THE PRACTICE OF CONVENTIONAL MODEL MAKING AND RAPID PROTOTYPING IN PRODUCT DESIGN EDUCATION AT THE SCHOOL OF ARTS, UNIVERSITI SAINS MALAYSIA. A COMPARATIVE STUDY

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by

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‘In the name of Allah the most beneficient and most merciful’

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TERMINOLOGY

3D Printing (3DP)	-	An additive manufacturing process producing prototypes.
Conventional Model Making (CMM)	-	A process of translating intangible ideas (2D) into tangible ideas (3D) using hands, hand tools, and machinery.
Industrial Design (Ide)	-	A professional service of creating products and systems that optimize function, value and appearance for the mutual benefit of user and manufacturer.
Model	-	A replica of a design in a 3D form.
Product Design (PD)	-	A process of creating a new product to be sold by a business to its customers. Efficient and effective ways of generating and developing ideas through a process that leads to new products.
Prototype	-	A functional model.
Rapid Prototyping (RP)	-	A rapid process of producing prototypes.

AMALAN PEMBUATAN MODEL KONVENSIONAL DAN RAPID PROTOTAIP DALAM PENDIDIKAN REKABENTUK PRODUK DI PUSAT PENGAJIAN SENI, UNIVERSITI SAINS MALAYSIA. KAJIAN PERBANDINGAN

ABSTRAK

Penyelidikan ini meneroka proses pembelajaran dalam Pembuatan Model Konvensional dan Rapid Prototaip seperti yang diamalkan dalam pendidikan Rekabentuk Produk di Pusat Pengajian Seni , Universiti Sains Malaysia. Parameter kedua-dua proses Pembuatan Model Konvensional dan Rapid Prototaip dikaji dalam membuat perbandingan untuk melihat perbezaan dan mencari kelebihan dan kekurangan didalam kedua-dua proses. Dalam kajian ini, kaedah perbandingan digunakan dalam memahami parameter yang dikaji iaitu kos , masa dan ruang yang digunakan didalam kedua-dua proses. Kos, masa dan ruang adalah parameter yang mempengaruhi pilihan kaedah dalam menghasilkan model atau prototaip oleh pelajar-pelajar Rekabentuk Produk. Satu Kajian Kes , Kaji Selidik, dan Temuduga Semi- berstruktur digunakan untuk menerangkan hubungan antara fenomena (CMM dan RP) dan sebab-musabab (pelajar Rekabentuk Produk) kedua-dua proses digunakan. Di Pusat Pengajian Seni, Universiti Sains Malaysia, proses pembuatan model konvensional dan system percetakan 3-Dimensi dikaji sebagai kaedah RP. Pengkaji menggunakan tiga kumpulan pelajar tahun akhir yang mahir dalam pembuatan model dan prototaip sebagai sampel untuk soal selidik kajian. Tiga profesional di dalam pendidikan Reka Bentuk Produk dan Reka Bentuk Perindustrian ditemuramah untuk memahami lebih mendalam proses Pembuatan Model

Konvensional dan RP yang diamalkan di dalam pendidikan Rekabentuk Produk. Terdapat perbezaan di dalam kedua-dua proses berkenaan parameter dikaji. Proses Pembuatan Model Konvensional didapati lebih kos efektif berbanding RP. Tetapi proses Pembuatan Model Konvensional adalah satu proses yang berulang-ulang untuk mendapatkan satu model persembahan yang baik . Dengan ketepatan dan detail, sistem RP boleh menghasilkan prototaip dalam masa yang lebih pendek berbanding proses Pembuatan Model Konvensional. Ruang yang minimum untuk RP mengurangkan penggunaan sistem diakibatkan dari jumlah pelajar yang besar, manakala Pembuatan Model Konvensional membenarkan pelajar untuk mengamalkan proses secara bebas sama ada dalam ruang yang disediakan atau ruang mereka sendiri. Kelebihan dan kekurangan kedua-dua proses adalah seimbang dalam memberi manfaat kepada pelajar-pelajar Rekabentuk Produk di Pusat Pengajian Seni, Universiti Sains Malaysia.

