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A RESEARCH OVERVIEW OF INDUSTRIAL DESIGN FRAMEWORK FOR MODULAR PRODUCT DESIGN

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1. Introduction

This research paper concerns industrial design and its potential to support design and development needs in product modularisation. The aim of the research is to develop a systemic approach to optimise industrial design prospects in modular product design through the application of a new framework known as *InDFM (Industrial Design Framework for Modular Product Design/Development).* The hypothesis is that product design and development organisations have failed to take full advantages of this prospect, taking an ad hoc or localised approach to industrial design within their modular product development process. The application of InDFM is supported by a defined and comprehensive technical guideline document that is essential for successful application of the framework. InDFM is the outcome of PhD research being conducted at Loughborough University in the UK that currently in its final development stage. Once fully developed the framework will undergo validation with a number of European based companies.

2. Motivations and reviews

A shift in competitive environment has forced many companies to diversify from the standard mass-market products into variations of similar products or mass-customisation [Kratochvil and Carson 2005]. Thus, the concept of modularity [Sanchez 2002, Baldwin and Clark 2000, Kamrani and Salhieh 2000, Ericsson and Erixon 1999] was introduced. Growing numbers of global product companies are now not only adopting modularity, but are also adopting new kinds of product strategies and implementing new development processes that are explicitly focused on achieving a range of competitive advantages through modular product design [Sanches 1999]. However, a review of literature in the area shows that current approaches to modularity are largely the domain of engineers and technical designers and there is little to suggest that the potential role of industrial design within modularity is recognised. Therefore, it is assumed that researchers and product organisations have failed to perceive the strategic importance of the industrial designer within the modular product design process. It is also assumed that in many product development processes, industrial design has rarely been described as an important element that contributes to the strategic planning programs of a product focused organisation.

The industrial mainstream tends to perceive industrial design as a source of aesthetics and rarely as a major contributor to the sales proposition [Desbarats 1994]. In reality, industrial design provides critical visual and tactile elements which are the ultimate influencers both on immediate sales and on total customer experience over a product's lifetime. The influence of industrial design is unrestricted as industrial design services can be applied to most industries (Ulrich and Eppinger, 2000). These concerns ultimately are the goals that prompted the importance of industrial design, which imperatively should be fully exploited throughout the process of modular product design.

Figure 1. Philips electric shaver series (Philips Electronics, 2010)

An example of a successful application of industrial design in modular product design is highlighted by Philips Electronics with its series of electric shavers (Refer to Figure 1). The company has demonstrated in this product family that industrial design played a critical role in providing spatial styling variations while maintaining the same degree of user interaction and ergonomics. Industrial design in products such as illustrated provides some of the few critical differentiators in developing compelling, and globally competitive brand propositions [Juratovac 2005, Mostowics and Grzecznowska 2004, Desbarats 1994].

3. Proposed research

The issue of industrial design's underutilised potential has prompted research into a dedicated framework and systemic approach to utilise the full potential of industrial design in a modular product design process.

The initial investigation of this research has indicated that there is a growing need to develop approaches to integrate and optimise industrial design in modular technical design as a growing number of global companies now adopt modularity concepts in managing the technical development of their new products. This is supported by an article from Sanchez and Collins (2001), that firmly states industrial design as one of the most important strategic tools in developing modular products. The strategic importance includes 1) The need to develop design concepts for more extensive product lines in order to increase product variety. 2) Refreshing product designs through styling changes in visible components for technologically mature modular products. 3) An essential role in modular product strategies by creating styling variations that can effectively distinguish individual product models within a modular product family. 4) Helping to bring a series of technologically upgraded products to market in rapid succession. 5) Providing effective differentiation of new product models by stylization in order to communicate visually the improved technical performance of the new product.

The research approach began with reviews of industrial design processes in order to fully understand the generic process and its intended goals. Emphasis is made on the perceived importance of industrial design functions, including strategic inputs and key roles in standard product design and development processes across a broad range of industries. In addition to industrial design, the modularity concept and the relevant processes of modular product design and development were also reviewed. Both reviews are conducted to identify the appropriate method within each domain. Other qualitative research methods particularly questionnaire surveys and interviews were also conducted with selected British and European companies that are involved in developing and manufacturing modular products, for the purpose of identifying when and where industrial design is being utilised in their design processes. The results from the initial investigation (Refer to Figure 2) showed that the senior management of the companies surveyed rated industrial design as applicable in their design process but with substantial deliberation. This result forms part of the basis to develop a new industrial design framework with associated technical guideline documents to facilitate the optimisation of industrial design in modular product design.

