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Enhancing design sensitivity and creativity in the detailing and materialisation stages of the design process through specific models and prototypes

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Abstract

In design education, detailing and materialisation activities are often underemphasised in a structured design process. Educators tend to teach students to focus on defining problems, developing creative design solution, as well as communicating the "nearly completed designs" through modes of holistic and refined representation, which misconceptually creates a perception of completeness among stakeholders. One of the main reasons are that time constraints in the detailing and materialisation activities, initiated other modes of presentation, which are faster, such as CAD, but lacks tactility and interactivity. Moreover, students´ misconceptions that creative "award-winning" explorations mainly take place in the idea and conceptualisation stages are myths, which need to be seriously addressed in design education.
The aim of this article is to propose a systematic approach for design practice and education to select the most appropriate models and prototypes to facilitate divergence, creativity and focus in the detailing and materialisation stages of the designing process. Moreover, as students and junior designers tend to converge towards concrete solutions quite early in the design process once detailing and materialisation work in being emphasised and prioritised, the authors propose to maintain an intensive cognitive and descriptive approach for analysing design problems and generating solutions, followed by a strict process of idea generation and conceptualisation. However this, strict development process should be compensated through a more extended divergence and convergence process in the detailing and materialisation stages using models and prototypes, complemented by a "master" and "apprenticeship" interactions between student and faculty which give ample room for hermeneutic inquiry and design reasoning.

Keywords: Models and prototypes, Detailing and Materialisation, Design Education

1 Introduction

In the design process, models and prototypes are produced to answer designers' questions, which arise during the design development. Broek, et. al. [1] claimed that models and prototypes can help designers to manage their design processes more effectively and efficiently, making them an indispensable tools for these designers to enhance their creativity in developing new and redesigning existing products [2]. According to Hallgrimson [2], Kelly

[3], Vandevelde, et. al. [4] and Kojima [5], physical modelling and prototyping are one of the most recognised and acceptable approaches used by designers to visualise and communicate their design solution. The aims, advantages and challenges of using models and prototypes have been extensively discussed by many researchers [2,3,5,6,7]. It has been generally agreed upon that models and prototypes are tools for investigating a design concept on its function and appearance. Furthermore, models and prototypes are used to enrich design processes self-reflection and communication activities, with or without the participation of stakeholders, especially when it concerns designer – client relationships.

In design education, Charlesworth [8] says physical modelling has always been used by design students to develop and communicate their ideas. However, the introduction of 3D computer modelling software has transitioned hands-on visualisation approaches, which were characterised by a slow, dirty and difficult process of making, into a quick and clean virtual way of designing and prototyping. On a more careful note, Charlesworth [8] added that the designer might face greater challenges and limitations when using CAD in the materialisation and realisation stages than originally anticipated (p.35). This is attributed to the lack of good information from educators to design students about the purpose and the effectiveness of models and prototypes and how these tools may contribute to enhancing students´ creativity and sensitivity. According to Ledewitz [9], design thinking and communication skills, as well as problem solving and project planning expertise are more effectively taught indirectly through experience than by instruction. In other words, it is hard to explain “designing” to the students without having them experiencing it themselves through a process of experiential learning [10]. Kolb’s learning theory is built upon a four stage learning cycle, which offers a way to understand individual learning styles according to two spectral axes. These axes are respectively: “Active Experimentation – Reflective Observation” and “Concrete Experience – Abstract Conceptualisation”. Furthermore, Goldschmidt and Rodgers [11] showed that the more experienced students are more analytically engaged displaying a more systematic design behaviour compared to less experienced students. This claim is supported by Romer et al´s [12] research, indicating that a significant 50 percent of less experienced design students use sketches and models extensively during the conceptualisation stages, but do not engage in experimentations in the final stages of the design process to make something work. However, Charlesworth [8] partly rejects the above claims, stating that final year students do use physical models in their design development process.

At the cross-road of modelmaking and prototyping, learning and design education (see figure 1), this article proposes a systematic approach for teaching design students how to select the most appropriate models and prototypes to facilitate divergence and creativity in the detailing and materialisation stages of the designing process.