THE PRACTICE OF CONVENTIONAL MODEL MAKING AND RAPID PROTOTYPING IN PRODUCT DESIGN EDUCATION AT THE SCHOOL OF ARTS, UNIVERSITI SAINS MALAYSIA. A COMPARATIVE STUDY

ABSTRACT

This research explores the learning processes of Conventional Model Making and Rapid Prototyping as practised in Product Design education at the School of Arts, Universiti Sains Malaysia. The parameters of both Conventional Model Making (CMM) and Rapid Prototyping (RP) are studied respectively to compare the differences and to look for advantages and disadvantages of both processes. In this research, a comparative method is used to understand the parameters concern; costs, time, and space. Costs, time, and space are the parameters that affected the choice of methods in producing a model or a prototype by students of Product Design. A Case Study, Survey, and Semi-structured Interview are used to explain the relationships between phenomena (CMM and RP) and causality (Product Design students) of both processes. In the School of Arts, Universiti Sains Malaysia, CMM process and a 3D printing system is studied as RP method. The researcher uses three batches of final year students who are proficient in model making and prototyping as samples for survey questionnaires. Three professionals in Product Design and Industrial Design educations are interviewed to understand more in depth on CMM and RP processes practised in Product Design education. There are differences found in both processes regarding the parameters concern respectively. CMM process is found more cost-effective compared to RP. But the CMM process is a time-consumed process with repetitive process in order to have a good presentation model. With precision and accuracy the RP system can produce a prototype in a shorter time compared to CMM

process. Minimal space for RP restricts the use of the system by the large number of students, whereas the CMM allowed students to practice the process freely either in a provided space or their own space. The advantages and disadvantages of both processes are balanced in benefitting the students of Product Design in the School of Arts, Universiti Sains Malaysia.

CHAPTER 1

INTRODUCTION

1.0 Introduction.

In the beginning of this thesis, the researcher will explain about the background and significant of this study in general. This chapter is divided into seven sections which will denotes the background of the study (section 1.1), problem statement (section 1.2), research objectives (section 1.3), research questions (section 1.4, limitations (section 1.5), significant of study (section 1.6), and scope of study (section 1.7). This will give the reader a glimpse of what this study is all about.

1.1 Background Study

Since Industrial Revolution, Industrial Design brought a new prospect in manufacturing world (Sotamaa Y, 1992, p. 7). Arguably popularised by Bauhaus in 1919, it became well known as an Industrial Design School. Industrial Design since taught in the higher institution to produce more designers in this modern world. The design process is taught in every Design School for future Industrial Designers.

Model making in industrial design is a crucial pre-final/final part in the design process. It is a process that assists designers to study and analyses form, detailing, material, and manufacturing process before it goes into the mass-production. Model making is one of sketching method in the design process but in three-dimensional forms; a final design as Tim Parsons (2009) put it; *'Capturing a rough impression or the complete picture'* (p. 182).

Model making is not a new method in design, which had been practised even before industrial revolution era (Goloboy.J.L, 2008, p. xi). This traditional techniques or craftsmanship is used to produce a model/prototype by fabricating, moulding, and forming (Morris, 2009). Fabrication is a process to produce parts in order to be assembled later by using welding for metal, joints such as dove-tail for wood, nails, glue and etc. Moulding in the other hand is used to produce one design piece in one mould such as ceramics, and jewellery. The moulding technique is widely used in the present day because of the precision and cost-effectiveness in mass production era. One of the prefer technique is injection moulding (Morris 2009), which melted plastic pellets are injected into a mould. Forming in other words; 'to produce something in a particular way or make it have a particular shape' (Hornby, A.S. 2015, p. 616). Shaping is a process to form or shape solid materials using hot or cold temperature. This technique was popularly used by blacksmiths in the past to forge weapons, cooking utensils, and decorative household products (Morris 2009). With exploration and research done over the years, even wood can be form according to desired design as popularised by Charles and Eames in the 1950s by custom-moulding plywood (Hallgrimson. B, 2012, p. 132).