1 – Not applicable	2 – No	3 – Maybe	4 – Yes	5 – Highly applicable

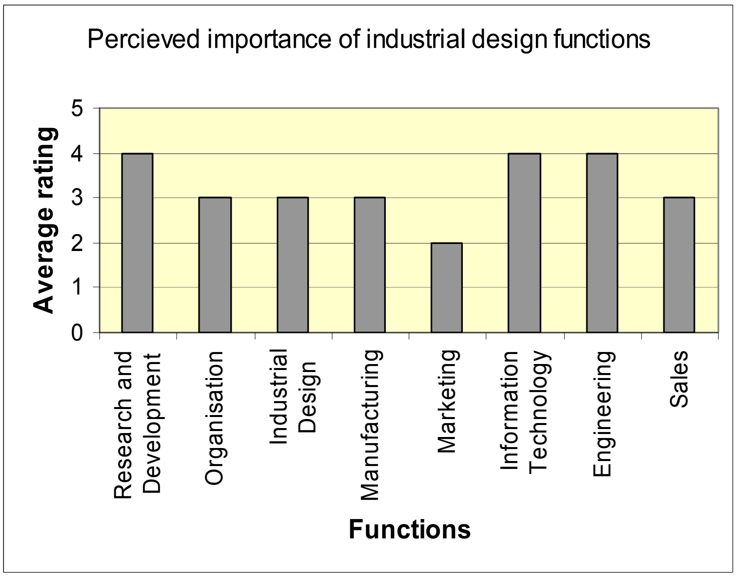

Figure 2. Application rating of industrial design in strategic product planning [Abdullah 2008]

This paper provides an overview of the proposed framework which includes the mechanism of the framework, the components of the mechanism, and the application representation of the framework. This paper will be concluded with suggestions for future work.

4. Intergrated process

The discipline of industrial design itself cannot contribute its full potential as a strategic planning tool unless it is integrated in the product design process. In order to do this, industrial designers need to be involved throughout the process as this is the best way to maximize the value that industrial design can bring to the finished product. This is especially crucial for a product with a high degree of user interaction and the need for aesthetic appeal. The other specialists in the multi-skilled teams will need to collaborate with the industrial designer to ensure the successful execution of an industrial design approach. The complete involvement of the industrial designer forms the basis to integrate industrial design formally as part of a new product design process and to provide a coherent strategy for the new process itself.

4.1 Industrial and modular design process

Generically, the process of industrial design involves six stages that begin with 1) Investigation of customer needs. 2) Conceptualisation of a design. 3) Preliminary refinement of a design. 4) Final concept selection of a design. 5) Production of control drawings. 6) Coordination with other relevant members who are involved in the project. For each stage of the process, emphasis is given to achieve the ultimate goals of satisfying both the manufacturer and consumer needs by constantly considering the industrial design critical dimensions. To assess the importance of industrial design in any product design processes, the researcher has identified five critical dimensions (Refer to Figure 3) that need to be achieved for any product to be considered successful in an industrial design context. These dimensions are then characterised into sub-dimensions, which describe the objectives of each dimension.

Dimensions	***Objectives***
Utilities	• Ease of use • Ease of maintenance • Quality and quantity of interaction • Safety • Novelty of interaction
Aesthetics	• Product differentiation • Pride of ownership, image, fashion • Communication
Costs	• Cost benefits and trade-offs • Appropriate usage of resources
Production	• Manufacture and assembly • Appropriate usage of raw materials • Tooling • Packaging
Product life-cycle	• Life-cycle design • Material selection

Figure 3. Industrial design critical dimensions (Adopted from [Dreyfuss 1967])

