BORNEO JOURNAL OF SCIENCES AND TECHNOLOGY (BJoST)
VOL. : 04, ISSUE: 02 , 90-98
DOI: http://doi.org/10.35370/bjost.2022.4.2-011
e-ISSN: 2672-7439 © 2018, UTS Publisher.

University of Technology Sarawak

ORIGINAL ARTICLE

Design Optimisation by Industrial Design Framework for Modular Product Design (InDFM): The Case Study of Paediatric Rehabilitation Device (PRD)

*[1]Muhammad Firdaus Abong Abdullah, [2]Prashobh Karunakaran and [2]Mohd Shahril Osman

[1]School of Computing and Creative Media, University of Technology Sarawak, No. 1, Jalan Universiti, 96000 Sibu, Sarawak, Malaysia

[2]School of Engineering and Technology, University of Technology Sarawak, No. 1, Jalan Universiti, 96000 Sibu, Sarawak, Malaysia

ABSTRACT - This research focused on the optimization of design for Paediatric assistive equipment that will be used for rehabilitation therapy and light exercise session. The Industrial Design Framework for Modular Product Design (InDFM) is applied. Product modularity optimization is explored, whereby each type of modularity was characterized by a different set of design attributes such as appearance, durability, and ergonomics, which are all important for product-use modularity. Industrial design applications in a highly technical process of modular design provide a design-driven innovation to complement the engineering driven innovation in the product development process. To evaluate its practicability, the InDFM was retrospectively applied in the design development of Paediatric Rehabilitation device. The evaluation focused on process compatibility of industrial design and modular design processes. Validation of the process compatibility emphasised the quality of integration at all stages of the design and development process in order to enhance the visual, interactive, and the feasibility contents of the device. Furthermore, the optimization approach requires a comprehensive understanding of the different modularity characteristics by designers and it is crucial to design products that address relevant customer needs, such as customization, cost, serviceability, and upgradeability

ARTICLE HISTORY
Received: 10 Apr 2022
Revised: 15 June 2022
Accepted: 10 July 2022

KEYWORDS
Framework,
Industrial Design,
Modular Design,
Customer Needs

INTRODUCTION

Successful product organisations, such as Apple, BMW, Logitech, and Tefal, have been successful mainly due to their emphasis on industrial design. These organisations have made design a priority than technology in their strategic product development plan [1];[2]. Most often product design and development is considered as a process for creating functional differentiation through superior performance and added features of a product. This idea, however, is changing today as industrial design is increasingly being seen as an important strategic tool in creating preference and deeper emotional value for the consumer [2];[3];[4]. Besides, the product design process is a highly complex set of integrated efforts. The complexity of this process increases in modular product design as the decomposition of the product into modules creates a dedicated process for each module. Thus, the ad-hoc approach to the implementation of industrial design to products with complex architectures, such as those that demand a modular approach, has highlighted deficiencies, particularly in aspects of design process management. Additionally, the dynamic nature of product development suggests that a systematic and holistic approach in the application industrial design is required. In order to address these concerns, this research utilised the Industrial Design Framework for Modular Product Design (InDFM). The application of InDFM is supported by a defined and comprehensive technical standard document that is essential for successful application of the framework.

*Corresponding Author: Muhammad Firdaus Abong Abdullah, email: Muhammad.firdaus@uts.edu.my