The conventional model making or prototyping process in education (design school, universities) is almost similar to the industry world. The lack of facilities such as forming, moulding, and fabrication machinery makes students uses whatever tools and materials in hands to form their models. Materials such as polystyrene foam, cardboards, foam board, wood, metal, and Styrofoam are used (Hallgrimson.B, 2012, p. 44). The myriads choices of materials make the model making the process easier and economical to students in order to make a presentable model. Hand tools are preferable in making small scale models such as computer mouse or toothbrush.

When creating a full-scale model (i.e.; furniture, kiosk) fabrication machines such as saw mill, drilling, boring, sanding, and welding is used for cutting or jointed parts. Moulding is also used by undergraduate students in Universiti Sains Malaysia (USM) but only limited to slip casting. Conventional model making is practice in Product Design education such as USM or any other design schools to educate students in developing sensitivity to design surfaces, shape, and form study, detailing analysis and exploring multiple approaches to achieving the best final presentation model/product. Manual model making also teaches students to be more creative since the actual materials are scarce and sometimes expensive to acquire.

Product Design evolves since the Bauhaus era because of one particular reason; technology. Researchers, scientists, and designers have always found new materials and methods to manufacture products as fast as possible, sustainable, eco-friendly, and recyclable. Even though manual model making is still used in industry or education, a new method was developed in the 1960s; rapid prototyping. This method soon was developed by University of Texas researcher, Carl Deckard in 1987 from only cutting excess from a block material to building up layer by layer materials or ‘printing three-dimensional models guided by laser into solid prototypes. In the recent development in rapid prototyping, the technology became widely used in industry and even in higher institutions that offer engineering and industrial design subject. This technology helps students to create more complex parts of their design. The method helps students to reduce the time of working on their model making (Hallgrimson, 2012). It involves the use of virtual designs from the computer aided design (CAD) softwares such as AutoCAD, CATIA, Solid works, Autodesk Inventor and other CAD software that can create a file which can be read by RP machines such as an STL (stereolithography) file. Some other three-dimensional surfaces

software such as 3D Rhino, 3D Studio Max, and Alias Studio Tools can also be converted into an STL file. Rapid Prototyping is a subtractive and additive process that uses materials such as wood blocks, metals, metal powder, polyamide, resin and much more. A variety of Rapid Prototyping machines are available in the market but for this particular research, only three-dimensional printing will be focused on.

1.2 **Problem Statement**

Model making is one of the design processes in Product Design. The purpose of model making is to study a design in three-dimensional ways where the design transforms from intangible sketches into a tangible object. The tangible design then can be feet, touch and analyse to understand the form, ergonomics or materials suggested on the design. Craftsmanship skills are taught in product design or industrial design school in order to equip students with essential skills for model making. Even so, technology has played its part in product design in changing the way of making a product or changing the way of the design process.

'Despite the rise of digital tools and rapid prototyping, it has never been more important for designers to make things with their hands. Comfort with three dimensions as a sketch and development tool enhances a designer's sensitivity to form tremendously and helps them understand how products are made in the real world. If you can build it, you're halfway to knowing how it could be manufactured. Instead, schools often allow students to jump into 3D CAD before they have a solid understanding of form and construction.' (Backett. P, 2011, p. 10). Concerns are focused on methods of model making taught in schools of product design. As tools for making a model has changed from conventional to Computer-Aided Design (CAD), some design schools began to utilise the technology more than the traditional

way of making a model. Lacking hand skills or craftsmanship lead to students having disadvantages in understanding on construction or manufacturing process. Manufacturing process can be explored by conventional model making as it is fast and stimulates sensory system (Backett, P. 2011, p. 13)