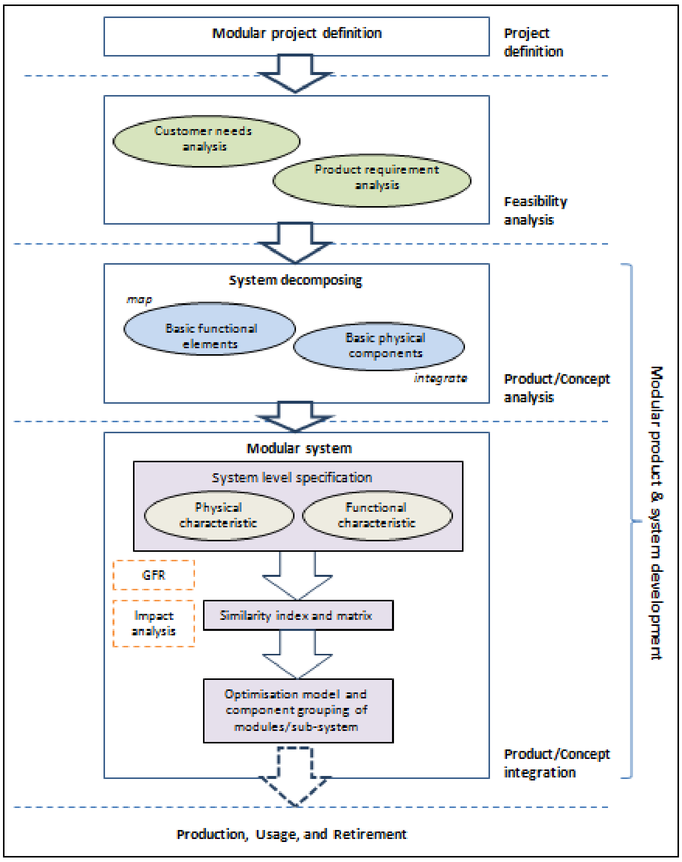

Figure 4. Overview of modular product design process (Adopted from Kamrani and Salhieh, 2000)

Modularity is an approach familiar to most designers. It is a powerful design strategy, which is now becoming an integral part of mainstream strategic management thinking [Sanchez 2002]. To develop a complex product using the modularity concept, a three-phase methodology would normally be applied [Kamrani 1997]. Design for modularity (Refer to Figure 4) provides several classifications [Kamrani and Salhieh 2000] which include 1) Product and problem decomposition. 2) Structural and modular decomposition. 3) Analysis between components and specifications. 4) Application of group technology classification system. 5) Measure matrix construction. 6) Module selection optimization.

4.2 Industrial design in modularity

There is an essential need to develop approaches to apply industrial design in modular product design and several important strategic objectives for industrial design in modularity have been identified. Currently there is a lack of a systemic implementation approach. The common approach adopted by most product organisations is engaging industrial designers with engineers or technical designers as a visual and tactile element specialist mainly to provide aesthetics and human factor values to the product being developed. The approach is generally ad-hoc or localised resulting in an inconsistently managed process without a defined methodology that optimises industrial design's full potential and the designer's capability. The next section will describe the proposed framework for industrial design to support modular product design processes.

4.3 Introduction to InDFM

The aim of InDFM is to provide a systemic method for managing industrial design implementation in modular product design and development. This framework then provides a means to optimise the potential benefits of industrial design that could be applied to both new and existing processes. This will in turn provide greater speed and flexibility in developing new products in addition to supporting faster and economical upgrading of technology for existing products. The final outcome of the application is the production of greater and improved product variants. The specifications of the framework include 1) Provide a method to optimise the potential of industrial design benefits in modular product design and development. 2) Enable the enhancement of the currently used process through the addition of a clearly defined structure containing new design and development elements. 3) Contain an industrial design management capability to optimise the capability of industrial designers in modular design and development. 4) Support collection, management (analyse, select, verify) and transmission of information and data on industrial design requirements. These specifications support application to any modular design and development processes and are flexible to adapt to any changes within the used modular design and development process stage.

4.3.1 Mechanism of InDFM

The InDMF consists of a clearly defined structure (Refer to Figure 5) containing industrial design critical dimensions (CD), which encompass the objective elements of industrial design functions within a generic industrial design (ID) process, a new modular product design and development process, an existing modular product design and development process, and the applied modular product design and development (MPD) process.

To apply the InDFM into a new process, the design team is required to map the activities within the process to the critical dimensions. The mapping is essential as every product development process involves numerous specific activities within each phase that correlate to the critical dimensions and the ID process. The design team need to group the activities into classifications in relation to industrial design processes that could be adopted into the generic tasks within each phase of the new process. For an existing process, the classified activities are incorporated into the generic tasks within each phase. Once all the industrial design elements are established in the processes, the processes can now be used with consistent quality assurance monitoring to ensure efficient management of related resources and timing.