MODULARITY STRATEGY AND INDUSTRIAL DESIGN

The application of industrial design within product development processes has become essential and is rapidly being recognised as one of the important strategic tools in product development. However, applying industrial design in a modular product design process is a complicated task that requires a precisely defined approach. Besides, a number of research studies have been conducted on modular product design, such as the development of an integrated methodology of modular product design [5]. This methodology contains additional tools and stages for a complete modular architecture design, in which the boundaries of the modular design process are widened by adding strategic issues, appropriateness to modularity, degree of modularity, and strategies of modularity. Integrating industrial design and modular product design processes is basically creating interdisciplinary collaboration between industrial designers and engineers since product modularisation is within the domain of engineering design. The interdisciplinary collaboration could provide better solutions to product design and development issues through complementary knowledge of different experts, whereby improvements can be made easily, and new common knowledge can be developed [6];[7]. Meanwhile, another study explored product modularity optimization [8], whereby each type of modularity was characterised by a different set of design attributes. Attributes, such as appearance, durability, and ergonomics, are all important for product-use modularity, while accessibility, recycling, and cost are key considerations for limited life modularity. All these attributes can provide a product with a competitive edge in the marketplace. Furthermore, the optimisation approach requires a comprehensive understanding of the different modularity characteristics by designers and it is crucial to design products that address relevant customer needs, such as customization, cost, serviceability, and upgradeability.

PEADIATRIC REHABILITATION DEVICE

To show the different modular characteristic of a product, the researcher highlighted a case study of a product with a series of Paediatric Rehabilitation Device (PRD) (Refer to Figure 1). The PRD is an assistive machine or device for exercise, therapy and rehabilitation of young patients with inability to move unassisted. The device also functions as supine gait rehabilitation for sub-acute stroke patients that focuses on the patient's lower limbs with motion or movements programmed to simulate exercise conducted by certified professional physiotherapist. The researcher demonstrated in the PRD product family that industrial design has played a critical role in providing spatial styling variations while maintaining the same degree of user interaction and ergonomics. Industrial design in this products, provides some of the few critical differentiators in developing compelling, and globally competitive brand propositions [4];[9].

Figure 1. PRD in used by sub-acute stroke patient rehabilitation and therapy.

DESIGN OPTIMISATION BY *InDFM*

InDFM is a generic framework, which can be applied in any modular product design. Based on this notion, the strategic importance of the industrial design framework for modular product design can be perceived as in the following (Refer to Table 1):

Table 1. Strategic importance of industrial design (Source: [10]).

Strategic Importance	Strategic tasks
Design concepts	Developing design concepts for more extensive product lines in order to increase product variety.
Product design refreshment	Refreshing product designs through styling changes in visible components for technologically mature modular products.
Styling variation	An essential role in modular product strategies by creating styling variations that can effectively distinguish individual product models within a modular product family.
Technology upgrade	Helping to bring a series of technologically upgraded products to market in rapid succession
Performance variation	Providing effective differentiation of new product models by stylising in order to communicate visually the improved technical performance of the new product.

The application of *InDFM* is vital in the industry sector as the potential of industrial design is currently less noticeable and generally ignored, especially in the consumer medical (Rehabilitation) sector. The products of these industries are mostly developed according to integral architecture, thus, the product design process is dedicated to a specific product. A new design process is then needed for another product, even if the product is from the same family line. Due to this, the researcher focused on the benefits of industrial design intervention, accessibility, and opportunism in design development for this sector in view of the fact that the products are designed with user-centred consideration (Refer to Figure 2).