Conventional model making is an economical way for students to conceptualise their designs. The myriads of materials choices are also an advantage to produce a presentable model. The disadvantages of manually making a model are time and space. To produce a final model student needs to go through a hefty process which started with plotting their design on a material (e.g.; polystyrene foam), cutting into basic shape of the plotted details, shaping the material, adding additive material such as filler or putty and finishing with paints (Hallgrimson, B. 2012, p. 54). Space needed for manual model making varied depending on the size of models (Hallgrimson, B. 2012, p. 51). If a model uses hand tools from starts to finish they only require a small space. Space is quite the concern in making a model and prototyping as the process involves 'noisy and dirty construction activities' and for storing on-going projects (Orr, K., 2008, p. 6). The workshop space is also different depending on the machines available. Basic machines such as bandsaws, table saws, disc sander, drill press, lathe and painting booth. For clay making or slip casting process another space is needed since it uses kiln and blunger (mixer to mix clay and water to create clay body slip).

The emergence of the RP technology in product design definitely brought a change to the product design process especially model making process. It is not only prototyping tools that are used in industries but also have been introduced to product design schools around the world. The methods use in model making varied among

product design school. Some integrate more on technologies such as RP and some focus on the conventional way of model making. This matter raised some questions in the product design educations such as; which process can benefit product design education? Will conventional model making become obsolete? Is one process dominant than the other? This study will give an insight on both methods in education and to find the advantages and disadvantages of both methods practised by BFA students in Product Design education in University Sains Malaysia.

The problems found in the literature reviewed are as follows:-

1. Lack of comparative studies done on the practised of conventional model making and rapid prototyping process in Product Design education.
2. A lot of studies were made in favour of rapid prototyping compared to conventional model making.
3. Previous studies discuss more on the benefits of rapid prototyping.

1.3 Research Objectives

The objectives of this research are as follows:-

1. To look into the Conventional Model Making (CMM) and Rapid Prototyping (RP) practised in Product Design at Universiti Sains Malaysia and learning process.
2. To identify the costs, time, and space that affects the Conventional Model Making and Rapid Prototyping process in Product Design.
3. To understand the variables of both processes in complementing the study of Product Design in Universiti Sains Malaysia.

1.4 Research Questions.

1. What methods are used in producing model and prototype in Product Design education?
2. What parameters affect the Conventional Model Making and Rapid Prototyping process in Product Design?
3. Is one of the processes more beneficial and more educational than the other for Product Design education in the School of Arts, Universiti Sains Malaysia?

1.5 Limitations

1. Only 3D printing system available for Rapid Prototyping process' observation.
2. Small sample.

1.6 Significant of Study

This research is done to understand the parameters that affected model making/prototyping process in Product Design education at the School of Arts, Universiti Sains Malaysia. In recent years, there are changes in making a model or prototype in Product Design education worldwide. The method of producing a model evolved technology-wise. The transitions from conventional model making to Rapid Prototyping process can be seen in many Higher Institutions that teach Product Design. The research is to compare both methods in order to seek differences and to find the advantages and disadvantages of both methods as practised in Product Design at the School of Arts, Universiti Sains Malaysia. The outcome of this research can be useful to Product Design education in the School of Arts, Universiti Sains Malaysia.

1.7 Scope of Study

1. Conventional Model Making and Rapid Prototyping processes practised by Product Design students in the School of Arts, Universiti Sains Malaysia.
2. Only final year students of BFA Product Design in Universiti Sains Malaysia will be used as a sample in this research.