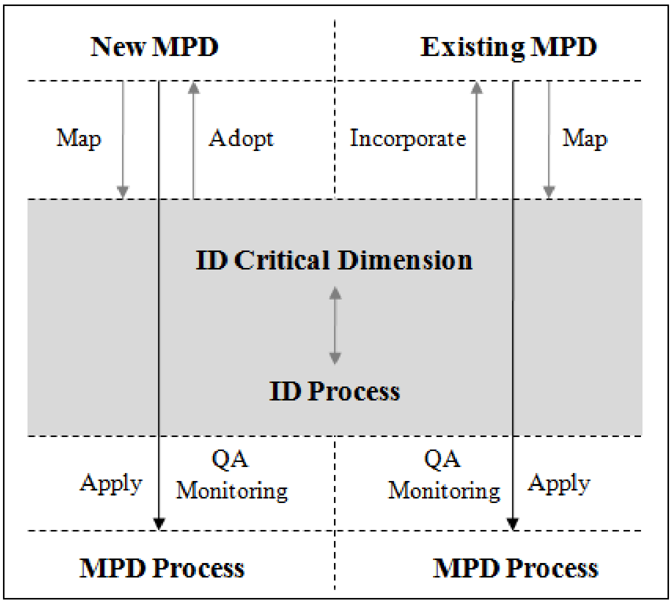

Figure 5. Mechanism of InDFM

4.3.2 Structure of InDFM

The process of structuring the framework begins by using the industrial design critical dimensions to assess the industrial design requirements in a proposed modular product. The basis of the investigation is justifying each sub-dimension (for example – *Ease of use*) against the generic intended functions of the modular product (for example – *Inputting a journey into a satellite navigation system*). The justification task is critical to determine the priority classifications of each sub-dimension within the modular product functions. The classification results are analysed and then used to specify sets of objectives (Refer to Figure 6) in relation to each phase of the industrial design process. Each stage of the industrial design process is then applied to a modular product design process, where the actual requirements of industrial design are needed. There is a tendency that several industrial design processes may apply to some modular product design phases (Refer to Figure 7, 8). This is because these phases, such as *concept generation, and decomposition of functional and physical elements* (Refer to Figure 7, 8) require several industrial design processes to be carried out for the phases to achive its intended function. The integrated processes of industrial design and modular product design is then either adopted as a new process, or incorporate into an existing process.