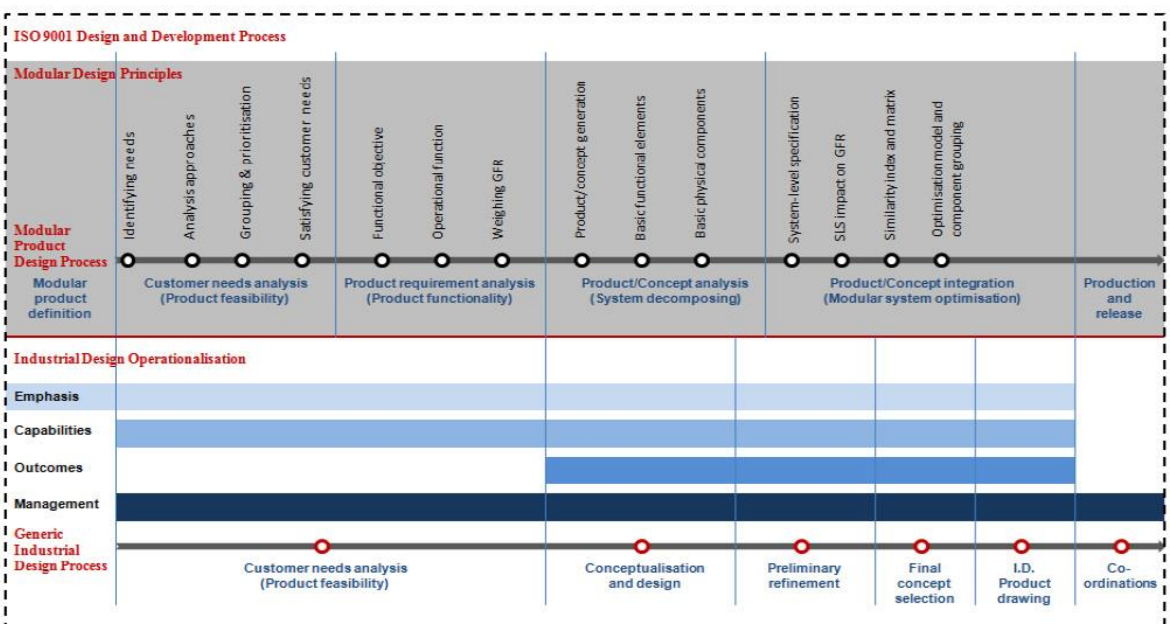

Figure 2. InDFM detail: formed with integration of key elements clearly shows how each element interacts within the new process environment.

Design Outcome

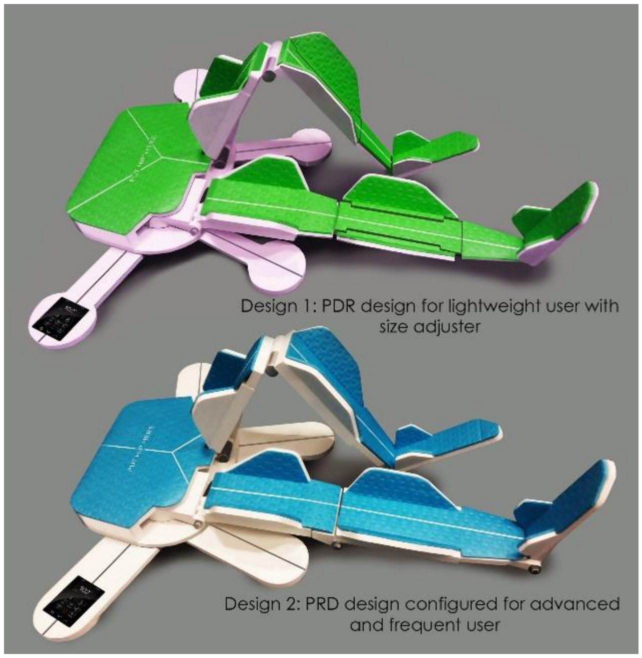

Figure 3. PRD proposed product range.

Most of the products in the market today rely heavily on the market needs and the drive to top the competitors list; therefore, innovation in products is generally influenced by competition that is purely on the basis of price, which in turn determines the overall features and performance of the product. The consumer medical products in the market today are mature in terms of concept and application. The fundamental design of the products is also similar. In order to have the competitive edge, many product companies turn to product styling to differentiate their product from their competitors. The styling differences of the product can have a significant impact and perception of the customers. The creativity and the innovation aspects of the design also need to be visually and technologically distinctive for a product to have significant advantages in the consumer product market, as demonstrated by proposed *PRD* product range (Refer to Figure 3). This approach requires product companies to be creative and innovative at every phase of the product development process right from identifying opportunities, designing, and engineering aspects of the product.