1.8 Research Framework

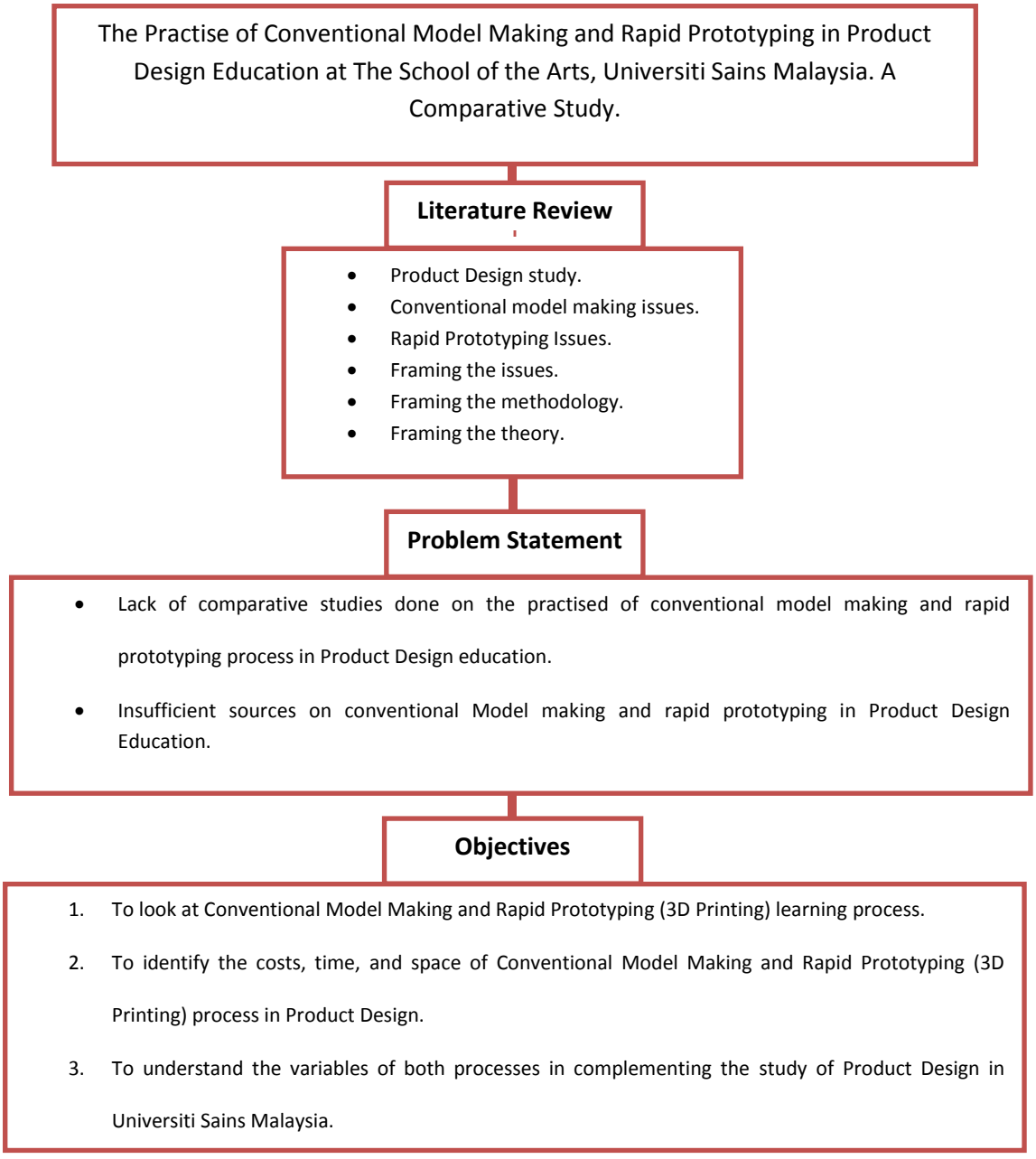

Figure 1.8: Research Framework

1.9 Summary

This research is conducted in order to compare two methods of model making in Product Design education. The researcher will study the processes of conventional model making and rapid prototyping in order to identify the advantages and disadvantages of both processes. In the processes; space, time and costs will be studied upon to identify the differences between manual model making and rapid prototyping. The outcome of this research will be to compare the data on Conventional Model Making and Rapid Prototyping (3D Printing) processes and identify benefits in complementing the Product Design study in USM. Literature for issues and problems for this research will be elaborate in the second chapter of the thesis.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction.