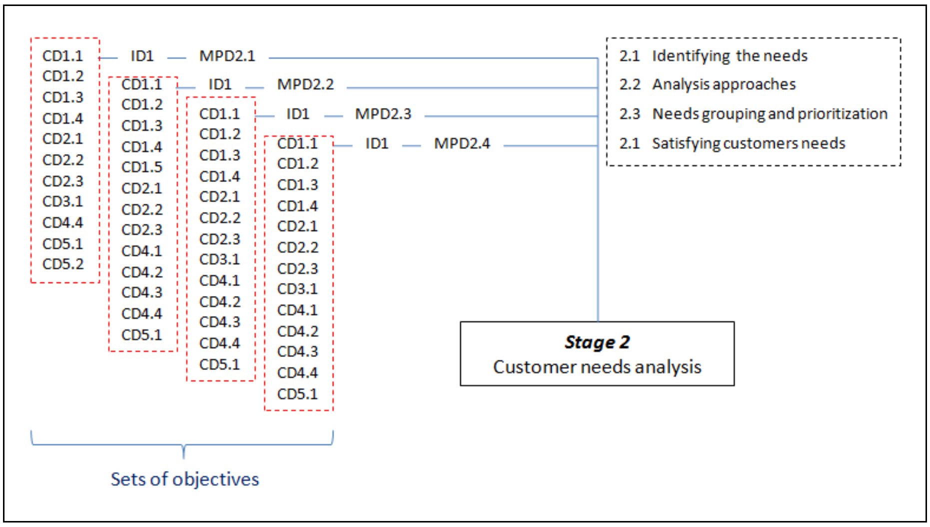

Figure 6. Example of objectives sets for phase 2 of modular product design

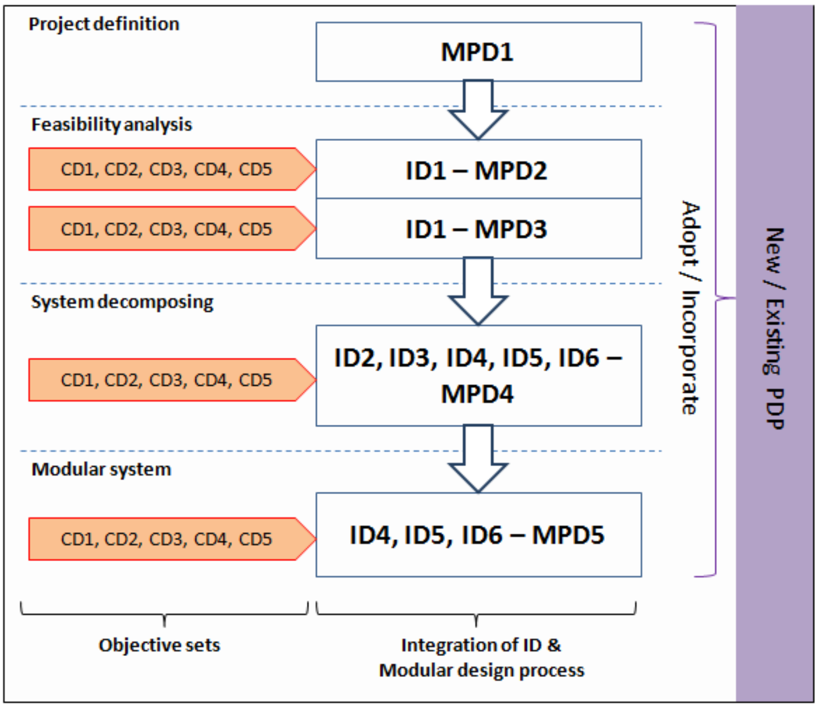

Figure 7. The structure of InDFM; Please refer to Table 1 for the numbering codes

Table 1. Codes references used in InDFM

Modular Product Development	
MPD1	Project definition
MPD2	Customer needs analysis
MPD2.1	Identifying needs
MPD2.2	Analysis approaches
MPD2.3	Needs grouping and prioritisation
MPD2.4	Satisfying customer needs
MPD3	Product requirement analysis
MPD3.1	Customer needs results application
MPD3.2	Weighing general function requirement
MPD4	Product/Concept analysis
MPD4.1	Product/Concept generation
MPD4.2	Decomposition – functional elements
MPD4.3	Decomposition – physical elements
MPD5	Product/Concept integration
MPD5.1	System level specification (SLS)
MPD5.2	Identification of SLS impact on GFR
MPD5.3	Providing similarity index and matrix
MPD5.4	Optimisation and component grouping of modules/sub-system
Generic I.D. Process	
ID1	Investigation of customer needs
ID2	Conceptualisation
ID3	Preliminary refinement
ID4	Final concept selection
ID5	Control drawing
ID6	Coordination with engineer, manufacturer and vendor

Industrial Design Critical Dimension	
CD1	Utilities
CD1.1	Ease of use
CD1.2	Ease of maintenance
CD1.3	Quality and quantity of interaction
CD1.4	Safety
CD1.5	Novelty of user interaction
CD2	Aesthetics
CD2.1	Product differentiation
CD2.2	Pride of ownership, image, fashion
CD2.3	Communication
CD3	Cost
CD3.1	Cost benefits and trade-offs
CD3.2	Appropriate use of resources
CD4	Production
CD4.1	Appropriate usage of raw materials
CD4.2	Tooling
CD4.3	Manufacture and assembly
CD4.4	Packaging
CD5	Product life-cycle
CD5.1	Life-cycle design
CD5.2	Material selection