PRD Modular Architecture

A modular architecture has a one-to-one correspondence between modules and functions. It is built of sub-systems or modules that interact with each other, and allows design change to be made to a module without changes to other modules for the product to function properly. The configurability is achieved by specifying component interfaces that allow the substitution of component variations into the product design, without having to change the design of other components in the product architecture both in functional and physical way [10]. This provides greater improvement in product re-configurability, which increases variety and the speed of introduction of a new product into the competitive market. Maintenance and service of the product is also easier as spares and replacement components are readily available due to subsequent modularisation of these components. Where mass production has shifted to mass customisation, *PRD* could also be manufactured in massive amount to meet customers' requirement, in a manner that is economically viable.

DESIGN STIMULATION

Based on the investigation on the design and development approach for *PRD*, the researcher underlined several factors that stimulated the major needs for industrial design. These needs could be addressed through the integration of industrial design and modularity concept within the process. The needs were observed in two vital activities encompassing *design* and *management*. The following are factors that prompted the industrial design needs:

Design

1. ***Integral design*** – The *PRD* has specialised system configurations resulting in integral design solutions.
2. ***Functional analysis*** – had never been conducted in the product design and development process.
3. ***Product value*** – There was lack of distinctive values in the existing product range.
4. ***Product development process*** – had been too focused on solutions instead of functions with no integration of both solutions and functions.
5. ***Innovation restriction*** – There has been a restricted approach to innovative design as the design of products is closely linked to the technology and manufacturing factors.

Management

1. ***Contentment*** – the existing design and development process restricts innovative design and development approach.
2. ***Customer preference*** – Unconventional product design configuration is not well accepted by customers.
3. ***Second choice*** – The concept of industrial design and modularity were not considered a priority in the process.

IMPLEMENTATION

During the investigation on the design and development process used, the researcher found that the process was ‘extensive and complicated’. Therefore, to facilitate the research, an investigation approach is proposed (Refer to Figure 4) on how the researcher could be involved in the investigation and implementation of *InDMF* in the design and development process of the *PRD*. The investigation approach was basically a schedule plan of how and when the researcher was going to be involved throughout the analysis period. The application of the investigation approach required the researcher to collaborate with the design engineer in each stage of the process to facilitate efficient integration of the *InDFM* within the process that was employed.

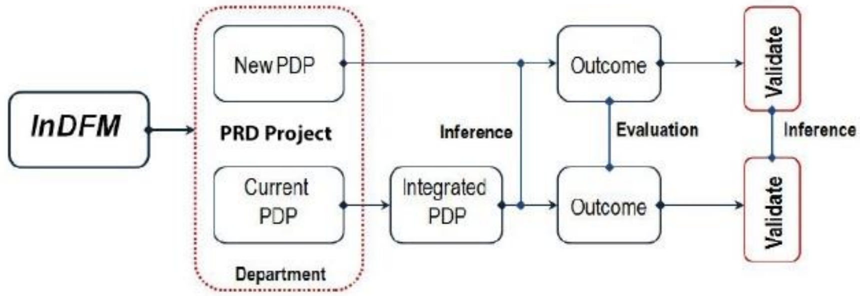

Figure 4. *InDFM* implementation process outline for *PRD*

The following are the elaboration of the research investigation and the involvement plan in implementing the framework process:

1. ***InDFM*** – The *InDFM* was introduced in detail to the design managers and engineers. The introduction task was crucial to get the design managers and engineers to fully understand the concept of *InDFM* before they could apply it within the project phase.
2. ***New PDP*** – The first step in applying *InDFM* in new product development process (PDP) was by fully integrating *InDFM* within the new PDP. This was done by convincing the product development managers about how *InDFM* could be useful to enhance the total PDP.
3. ***Current PDP*** – The *InDFM* needed to be retrospectively integrated into the current PDP. The researcher collaborated with the design engineer to identify the appropriate stages of the current process where industrial design and modularity aspects could be applied.
4. ***Integrated PDP*** – Each identified stage was comprehensively analysed to verify the appropriate industrial design and modularity aspect. The analysis was a significant step to ensure that the newly introduced aspects did not compromise product specifications. An analysis was also conducted to determine the inferences between the new PDP (with *InDFM*) and the current PDP (with *InDFM*).
5. ***Outcome*** – The outcomes from the application of *InDFM* into the new and the employed PDP were recorded and analysed. The results of the analysis were then used as a reference for further improvement and development. The physical outcome from the implementation was evaluated through a standard evaluation form.
6. ***Validate*** – The feasibility of *InDFM* was validated with the product design and development manager. The validation task encompassed all the stages involved in the PDP. The validation task involved qualitative analysis of the evaluation outcome (through the standard evaluation form), in which the outcome of the analysis were then endorsed by the design and development manager for approval or rejection.

DISCUSSION

The properties of the framework initially seem to be rather paradoxical or inconsistent. The methodology of industrial design itself emphasised on cognitive skills, which relates directly to the human characteristics, needs, and interests, thus generating creativity and innovation beyond scientific reasoning. The *InDFM* seeks to expand the area of knowledge and revise the identity of the *PRD* through industrial design creativity and innovativeness by adopting the strategy of *'variety'* [2], which is the ability to propose a wide range of possible forms from a given conceptual brief. The implementation of *InDFM* in the project had given the design team the option to expand the functions and the appearance characteristics within the existing design concept, as well as in facilitating the application of creativity techniques and innovative design function of industrial design throughout the entire process.

The *InDFM* implementation on the *PDR* system (Refer to Figure 5) is discussed based on two (2) main justifications: – i). *Analysis of Implementation function* and ii). *Compatibility with existing process*. Although the implementation of the *InDFM* initially seemed to be a relatively complex task, a comprehensive functional description of the framework was proposed and explained to associate the analysis of the possible *InDFM* functions within the modular design process. In supporting the functional description, the subscripts and the implementation codes were added to the generalised descriptions of each design and development stages, such as those that assist in the implementation start-up. Meanwhile, the *Product Definition* (Code: *MPD1*) stage involved the company's strategic planning exercise, i.e., making decision to include (or exclude) industrial design in the modular product design process. If the decision was made to include industrial design – the scale of *Industrial Design Measures* (Code: *EM, CA, MG,* and *OC*) must be determined prior to the induction of the project definition. For this research, only *EM* (Industrial Design *Emphasis*) was applicable as the other measures were only significant in the next following stages. Besides, the analysis of process compatibility must be conducted against the design research process documents if retrospective implementation of the *InDFM* is required in the existing design and development process.