The first phase of this study, the researcher conducts literature reviews and found writing by Ziba's Industrial Design Director, Paul Backett. In this article, Backett (2011) emphasis on the lack of skills in manual model making by industrial design graduate caused by technology evolution that creates graduates dependable only by technology, not raw skills. The researcher found out that both processes of model making are quite the debate around Product Design education system. Professionals like Backett disagrees with too much technology i.e.; 3D printing, 3D software to be implemented in industrial design schools which will create the lack of understanding in design forms. In his claim, the net generations conclusively utilise technology instead of the conventional method of model making (2011). In a study by Irene J. Petrick & Timothy W. Simpson (2013), they put it in the more drastic claim; technology such as 3D printing posts a disruptive effect on conventional method. In other studies (Lantada, A.D., et al., 2007; Berman, B., 2012) disputes the claims as they indicate the advent of rapid prototyping technology, CAD and CAID reduce the model making process in terms of time and costs. Whereas, Cheshire D.G., et al. (2001) suggests in their study on combining both methods as converging factors in achieving better design results.

With different views on model making process, the researcher found a gap in the previous research indicating a lack of research conducted in comparing the

practice of conventional model making and rapid prototyping process in Product Design education.

2.1 Classifications of Physical Model.

A model and a prototype are both physical models which are tangible ideas derived from the iterative process of two-dimensional sketching. As defined by Hallgrimson (2012), physical models are used to 'described a preliminary three-dimensional representation of a product, service or system.' (p.6). The physical models work as a communication tool representing the ideas of the designers in three-dimensional forms. The purpose of physical models is not for manufacturing, but it works as design tools for future ideas and will encourage more exploration on the design itself. The physical models are crucial in design as it is not just a visual representation of a design such as sketching but the tangibility makes it explore-able. (Dunn N., 2010). Broek J.J et al. (2000) point out the physical model's' functions are used to 'answer designers' questions' (p. 155). Parsons T. (2009) states that the designers need to consider the purpose of making the models, things to analyse and effect to produce the models as to 'increased closeness to the designer's imagination (p. 182). It is a part of the problem-solving process and designers need a tangible idea to 'intrigues the imagination and allows for a constant stream of sculpted ideas to be evaluated'. (Bramston D., 2010, p. 42)

Physical models are tools to analyse ergonomics, forms, aesthetics, functionality depend on the levels or categories they are in. Tim Parsons (2009) categorised physical models into three levels; (1) maquette, (2) model, and (3) prototype (p.182). The different levels are made based on the speed and detail on

producing the physical models. Maquette and model functions are to study forms and aesthetics, whereas a prototype is used as a tool to study ergonomics, materials, and functionality of an idea. Isa, S.S., & Liem, A. (2014) classified physical models into four categories (see figure 2.0); (1) soft model, (2) hard model, (3) presentation model, and (4) prototype (p.3), as explained in Figure 2.0.

Table 1: Classifications of models based inputs from several sources.

Soft Model	Hard Model	Presentation Model	Prototype
● rough modelling ● use to assess the overall size, proportion, and shape of many proposed concept. ● constructed from dense sculpting foam. ● fast evaluation of basic sizes and proportions ● reshaped and refined by hand to explore and improve its tactile quality	● technically non-functional yet are close replicas of the final design ● very realistic look and feel ● made from wood, dense foam, plastic, or metal are painted and textured ● have some "working" features such as button that push or sliders that move	● model that constructed and matched from CAD data or control drawing ● complete model and fully detailed composition of the product ● Component of this model will be simplified or neglected due to cost or time shortages	● high-quality model or functioning product that is produce to realize a design solution. ● would be tested and evaluated before the product is considered for production.

Figure 2.0.1: Classifications of Physical Models by Isa, S.S., & Liem, A., 2014, p. 3.

Based on the classifications as shown in Figure 2.0, there are two types of the physical model focused in this research; Presentation Model and Rapid Prototyping (advance method of prototyping). The researcher looks into the process of making using both methods that have been assisting students in making a tangible idea. Some issues from previous studies are break down into two main issues as analysed in next point.

