TANGIBLE IDEATION: HOW DIGITAL FABRICATION ACTS AS A CATALYST IN THE EARLY STEPS OF PRODUCT DEVELOPMENT

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ABSTRACT
Embodiment of a concept has constantly been a preventive factor in creativity when it comes to complex topics. This has been moderated by emergence of digital fabrication since late 80's. Making the ultimate prototype of a design was the initial assumed use for these technologies in the design process. However, new technology advances in this area bring up further opportunities for designers.
In this research, these opportunities have been explored through a case study by discussing the findings and theories of Industrial Design methodology and engineering. Considering the span of digital fabrication capabilities, this research looks into the relation of design-fabrication from the methodology perspective and focuses on addressing the impact of digital fabrication methods, which can be integrated into the Industrial Design process in the very first stage.
It is argued that the above is achievable in certain design topics - i.e. those with known components but unknown architecture. This has been studied through the development of two hypothetical design processes emphasizing the role of digital fabrication as an ideation tool rather than a presentation tool. It is hoped that these findings along with the advances in the area of additive and subtractive fabrication will assist industrial designers to create design methodologies to deal with the complicated needs in both design practice and education.

Keywords: Digital fabrication, rapid prototyping, design process, methodology and complexity

1 BACKGROUND

Physical modelling is a way that designers realize mental concepts [4]. As a design representational tool, the model making process can lead to new forms beyond the original concept. Computer model making has been a good interface between design ideas and product manufacturers. It also gives the capability of making surfaces with any complexity. The process of computer model making has been time consuming and it is the complex part in the design process. Rapid prototyping (RP) today is absorbed into practice and is being recognized as a significant technology for design [1]. From the time, design schools began to use RP technologies, the interface between design ideas and producers, centred on the nature of the design process. Beyond the design-related and material-representational benefits of RP within overall design and fabrication processes, there also appears to be significant pedagogical benefits to be derived from these technologies.
Today, many designers use digital design to demonstrate their ideas. Larry Sass [1] attempts to formulate certain key aspects of the design methodological frameworks that are coalescing with RP's capability to build artifacts as part of the creative design process. He concentrates on the emphases of conceptual stage materialization through RP and construction information modelling. It demonstrates a process of design situated between conceptual design and real-world construction [1]. In addition, RP may be used to present finalized design or to study complex forms as physical artifacts. Also he noted, RP-based digital design and digital fabrication defines the characteristics of both fields and the advantages that come from the integration of the two areas. On the other hand, Simodetti [6] offered small-scale to full-scale manufacturing via RP accompany CAD-CAM methods of production. He illustrated the influence and advantage of full-scale mock ups in functional revelations and visual aspects through the cognitive development of design [6]. However, designers are sometimes limited by their skills or several other parameters [3]. This attitude results in over-simplification of the

outcome which reduces the efficiency of the product. Those limitations and complexity makes it more necessary to have access to a higher level of flexibility in the creative process of product design.

2 ADVANTAGE OF DIGITAL FABRICATION

Digital fabrication provides realistic opportunities for representing, evaluating and redesigning complicated forms. It extends learning in a digital design environment since designers will be engaged with materials and machine processes similar to industrial production. According to the Sass & Oxman, it may also be said that the use of these appliances and software extends creative design beyond the early stages of design and supports the continuity of design through its various stages. Design materialization also has advantage in design that supports the inception of knowledge and the learning of design procedural structures [7]. Another advantage is the development of knowledge of shape and future possibilities for real scale 1:1 fabrication [8]. Working with RP in design process includes conceptualization, materialization and fabrication design. Rapid Prototyping is now the most important tool for product designers to demonstrate a product's functional and ergonomic considerations. Studies noted that the next revolution for RP would tie the two ends of the spectrum with generative technologies in both software and machinery [12].

3 THE THEORY

People naturally tend to analyze problems by reductionism. In other words, people think about large notions by decomposing them into more simple components [10]. In the world of design, these simple components are to recompose an integrated product through the design process [9]. Through the application of the theory of complexity in this research, it is intended to propose a comprehensive categorization for possible modes of product design. These categories are conceptualized in the diagram below (figure 1).