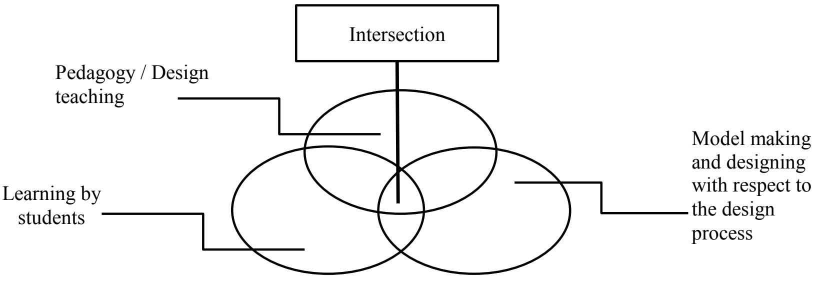

Figure 1 : Intersection among modelmaking and prototyping, learning and design education

Coherently, the following research questions will be addressed: (RQ1) What type of models and prototypes are most suited for developing detail design solutions and to what extent can they broaden the creative space in this rather converging stage of designing? (RQ2) How and to what extent can these typical models and prototypes contribute to form, construction and user sensitivity among design students in the detail design stage? (RQ3) Do elaborate explorations through model making in the detail design stage have an influence on how design students manage creativity, accuracy and proof of functionality in earlier idea generation and conceptualisation stages of the design process? RQ 4: What pedagogical approach and student – faculty relationship need to be adopted to facilitate design sensitivity and creativity in the detailing and materialisation stage?

2 How models and prototypes facilitate different modes of learning and teaching with respect to design detailing and materialisation stages

Biggs [13], Liem [14] and Faerm [15] shared that many educators faced major challenges in sustaining academic standards in today's higher education. According to Biggs [13] effective teaching methods will increase students′ engagements with the appropriate learning activities. Due to globalisation trends and pressures on "mature and new economies" which requires highly skilled and knowledgeable human resources, educator and learners should be more reflective and critical towards which methods of learning should be promoted in which contexts. They should create a common understanding of "what" should be taught and "what" should be explored and experimented in first instance. Faerm [15] emphasized that today's Industrial Design educator must adopt a radically different and creative teaching strategy to adapt to a paradigm shift in the formation of design education, from a traditional and vocational emphasis on "making" to a broader interdisciplinary focus on "design thinking". Educators should also re-evaluate their teaching method by establishing far more deeper personalized teacher-student relationships if they want to effectively guide and nurture the students. Given this situation, educators must not only be well versed in communicating and transferring project relevant design methodologies [15], but also be capable of acknowledging and working with synergies between research and teaching. According to Liem [14], a more the following approaches in design teaching and learning should be examined: Systematic and Process-oriented Design Teaching, Reflective and Experiential Learning, and Learning through a Master-Apprentice relationship in design.

In systematic and process-oriented design teaching, students are taught a strict development process of problems solving [16]. The central concept in such a process, is the systematic and deterministic ways of designing, inspired by a mechanistically inspired engineering process. Here the main problem is partitioned into smaller sub-problems accompanied by sub-processes, which can be solved using problem-solving methods [17]. Although interaction, divergence and convergence take place in a strict development process, students tend to perceive it as a kind of "recipe" for designing. With respect to models and prototypes, modes of representation are then specifically dedicated to certain stages of the process. For example, a sketch model out of foam is being created to complement the idea generation stages, whereas a non-functional design model is created to supplement the final design. This somehow prescriptive approach on how to use models to support the designing activity may restrict to some extent creative thinking. Consequently, it will also lead to a rather narrow exploration of design detailing and materialisation space.

In terms of learning, several problems were observed with a systematic and process-oriented design process. A somehow linear design approach makes students unable to carry forward and integrate learnings from one stage to the next. They find it difficult to revisit some earlier design decisions, which might qualitatively improve the design [18]. From this perspective, the author argues for a more constructionist reflection-in-action approach as a reaction to the rational problem-solving philosophy [19]. As design problems are unique and difficult to generalize, designers' or developers' actions and efforts, should focus on reflective and conjectural conversations with the situation in order to reinterpret and improve the problem as a whole. Methods applied by the designer are to be based on acquired knowledge, experience, and reasoning. This approach is in line with Kolb's theory on experiential learning, where individual learning styles are made explicit according to two spectral axes. These axes are respectively: "Active Experimentation – Reflective Observation" and "Concrete Experience – Abstract Conceptualisation". In terms of representation and exploration, such an approach in designing and design learning will facilitate the use of a broader spectrum of model making and prototyping methods and tools