Figure 2.0.2: Types of soft models.

(Source: Researcher's Source)

Figure 2.0.3: Type of Presentation Model.

(Source: Researcher's Source)

Figure 2.0.4: Types of Prototype

(Source: http://www.core77.com/posts/36551/7-Tips-for-Nailing-that-Industrial-Design-Job-Interview)

2.2 Conventional Model Making (CMM) Issues.

For producing CMM, designers take into considerations on time, speed, and costs' factors involving the whole process. Materials play a big factor in determining the speed and costs of CMM. According to Dunn (2010), materials selection for the model making are determined by three key factors; 'the speed of production, the stage of the design process and the intended purpose or function of the model.' (p. 30)

Looking at time-constraint parameter in previous studies (Osaid H.M., et al. 2015; Isa, S.S., & Liem, A., 2014), CMM process requires skilled labours, different machinery utilisation, and manipulation of different materials that prolong the process' duration. As the physical model is a representation of the final design ideas, suitable materials are needed in order to replicate. Model maker with less experience and skills will delay the process of model making. Kristian Orr (2008) stated 'availability of time' as one of the challenges in making models and prototype in architecture education environment. As the model making process is the most crucial part of the design process, longer times are needed to produce a model. Broek, J.J., et al. (2000) agrees on this issue as they stated in their study that producing a model in a shorter time will benefit the problem-solving process. Kolko, Jon (2005) denotes that changes from the traditional method to the new method are imminent regarding production cycle time to market and increasing in speed of production is inevitable. This is a proof that CMM is a time-consuming process practised either in industries or education levels. A design project given to designers or students is time-constraint. Dateline are given in order for designers to plan their process of design thinking, problem-solving and analysis of the given project. Making a model or a

prototype is a crucial process in representing the solution of the design. Completing the model or prototype in time allow manufacturing and marketing of the product be made.

Costs are discussed in previous research extensively regarding model making and prototyping. Materials using is one aspect that affects cost especially in 'an era of tightened university budgets' (Orr, K., 2008, p. 6). Hafiz Muhammad Osaid et al., (2015) listed materials and tools (machinery) as part of cost issue in CMM. Designers have to choose the materials that will not slow down the process or delay the production process. In an educational environment, choices of materials are vast as the models are an only tangible representation of their intended design. The key factor for students is to practically choose materials that abundantly found whether discarded materials or cheap materials such as Styrofoam, box, PVC and etc. Parsons T. (2009) indicates by using inexpensive materials, 'enables designers to work without a restricting sense of preciousness' (p. 184). Manipulating ready-made object and re-shaping it into the desired shape can reduce the cost of CMM.

The process of CMM is divided into two; subtractive and additive. This process consists of shaping raw materials into a form following a design and adding materials such as putty and hardener if needed in order to harden the raw materials or fixing any abrasion on the product's surface. The material in the definition is a substance or substances from which something else is or can be made; a thing or things with which something is done (Hornby, 1995). Materials used for CMM are varied depending on the size and needs of the design. In CMM using either recycle materials or substitute materials is easier to work with and can be found easily in comparison with manufacturing materials.

‘Combining materials in order to emphasize their contrasting qualities and make best use of them requires considerable experimentation, and model makers should be encouraged to explore the use of novel, ‘found’ materials as well as to recycle packaging and other everyday objects in the search for appropriate materials.’ (Dunn N., 2010, p. 31)

In Product Design discarded materials with other materials such as polystyrene foam, wood (*jelutong*, pine, and plywood), polyvinyl chloride (PVC) and etc. are utilised and sometimes combine to create 3D visual of different materials. Using recycle materials reduce the costs for model making especially when it comes to the educational environment. Size and scale also play a crucial part in determining types of materials that the designer or modeller for the model making process. ‘It is typically more cost- and time-efficient to substitute softer materials in place of production materials’ (Hallgrimson B., 2012) A model is not a final product (production), it is an imitation to what it should look like, feel, and functions. Softer materials give an advantage to designers to sculpt the model quickly and efficiently in acquiring the form of the design. ‘Preliminary models, often made of polymer foam, plaster, wood or clay, capture the form of the product; later models show the form, colour, texture, mechanisms and weight.’ (Ashby M., & Johnson K., 2002, p. 43)