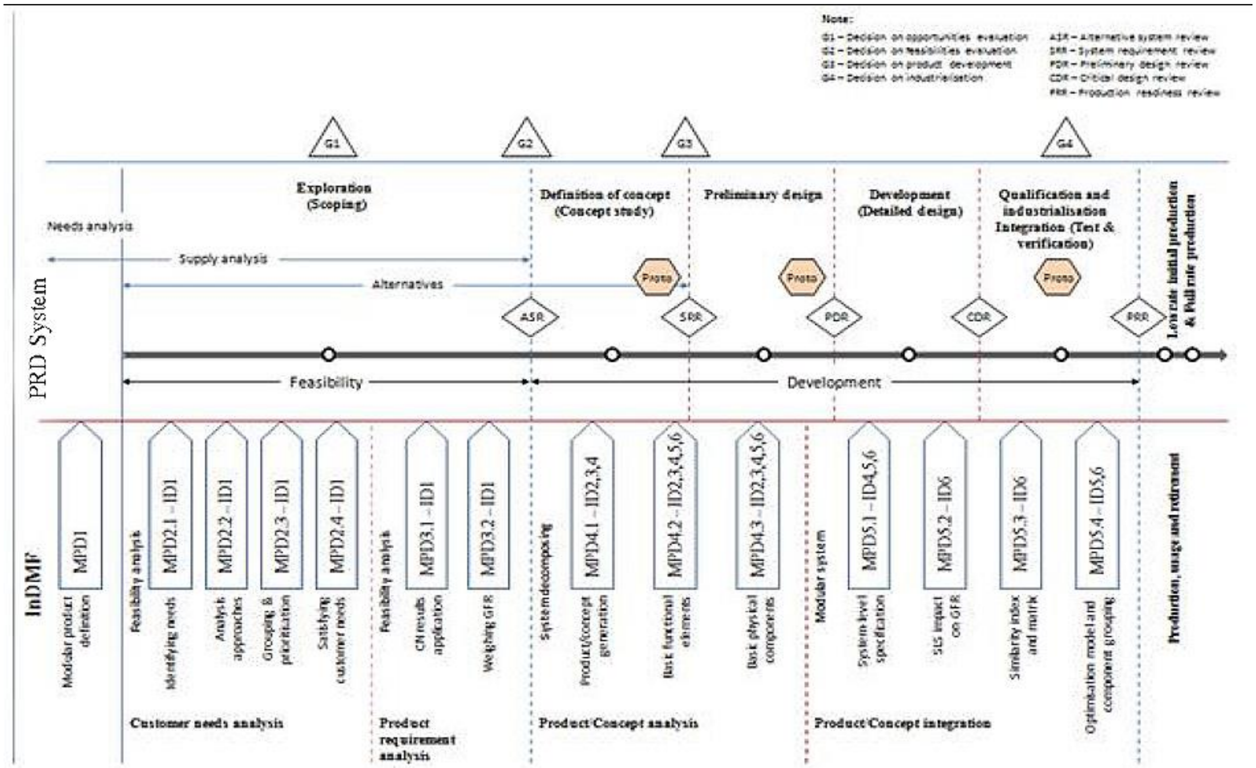

Figure 5. An overview of the *InDFM* on the *PRD* system product development process

For this particular design project, the *Customers' Needs Analysis* (*Code: MPD2*) tasks were already defined by the user and the initial product functional requirements were already established prior to product design and development request. The industrial design measures involved *EM, CA*, and *MG* at all stages of *MPD2*. Moreover, the *OC* (outcome) measure was not conducted at this stage because there was basically no need of tangible output at this stage. At this stage, the potential of industrial design in the aspect of customer and functional requirements investigation had been concerned with *Product Usability*

(Code: *CD1*) and *Appearance* (Code: *CD2*). On expanding the area of knowledge, the design team also conducted investigations for potential new customers and functional requirements. This stage also saw the design team conducting analysis on the *PRD* competitions, which were vital data for any possible product enhancement opportunities. These data could also be used to formulate new product variations. In addition, grouping and prioritising the needs requirement stage had been varied based on product operational and physical configurations. This stage determined the variations of the product from the basic configuration up to the specialized configuration for a specific rehabilitation and exercise stages. The product variants derived from this stage must be able to satisfy the specific needs of the users, on both the functionality and appearance aspects. Moreover, the task of satisfying the needs was vital and highly emphasised as dissatisfaction on the required needs could lead to design and technical revisions of the entire product system. The design team was always alert of this circumstance, and the *InDFM* standards further established the alertness.