Learning through Master-Apprentice relationships in design has its roots in the hermeneutic ways of reasoning. Here, the central challenge for the master and apprentice is to gain a sustained and increasing understanding of the designed product, its contexts, values, and functions until the both have decided that saturation has been reached [20]. As the potential solutions and the choices faced are practically infinite, the design apprentice must, with the help of the master, reduce variety by establishing a direct understanding among its objectives, processes and solution [21]. The implication that the designer's personal experience and subjectivity in the designing process are essential qualities, demands a research-based learning approach, where the "apprentice" is encouraged to learn from the "master" and have direct access to the latest knowledge and ideas from the "master". In return, the "master" can assign the students to assist him to search for new knowledge.

3 Physical Models and Prototypes as a Learning Tools in Design Process

Modelmaking and prototyping are focal areas in Industrial Design education. Every Industrial design student should have basic skills in model making to explore form, composition and functionality from idea development to detail design. Being involved in modelmaking at an early stage, may enhance the "junior designer´s" critical understanding of the design process and experience with experimentation and design decision making [22]. Hence in industry, models and prototypes are being revisited and getting more acknowledged compared to 3D computer and Virtual Reality models, because of their interactive and haptic qualities. These qualities are invaluable for design communication among different stakeholders. [2, 12, 22].

In his studies, Evans [23] has indicated the possibility that CAD, haptic feedback interfaces and virtual reality may replace physical modelling as tools for design development. However, Charlesworth (2007) claims that virtual reality methods and tools are merely complementary, whereas physical models and prototypes have proven to be recognized in design industry. In this article, the authors agree with Charlesworth [8] and Kelly [3] supporting the existence of physical models and renouncing the dependency on virtual models as a tool for solving design problems.

To avoid misconception during the materialisation and detailing stages in the design process, new learning concepts and tools are needed to assist design educators in transferring knowledge and skills to design students. Educators and students in product design should re-think the functionality of 3D physical models as these tools are not only useful in for generating design ideas, but in conceptualising and materialising the detailing aspects of the final design. Aiming to inculcate a sense of urgency among design students to develop final design concepts with high quality of detailing, this paper proposes several learning concepts on how to use 3D visualisation, as a tool to communicate among product designers and to achieve better understanding on how physical models and prototypes can be used during detail designing and materialisation stages.

4 Creativity in the Design Process

Various literature studies support the fact that designers use their creativity in developing a wide variety of physical models based on their intuition and experience [3, 24, 12, 25]. According to Viswanathan and Linsey [24] there is a limitation as how to teach creativity to designers. However, Hasirci and Demirkan [26], claim that teaching students creativity methods and techniques can stimulate creativity. Loewy, [27] mentioned that the most important design discoveries took place during modelmaking practices with various materials in the detailing and refinement stages of the design process. He suggested that students should be given a freedom to develop their own design methods and tools by encouraging them to experiment with materials and constructions without being worried of making mistakes or exceeding deadlines.

By appropriately using physical models in the design process, it can help the designers to evaluate and fine-tune their final design as well as confirm certain critical requirements. In this context, Viswanathan and Linsey's experiment also demonstrated that creating appropriate physical prototypes enhances the designer´s innovative and creative capabilities at a micro-level of idea generation and conceptualisation, which may contribute to a more elaborate materialisation and detailing design activities. Complementary, Steffany [22] also found in her research that models are one of the greatest assets in inspiring, developing and improving students awareness about aesthetics, construction, durability, proportion, scale, sensory, quality or any other educational dimension.