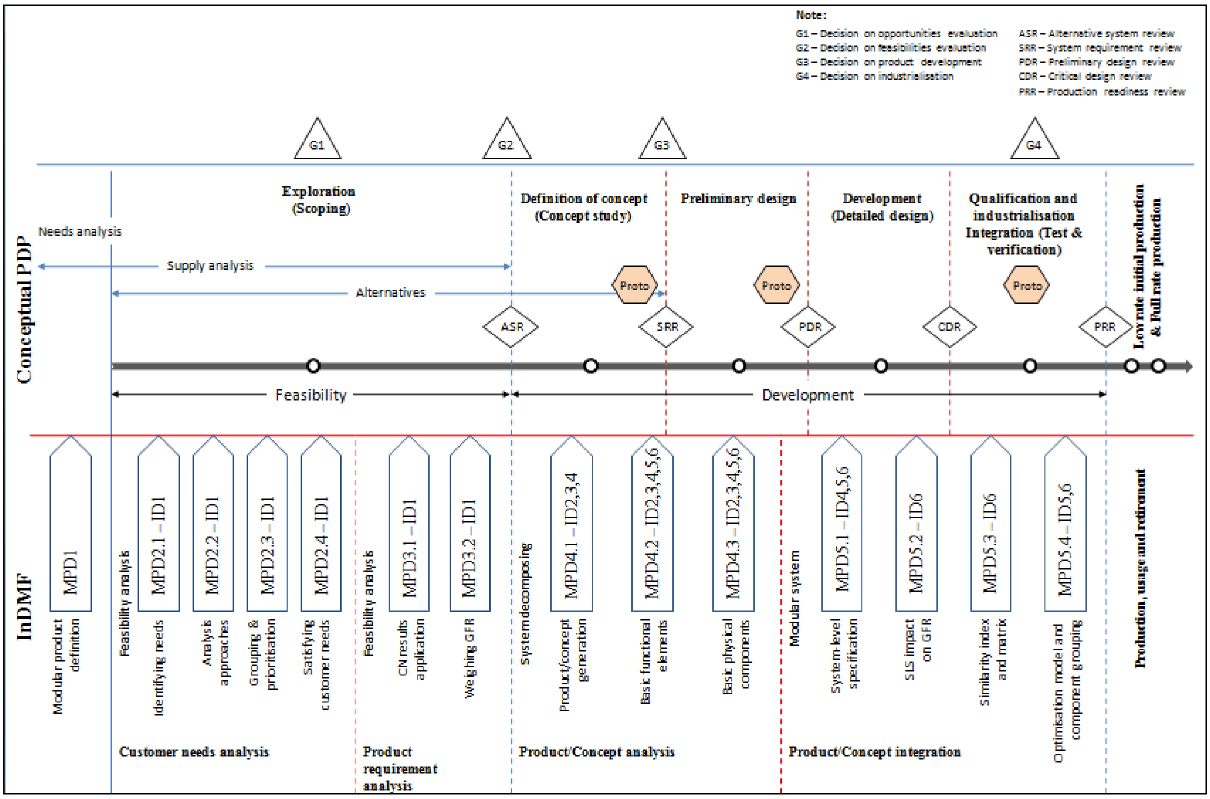

Figure 8. Application of InDFM on a conceptual product design process

4.4 Representation of InDFM

The application example of the InDFM is as shown in Figure 8. There are two (2) main parts in the process configuration, which include the conceptual product design process and the InDFM. The conceptual product design process is a process that is either newly proposed or existing. The InDFM elements that specifically relate to the critical dimensions vary between different products. An example of the conceptual product design process of a company collaborating in the research is adopted. The InDFM is applied to the conceptual process through synchronisation of phases in order to appropriately manage the implementation of industrial design in each phase of the conceptual product design process.

To support the users of the InDFM a set of implementation guidelines is provided. These guidelines are intended to provide an appropriate practical approach for utilising industrial design within a generic modular product design process based on the core activities within each phase. Each guideline is presented as a checkpoint table for reference. The checkpoints used in these guidelines enable the user to determine and respond to the requirements needed in order to accomplish the industrial design input tasks. These checkpoints also facilitate the user in establishing the fundamental objectives of utilising industrial design in their development process by providing a breakdown of subjects that need prior consideration.

The implementation of the InDFM will also support the planning and operational aspects of the whole design and development process by the cross functional team. This provides the team with a defined structure of how and when industrial design should be implemented in each phase. This also provides the team with a parameter on the "hard points" [Sanchez 2002], where changes during component development are not allowed once interfaces between sub-systems of a new product architecture are defined. The InDFM provides a structure that determines the utilisation of industrial design to specific points where the component interface specifications for a new architecture are being investigated, and industrial designers are prepared to work within those interface parameters throughout the design and development process.

5. Conclusion

The development of the InDMF is part of PhD research that aims to provide a systemic approach in optimising industrial design in modular product design and development. The approach is based on the view that industrial design is not fully represented in the modular product development process as an integral part of the design and development strategy where the industrial design process itself represents a large amount of design knowledge. At present the framework is nearing completion and the intention is to perform a qualitative evaluation with a number of European based companies. A model of the InDMF will be presented to the participating companies and retrospectively applied to their existing product development process. Further research on the InDMF will involve implementation of the framework on an actual project, and evaluation and analysis will be done throughout its progress. Further research will also involve the development of the InDMF to support modular product design and development for technology driven products.

By employing the InDFM, it is anticipated that many modular product companies would find it easier to implement and optimise industrial design in their development process in order to produce an exciting, highly competitive and successful product in the market.

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