different overarching learning outcomes.in terms of innovation, technology and creativity skills and competencies as well as the competencies to make value and sustainability judgements. The overall achievement is to enable the learner to define and analyse a problem space, generate new solutions and assess their validity and to create solutions.

3.2 Implementation

The curriculum comprises different educational paths and focused on a mixture of theory and practice, which is specialised to the learner. The combination of theoretical knowledge and software-independent examples lead to develop the understanding of Generative Design CAD tools, their methodology and application for GE. The focus is not on master the available tools but acquire the required methodologies and mindset shifts that will leverage the full potential of GE&D and other AI driven engineering design tools and techniques. A special focus is on the comparison of classic engineering design approach with GE and the interaction between GE and classic modelling. All learning paths contain nuggets with practical content using state of the art design tools. In this context new processes-oriented tools using the visual and low code programming interface are also part of the practical application. The given learning nuggets in each category enable design engineers to understand, to validate, to apply and to integrated AI driven GE and Design Automation in product development process.
To reach this scope, the approach of the skill development program is divided into three different learning paths with individual focal points and a hybrid the workshop (Figure 1). The individual focal points are close related to awareness as a general overview of this topic, GE&D, simulation, and business aspect of GE. The first path is focus on the GE approach in general, with all necessary core principles, key competences, and streams like topology optimisation, design automation and design space exploration, machine learning and artificial intelligence. The learners learn how GE improves and changes the product development process, expand the solution space, explore and evaluate new ideas. The second path is about GE in terms of optimisation of products close to simulation and lightweight design. The path covers the basic of simulation and algorithms behind the optimisation, based on Artificial Intelligence. The learners learn steps to avoid errors and acquire the knowledge and skills to apply initial approaches. Possibilities for automation are shown and new possibilities are opened up through so called “field driven design” for lightweight design. The third path is about GE from a business perspective as part of the innovation process. The basics of GE, as well as innovation and product development processes are presented. Subsequently, both theoretical elements are linked. This learning path also gives examples of how and where GE can aid design and development decisions in view of more innovative solutions. The hybrid workshop is close related to the first learning path and covers the different streams and transfers these into practical application examples. Discussions rounds and interactive hands-on complete the workshop. The final assessment will be accomplished in a project-based case study to ensure that interactive elements are in the foreground of the education activity and that engaging each participant on an individual basis is ensured. The learning paths are independent and do not necessarily have to be consumed in combination with the others. Only the workshop primarily focuses on the first learning path to strengthen the learner's understanding of CAD tools, methodology and application of GE and is based on that. The target audience addressed by the content are engineers, product developers & designers, CAD designers, team and department management (development and production) as well as students (e.g. mechanical engineering)