As for the *Product Requirement Analysis* (Code: *MPD3*) stage, the basic functional objective of the product was determined by the user. However, further discussions were also done with the design team to propose a secondary objective in case needed. In the existing product design process that was employed, the design team did not conduct any basic product functional analysis because the basic product functions had been established. The implementation of the *InDFM* opened a new approach to this task as the design team was able to propose alternative functional applications through modifications of the product configuration in order to meet a variety of other rehabilitation functions, such as continuous passive motion (CPM), supine gait rehabilitation, gait training therapy, and electrical muscle stimulation. The proposals for alternative functional applications, however, experienced several major constraints, particularly in relation to component modularity and compatibility issues. Similar to *MPD2*, the industrial design measures involved *EM, CA*, and *MG* at all stages of *MPD3*. The *OC* (outcome) measure, however, was not conducted at this stage because there was basically no need of tangible output at this stage. The other elements for consideration included *CD3* (*Cost* – which considered cost benefits and trade-off, as well as the appropriate use of resources involved in the design process), *CD4* (*Production* – which considered the appropriate use of material, tooling and production techniques, as well as product packaging), and *CD5* (*Product life-cycle* – which considered the product life-cycle planning and the appropriate material selection to ensure sustainable design). Meanwhile, in *MPD3: 3.3*, several requirements were identified and assigned based on their importance – User needs for specific components, accessories, and the procurement quantity were included in the requirements. The highest priority requirement was to rectify the limitation of earlier prototype models through improved basic features in the new design. Furthermore, the *System Decomposition* (Code: *MPD4*) stage included the creative potentials of industrial design. The generation of conceptual ideas for this project had been limited by the general function requirements that had been set by the client. However, the creativity of the Industrial Designers was concentrated on enhancing the user product interaction and appearance of the product for specific operation. The ideas were further developed to reach a point where embodiment solution was discovered. Besides, the final design of the product allowed integration and connection of sub-components (and sub-systems). Most aspects of the industrial design process and critical dimensions had been applied as well, and in addition, all industrial design measures were considered.

Lastly, the *System Optimisation* stage (Code: *MPD5*) established the modules as a working component and a complete product, while the output from the decomposition enabled the component to be integrated into a functional system.

ACKNOWLEDGEMENT

This research was supported and funded by the University of Technology Sarawak under UTS Research Grant (URG) 'URG 4/2017/03'. The authors would also like to thank the anonymous reviewers for the invaluable suggestions to improve the accuracy and quality of information written in this article.

REFERENCES

[1] Turner, D. *The Secret of Apple Design*, MIT Technology Review, Issue May/June 2007

[2] Masson, P. L., Weil, B., Hatchuel, A. *Strategic Management of Innovation and Design*, Cambridge University Press, Cambridge, UK, ISBN 978-0-521-18243-0.2010

[3] Melles, G., Kuys, B. *Legitimating Industrial Design as an Academic Discipline in the Context of an Australian Cooperative Centre*, Procedia Social and Behavioral Sciences 2, Page 5228–5232.2010

[4] Mostowics, E. and Grzecznowska, A. *Industrial design: A competitive strategy.* Design Management Journal. Vol. 15.2004

[5] Asan, U., Polat, S., Serdar, S. *An Integrated Method for Designing Modular Products*, Journal of Manufacturing Technology Management, Vol. 15 Issue 1, Page 29 – 49, ISSN: 1741-038X.2004

[6] Wang, L., Shen, W., Xie, H., Neelamkavil, J., Pardasani, A. *Collaborative Conceptual Design – State of the Art and Future Trends*, Computer-Aided Design, Vol. 34, Page 981-996.2009

[7] Rossi, R.M., Brown, D., Park, B., Boser, R. *The Integrated Design Process on Paper and In Practice: A Case Study*, Proceeding of the 2009 ASC Region III Conference, Downers Grove, Illinois.2009

[8] Simpson, T.W., Siddique, Z., Jiao, J. *Product Platform and Product Family Design: Methods and Applications*, Springer, New York, U.S.A., Page 1-15.2005

[9] Juratovac, J. *Building a bridge to the end user: How industrial designers contribute to product development.* The PDMA Handbook of New Product Development (Second Edition). John Wiley and Son, Inc. Hoboken, New Jersey, U.S.A.2005

[10] Sanchez, R. *Using Modularity to Manage the Interactions of Technical and Industrial Design*, Design Management Journal, 2, Page 8.2002