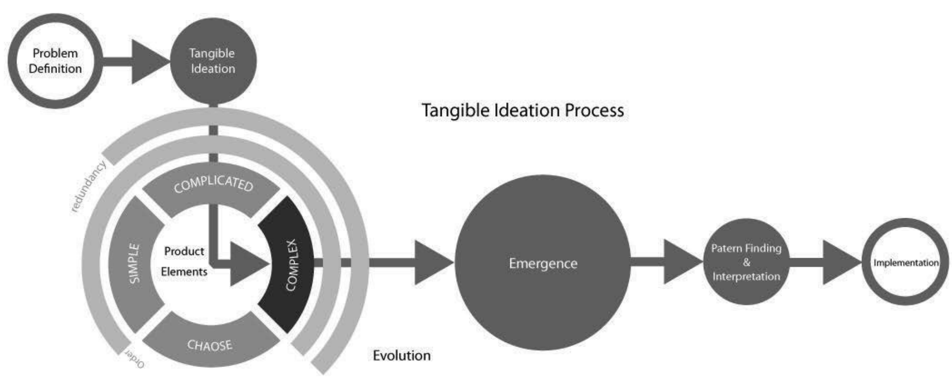

Figure 1. Digital Modelling Fabrication (DMF) process based on the theory of complexity

In a complex system, cause and effect are only coherent in retrospect, and do not repeat [11]. Complexity in design is generally considered in relation to component geometry where it has been studied for its influence in many areas [9]. Therefore, application of identical findings or phenomena in a creative design process can lead to radically different interpretations and commensurately different products. As featured in the above diagram, the focus of this study will be on the complex mode. The theory of complexity studies how patterns emerge through the interaction of many agents. Emergent patterns can be perceived, but not predicted. This phenomenon is called retrospective coherence [11]. This ultimately leads to emerging a pattern, which is recognizable but not predictable. Based on the theory of complexity, in the same system, patterns are not necessarily identical over time.

Since a physical artifact enables designers to be exposed to unlimited perspectives and combinations, it becomes a beneficial substitute for the traditional ideation tools [15]. Based on the complexity theory discussed earlier, the main required attribute for a complex system to be moved toward emergence of a recognizable pattern, is to be exposed to unlimited configurations. An RP sketch would definitely offer this new and valuable capability to the design process. In addition to the ideation use, the new tool helps designer learn more details and obtain more reliable evaluative data during the research phase due to the accessibility to tangible media as a research tool [15].

4 CASE STUDY

This case study is based on the results of projects implemented by two junior industrial design students at Arizona State University in the US. Both projects address identical problems while each incorporates different design methodologies.
The following diagram (Figure 2) compares the existing design process with the proposed "Digital modelling fabrication (DMF)" process. They share many steps except ideation and design development steps. The studied product is a metal shear that cuts through different gauges and alloys of sheet metal with efficiency.

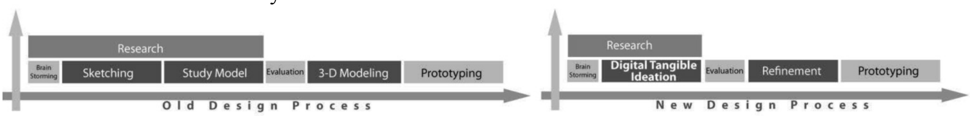

Figure 2. Design processes used for the case studies

4.1 Case "A"

This project benefits from the new methodology (DMF), which allows the designer use digital modelling and rapid prototyping as a substitute of the traditional ideation tools. The student was to explore potential improvements based on the initial research phase, and develop two primary ideas through digital fabrication techniques.

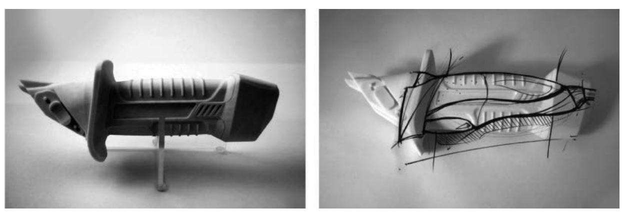

Figure 3. 3D sketching and 2D development

Figure 3 left shows one of the concept that in the shape of a white physical rapid prototyped model. In this case, a 3D printer (Z-Printer) was used to fabricate concepts, as the machine is known to be fast and cost efficient. These physical models then were used to conduct an interview with users. It enabled the users to touch the primary version of the product, and shared their experiences with the designer.
Inputs gained through the interview were applied to the primary concepts. In the next step these manipulations took place in various aspects such as; human factors, aesthetic, function, usability, safety, performance and sustainability. This process is similar to a redesign process where a designer manipulates existing objects. Figure 3 right illustrates the process of implementing the new aesthetics based on the 3-D sketch.