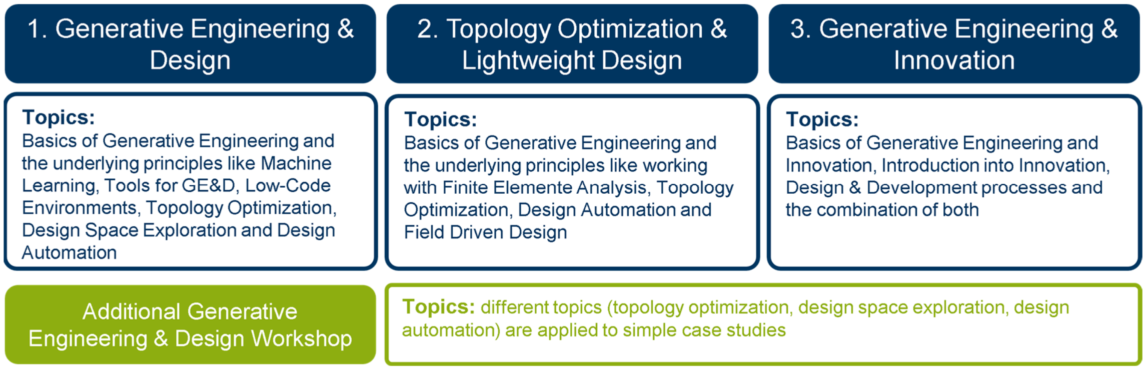

Figure 1. Structure of the learning paths

4 EVALUATIONS OF THE E-LEARNING

To gather feedback and insights from the participants of the pilots workshops a voluntary survey was administered. This survey saw participation from 12 individuals, all based in Italy, working in the electronical manufacturing field, to evaluate the eLearning content. The majority of the respondents were engineering professionals from different areas. This range of backgrounds provided a broad spectrum of perspectives and experiences, contributing to a comprehensive understanding of the workshop's impact and areas for improvement. The following figure 2 shows an extract of the results from the survey to six from fourteen questions. Each question, in the figure shown in different colours, could be answered by the participants on a scale from 1 (low approval) to 10 (high approval).

The participants syndicated their current knowledge of GE&D. Prior to the workshop, the general experience with GE&D among participants was predominantly low, indicating limited prior exposure to the technology and methodology. However, there were still several participants who had a moderate to substantial level of experience before participating in the workshop (red). The participants gave a positive assessment of both the consistency of their expectations of the content (orange) and the depth of the content (grey). These responses indicate that the workshop has had an impact on the perception and anticipated content, suggesting an expansion of practical understanding and acceptance of GE&D while also containing an intermediate level. The knowledge, skills and concepts are only moderately to well evaluated for the explained content (yellow). Based on the textual additions and in connection with the following aspects (blue), it can be concluded that the type of learning (e-Learning) is primarily the cause of the non-adequate explanation. This is also made clear by some comments calling for an even greater focus on examples. Based on what participants learned in the workshop, there is a notable belief in the relevance of GE&D topics for their own work (green).

The workshops' content, structure, and the incorporation of hands-on GE&D experiences were particularly well-received, highlighting the effectiveness of the practical and interactive approach employed. The quality and relevance of the online learning content provided prior to the in-person session received mixed reviews, though the majority still rated it positively, suggesting that while satisfactory, there is space for improvement in aligning pre-workshop materials with the participants' needs.

The additional text evaluations received provide additional potential for improvements. The remarks received suggestions to implement more real industry examples, notes on the content of individual nuggets and especially of less text based and more video-based content. The assessments at the end of the nuggets and paths were also rated as positive. It was also emphasised that the learning form as learning nugget is well suited for time-spread learning, but not for learning in one go.