The use of creativity techniques in design processes can effectively assist designers´ materialisation and detailing activities. Similarly as in industry, Hsiao and Chou [28] proposed a Creativity-driven Design Process to be used in design education. According to them an appropriate product design process comprises of integrated creative, analytical and development activities. Additionally, they developed a creativity method based on the natural sensuous ability of human beings, known as "Sensuous Association Method (SAM)", which main purpose is to produce creative ideas to facilitate designer's individual association and stimulation [28, p.423]. Hasirci and Demirkan [26] also proposed a creative design process, adapted from the five stages (5R's) of the Sensational Thinking model of O'Neill and Shallcross. Green [29] also designed a seven stage Major Project Development Model (MPD Model), which has been implemented in industrial design teaching at the University of New South Wales. In table 1, three creative design models were mapped against several stages of the designing process as well as their innate human activities. More specifically, different types of operational activities supporting the SAM and MPD model /methods are then reflected upon how each human activity embraces certain creative methods. A literature survey has shown that these three creative methods have contributed to insights on the role of complex of models and prototypes in facilitating creativity and synthesis throughout all stages of the designing processes, especially with respect to detailing and materialisation [26, 28, 29].

Table 1 : Three Modes of creative methods with its proposed operation adapted from Hsiao et al [28], Hasirci and Demirkan [26], and Green [29]

Sensuous Association Method (SAM) Hsao et al. (2008)		**Adapted 5R's Sensational Thinking Model of O'Neill and Shallcross** Hasirci and Demirkan (2010)		**Major Project Development Model (MPD Model)** Green (2007)	
Human Senses	**Operation**	**5 R's stages**	**Operation**	**Phase of MPD**	**Operation**
Looking: Look at the involved things	Gather group of team designer in informative and creative environment	***Readiness:*** activity that being open on possibilities	Imagery, ideas searching and observation.	***Product Planning (PP):*** determine a new product idea	Literature search , Benchmarking, SWOT analysis,
Thinking : Think about origins and evolutionary trends	***Discussions begins:*** thinking logically about the origins and evolutionary trends of target product	***Reception:*** To experience fully and observe with all senses	imagination, generation, idea selection, refinement evident	***Task clarification (TC):*** negotiating brief with the client	Objectives-tree method, Function analysis
				Concept Generation (CG): creative design concepts	Brainstorming, Concept selection, Morphological
Comparing: Compare "what you see" with "what you think"	***SAM:*** participant has to compare their associations with information/pictures observation and contemplation	***Reflection:*** Remembering activity and allowing time for internal interaction	evaluation, idea development, enriching, expanding discovery	***Evaluation and Refinement (ER) :*** analytical and creative tasks are evaluated	House of Quality , Design by drawing, CAD, Design review
				Detailed Design (DD) : developing and validating concept	CAD , Value Engineering, Robust design
Describing: Describe your mental image	must be described in a sensuous phrase, and written down by the recorder.	***Revelation:*** Focusing and pattern recognition.	develop and enhance the idea	***Communication of Results (CR):*** Communicate detail concept to client via 2D / 3D media	Design drawings, Renderings, Prototypes
Stimulation: designer's creative inspiration is increased through interaction	members' interactions will stimulate each other's creative inspirations in a highly conducive environments.	***Recreation:*** To determine full contents and express it by various methods, such as drawing	final representation for missing parts, finishes.	***Preparation for Production (PP) :*** determine the needs of product production.	Revised cost visibility, statistical process control, Fault tree analysis, CAD

According to Jones [30] the creative design process comprises of three essential stages: analysis, synthesis and evaluation. The process can be described as breaking the problem into pieces, putting the pieces together in a new way and testing it to discover the consequences of putting new arrangement into practice. Figure 2, which shows the creativity based design process adapted from Jones [30] indicates that "Transformation" and "Convergence" happens at the three stages. In the transformation and convergence stages, the detailing and materialisation processes are integrated with Green's model for measuring complexity of projects and Welch's theoretical and empirical codes for problem solving in design process. The contribution of Green [29] to the model is more focused towards Industrial Design practice where ten categories of assessment determine certain learning objectives that are essential for Industrial Design students to develop their sensitivity and creativity with respect to materialisation and detailing. Meanwhile, Welch´s [31] proposed coding schemes for evaluating student's problem solving and designing skills through three-dimensional modelling.