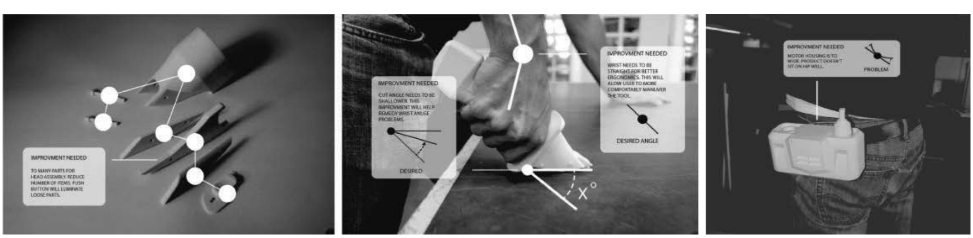

Figure 4. Lessons learned from 3D sketching

As shown in the picture (figure 4), the tangible model helped maintain the proportion of the original concept using the image of the prototype in the digital sketching process. In this case, the final appearance was adjusted based on the users' inputs in a way that a more fluid design language replaced a muscle car inspired ridged style. Based on the results of the study, a smoother design increased the sense of precision, which was desired by the potential users. Human factors were among the highest priorities of this case. The actual model of the primary concept dramatically helped understand the ergonomic issues of the concept. This was what mostly happens during the redesign projects. The image shows the angle issue of the first concept that needed to be improved. Finding a way to reduce the number of moving parts of the shear was among the achievements of this procedure, as moving and testing the real scale parts showed that two sets of parts were doing one job. Figure 6 illustrates the final product designed through DMF. Overall, the characteristics of this design include: dynamic aesthetics elements, redundancy in functional parts and appearance, good product-user interaction, high priority ergonomics and many more.

4.2 Case "B"

"Case B" follows the traditional design process. This process is formed upon the application of inspirational metaphors. More than 100 sketches before conducting the initial research shaped the creativity foundations. This was followed by a primary evaluation.

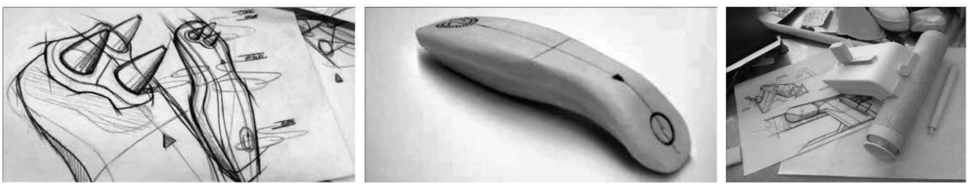

Figure 5. Traditional process

A handmade model of the selected concept was then created out of blue foam using known subtractive techniques. This is the model that was used for the secondary evaluation, nevertheless; the concept was rejected based on the users' inputs.

Due to an improved embodiment with a physical mock up, their reaction to the concept changed when they experienced the study model. This led to unreliability of research data in this case. As a result, the designer ended up developing the third concept, which employs a totally different technique for cutting sheet metal (figure 5). The final concept functions similar to a plasma cutter. It consumes water as the main fuel, breaks it up into hydrogen and oxygen, which is then ignited. Figure 6 illustrates the final product design through the traditional methodology. Overall characteristics of this design include: conservative aesthetic elements, minimal and simplified design, average product-user interaction, and low priority ergonomics.

5 ANALYSIS

This section is to answer the question: whether or not, the digital tangible modelling as an ideation tool can increase the efficiency of the design process of a complex product. It is, however, not within the scope of this study to validate all parameters of the theory. Human factors, aesthetic and performance appear to be instances of the component complexity, which has been addressed in the case study and analysis.

Table 1. Case study comparative table

	Number of sketches	Conceptualization cycles	Duration	Number of participants	Budget	Component complexity	Number of study Models
Case A	40	2	86	9	$240	High	4
Case B	87	4	119	9	$295	High	4

5.1 Evaluative Research

Decision-making and evaluation are critical points in a user-centred design process. In a successful project, designer evaluates achievements and innovation according to the parameters learned in the research to ensure a reliable outcome. Thus, an evaluation effectiveness analysis could be beneficial. Both cases were compared based on two parameters: accuracy and reliability of evaluation. Various research methods were employed in both cases to obtain the user's feedback to validate preliminary and processed solutions over the design process. To characterize the contribution and effectiveness of design research in this case study, a biaxial map with four zones was developed (figure 6- right).