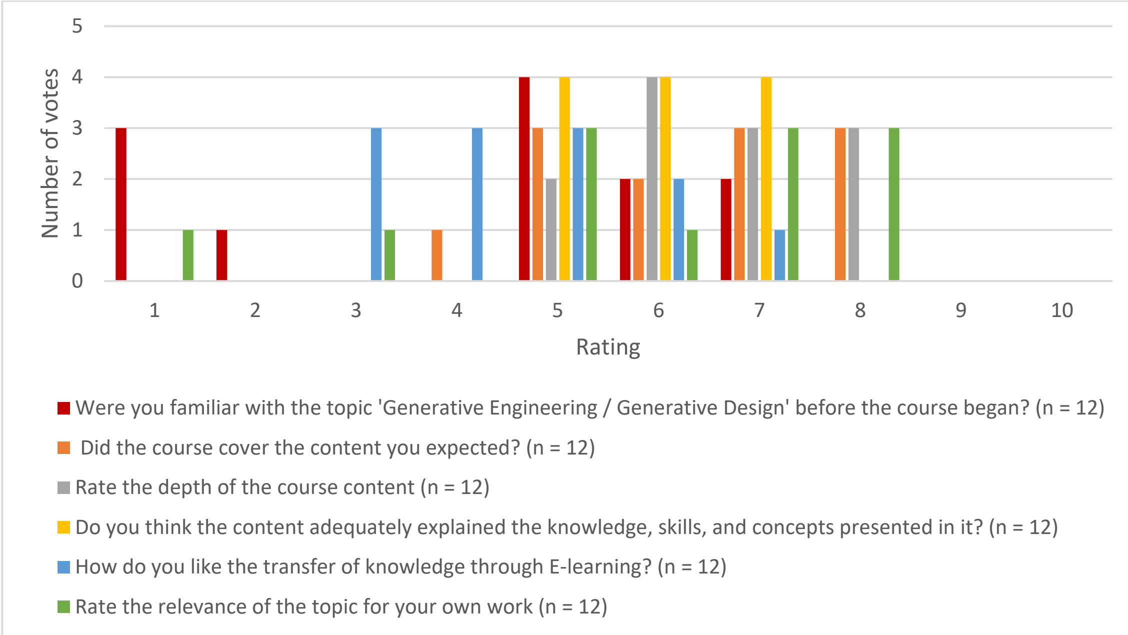

Figure 2. Feedback evaluation

4.1 Adjustments of eLearning content

As a result of this survey, the structure of the e-learning courses was adapted for future training courses (Figure 3). The basic division into three learning paths with the option of a practical workshop remains unchanged. The content and scope have been adapted. Instead of the very comprehensive first learning path, the content in this one has been reduced to make it an "awareness" workshop. This still covers all subject areas, but with less depth of content. The second learning path continues to cover topology optimisation and lightweight construction, but with a reduced focus and also includes the content of the first learning path in advance. As a result, these are no longer sequential but parallel. This learning path is therefore also a prerequisite for the practical workshop. The third learning path with GE and innovation remains unchanged. Overall, the focus on application examples was stressed out by reducing the text and implementing more videos and interactive examples. Furthermore, the content will be made available to the learners with enough time to complete it before the actual workshop in case of the hybrid approach.

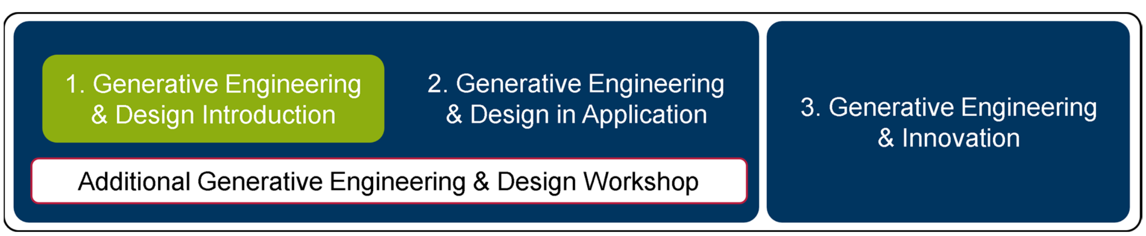

Figure 3. Adjusted structure of learning paths

5 CONCLUSIONS

The integration of artificial intelligence into the engineering design process through GE&D shows possibilities for sustainable change in the process. This change makes it essential to offer both students and professionals an opportunity for software-independent further training. To meet this new need for education, a skill development program for teaching GE&D with its related technological foundations and current streams for different fields of specialisation was introduced. The learning content aims to convey the subject matter in a fundamental and comprehensive manner, but do not address particular tasks or software tools. The content forms the foundation for mastering the necessary transfer to the participants' own problems. However, practical examples and various CAD tools are shown to convey these. The results show the enthusiasm for the potential of GE&D in the product development process. The feedback from industrial professionals indicates that content relevance, presentation and depth are critical factors that need to be addressed to facilitate wider adoption and knowledge transfer. The presentation of real, industry-related examples is one important aspect of this. The evaluation also showed that the presentation of content must be primarily supported interactively through videos and other options in order to generate widespread interest. At the same time, it was determined that the current focus is primarily on technology awareness instead of certificate courses for special interests. This initiative's successful execution demonstrates a strong foundation for future training programs and shows the effective integration of emerging technologies in education and training.

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