Although there are ample methods and tools for modelling, improving and building a solution as well as evaluating it, limited research has been conducted concerning selecting the right type of models and prototypes to be applied during the design process, especially with respect to materialisation and detailing stages. As a result, design educators often overlook the importance to train students to select suitable methodologies to develop physical models to facilitate choosing appropriate materials, developing technical constructions and confirming final finishes [1]. However, few approaches were proposed by various researchers to construct physical model to facilitate the design process. As proposed by Michaelraj [25] and Steffany [22], the taxonomy of physical models is one of the approaches that support both educators and students in respectively their teaching and learning practices. With respect to creative methods and processes outlined in table 1 and figure 2, Michaelraj [18] described various purposes and applications of physical prototypes, which support learning, communication and integration. Furthermore, he indicates the need for this taxonomy to formalise milestones in the design process and guide designers in selecting and identifying the appropriate prototypes in specific design scenarios. In short, the "Taxonomy Physical Model" by Michaelraj [18] can be used as a roadmap to examine appropriate methods and processes for developing detail design solutions and materialisation design activities. As there are limited taxonomies of prototypes, which clearly explain features and functionalities of prototypes, Michaelraj [18], urged designers to know prototype taxonomy, because it will facilitate them to create models and prototypes in an efficient way decreasing complications in fabrication and material selection.

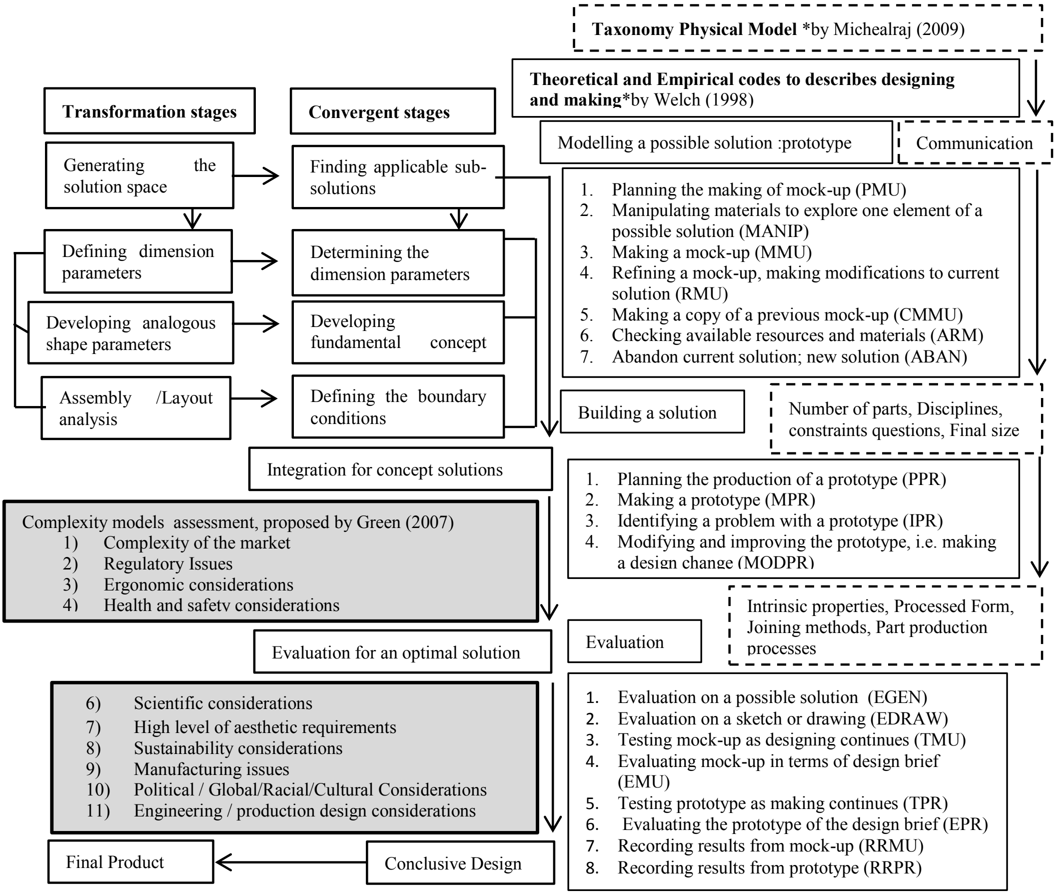

Figure 2: Creative based design processes during convergent and transforming stages. Adapted from Jones [30], Welch [31] Green [29] and Michealraj [18].