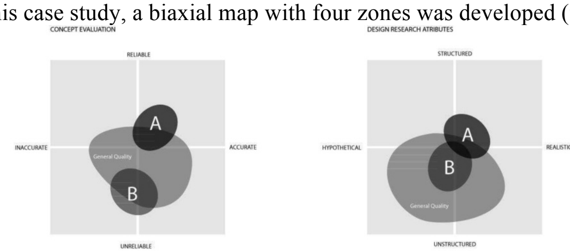

Figure 6. Qualitative comparison of the design evaluation

These zones include: structured, unstructured, hypothetical and realistic which address two differing aspects of the research; the research design and the research outcome. Case "A" appears to be more successful in this area. The research is more structured which generally results in shorter research timeframe. Simultaneously, results are more realistic. Increased level of tangible features has definitely had a positive influence on yielding more realistic outcome with minimum effort. This could be considered a positive contribution of DMF methodology, which has been beyond the theoretical expectations of this study. In both diagrams, the gray areas represent the expectation in the projects.

5.2 Timing

Although both cases address the same design problem, the different design methodologies used in these two cases have made a significant difference in the actual timing. Based on the actual records, "Case A" shows fewer time consumed for all phases which were different from project B. Common activities, however, have taken nearly identical time for both designers, even though some tasks have been implemented individually.

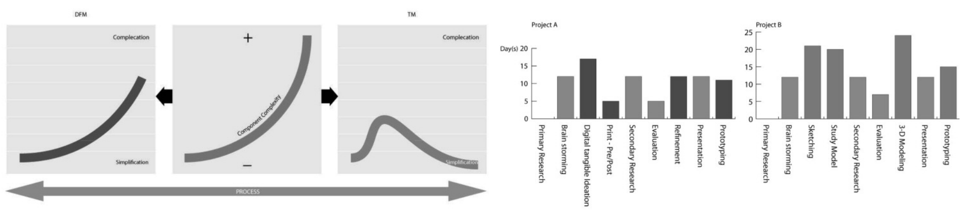

Figure 7. Timing

Despite the qualitative effect of the new design methodology, the case study features a considerably shorter overall timeframe for the project "A", compared to project "B". Based on figure 6, the effective overall time spent on project "A" was 86 days while this time for project "B" was 119 days. In order to better generalize this result, looking in depth at single tasks is required in both projects to develop a qualitative interpretation.

6 CONCLUSION

Considering the concept of learning through doing, this study proposed a new product design methodology entitled "Digital Modelling Fabrication" (DMF). This methodology ensures an extensive use of rapid prototyping as a tool to generate breakthrough ideas in a timely manner. Through the case study, it was learned that the DMF methodology, while more time efficient than traditional methods, could serve as an advantageous tool for both the design and research phases of the project. The diagram shown below (figure 7) was created to visually conceptualize the relationship between the increase of redundancy (that shapes complex configurations) and overall efficiency of each methodology based on the results of the case study analysis. What was learned through the study is important because current research has not fully addressed the effects of the DMF process on the efficiency of a design project. While Sass and Oxman bring up a concept similar to DMF, they have not evaluated the impacts of the theory on design of a methodology. Based on the current findings and those were reviewed, DMF could serve as a powerful methodology when a reliable creative design solution is desired for a design complex. It also featured that DMF cannot be considered as an effective methodology for circumstances with simplicity.

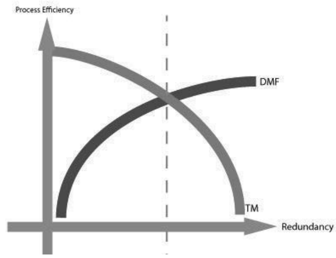

Figure 8. Efficiency of the process to redundancy

The results of this study support Sass & Oxman which stated, digital fabrication oriented design improves the current status of design, which is situated between conceptual design and real world manufacturing. Not only does DMF facilitate design activities, but also validates the creative process of designing products, as it bridges the creative design activities with engineering. Thus, DMF can serve as one of the future tools in both research and design practice. While this study should not be considered an ends-all for design methodology in industrial design, it can be an important step as every advancements in this area brings us closer to a design methodology that meets the expectation of the 21st century.

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