5 Discussion

To recapitulate, three main aspects were addressed in this study. These aspects are, (i) pedagogy in design teaching – to help educators to think explicitly what are the most appropriate range and sequence of learning activities for their students; (ii) model making and designing with respect to the design process – to explore appropriate models and prototypes in the detailing stages of the product design process; and (iii) to implement existing or develop new strategies for students to help them to understand information management, solving design problems and realising design solutions. Integrating these elements aims to create a more in depth understanding among design educators on how to support student learning with respect to finding detail design solutions in the materialisation stages of the design process through effective physical models and prototypes. In this discussion chapter the earlier mentioned research questions will be discussed as follows: Based from the findings as shown in table 1 and figure 2, all types of models and prototypes are suited for developing detail design solutions. However, it depends on what aspects of the detail design need to be further explored; form, technical or ergonomic functionality. The use of prototypes and models will help students in broadening their thinking processes and make them conscientious that divergent, convergent and reflective design practices should not be overlooked in these final stages of designing. It is therefore encouraged that students allocate extra time and effort to explore the creative space through physical models and prototypes during the materialisation and detailing stage instead of focussing too much on final presentations. This requires design educators to emphasis more on methods, processes and tools in their teachings with respect to detailing and materialisation. These processes, methods and tools, whether cognitive or visually explicit in nature, should encourage iterative analytical, creative and generative ways of thinking.

Numerous research have shown that design students who use physical model as a creativity tool in every stages of their design process will gain a clearer understanding of form, function and construction compared to student who did not do it. However, there is a tendency, that Industrial Design students prefer to develop their designs mainly through sketches, renderings and 3D computer models rather than being hands-on engaged in modelmaking and prototyping, especially when it concerns the final design stages of the design process. They believe that constructing models can be expensive and time- consuming, and do not see that exploring the solution space through appropriate models and prototypes will actually enhance rather than compromise their cognitive design capabilities, especially during the final stages, where design confirmations are required. Literature reviews have indicated that compared to using CAD tools, increased model making and prototyping practices in the detail designing and materialisation stages enhances students´ sensitivity towards the generation of well-defined and thought through quality products. However, this requires a creativity approach towards integrating modelmaking and prototyping practices in the product design process. The “Sensuous Association Method “, “Adapted 5R’s Sensational Thinking Model of O’Neill and Shallcross”, as well as Welch’s “Theoretical and Empirical Codes to describe Designing and Making” in the “Major Project Development Model”, are methods which can be suggested to educators to facilitate students creativity and synthesis skills in the early idea generation, as well as detailing and materialisation stages of the design process.

Goldschmidt and Rodgers [11] highlighted that educators should teach their students structured and systematic design processes when solving ill-defined problems. However, these processes should not impose rigid ways of design thinking, but stimulate exploration and reflection through iterative, divergent and convergent modes of designing throughout all stages of the design process. Given this context, educators are challenged to assist students to plan their design process in such a way as to allow sufficient time for detailing, while in the meantime highlighting the importance of it for creating quality designs. However, the concern is that once an emphasis is placed on detailing and materialisation work, students tend to converge towards concrete solutions quite early in the design process.

6 Conclusion

Literature reviews have indicated that compared to using CAD tools, increased model making and prototyping practices in the detail designing and materialisation stages enhances students´ sensitivity towards the generation of well-defined and thought through quality products. Hereby, educators are challenged to assist students to plan their design process in such a way as to allow sufficient time for detailing, as well as to highlight the importance of it for creating "award-winning" products. However, the concern is that once the studio teacher has pre-empted the importance of detailing and materialisation work, students tend to converge towards concrete solutions quite early in the design process. Given this educational dilemma, the author proposes an intensive cognitive and descriptive approach for analysing design problems and generating solutions, followed by a strict process of idea generation and conceptualisation. However this, strict development process should be compensated through a more extended divergence and convergence process in the detailing and materialisation stages using models and prototypes, complemented by a "master" and "apprenticeship" interactions between student and faculty to facilitate hermeneutic inquiry and design reasoning.

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