Affecting the CMM process includes space and environment which depends on materials, and tools available. According to Hallgrimson (2012, p. 51), some materials requires ‘small, and simple workshop, whereas others require substantial model making facilities’. In some design industries, to be able to do sketch-model or model making, designers use their provided workshop. Space required for model

making or prototyping is crucial here. Kristen Orr (2008) argued about the availability of space, as producing a model in time in an educational environment is hard to achieve as he provided space is insufficient to accommodate the large numbers of students. Some of the researchers mention on issues regarding space use in the CMM but lacking emphasis on the matter.

Figure 2.2: Example of Materials used in CMM.

(Source: Researcher's Source)

2.3 Rapid Prototyping (RP) Issues.

Prototyping is a process of producing functional design model or prototype before undergoing manufacturing or production process. Nowadays, the process has become better because of new technology in prototyping; rapid prototyping. As it sounds, this process is faster than conventional model making and produce complicated details that cannot be achieved by conventional means.

Rapid prototyping (RP) is vastly used in manufacturing industries worldwide and becoming more prevalent as it helps designers and engineers to 'visualise design concept, ergonomics evaluation, master patterns, functionalities' evaluation, and customised products' (Stampfl J., Liska R., 2005, p. 1253). Rapid prototyping process can produce detailed parts as it forms the parts by 'depositing contoured material' on x and y-axis. The third axis; z-axis creates stepping shape as this third dimension axis depends on the thickness of the deposited materials (Pandey, 2010). RP allows the designer to prototype more frequent to analyse the functionality of the design, problems and finding solutions for their design. Realising an idea from two-dimensional drawing to three-dimensional object minimised mistakes 'and product development costs and lead times substantially reduced' (Pham, D.T & Gault, R.S., 1998, p. 1258). Several studies (Pham, D.T. & Gault, R.S., 1998; Diegel, O. et al., 2006; C. Weller, et al. 2015) agrees on the factors such as time and costs can be reduced in prototyping compared to CMM. The traditional process of design and prototyping are minimalised using RP as a tool for producing more details, and analytical prototype. RP also allows designers to experience several iterations of their design and helps in encountering issues in more details. O. Diegel, et al., (2006) explains that 'the process of prototyping any ideas as they come along means that

you often have to look at parts of the manufacturing, and even in marketing processes, even when you are still at the fuzzy front-end concept development stage' (p. 357). But in this situation, where the designers can easily prototype several iterations of design using RP will cost more than CMM since materials for RP are not cost-effective. Looking at too many details & functions also lead to a time-consuming process. Iteration of ideas by RP means also depends on the number of RP system available. As in Product Design education, a model or prototype mostly functions as presentation design object. Manufacturing aspect is not a priority in model making or prototyping practised in Product Design education.

Materials used in rapid prototyping are varied from wood, ABS (acrylonitrile butadiene styrene), nylon, metal, thermoplastics and etc. Every RP machine has different materials that it can produce. Hallgrimson divides materials for RP systems into three; 'Photo-curable liquids (photopolymers), solid powders or extruded plastic'. Hallgrimson (2012) emphasis on the importance of materials selection in RP process as it determines the level of quality that it produces. The materials chosen determine the 'cost, strength, surface quality and colours' (p. 67). O. Diegel et al. (2006) argued that 'Traditional project management tends to focus on what is often called the 'holy triangle' of project management; cost, time, quality' (p. 350). With RP, costs and time can be reduced to achieve the market goal on time. RP makes it possible to build intricate prototypes and working prototypes allowing testing and predominantly reduce time than conventional methods. This method allows designers to analyse forms, ergonomics and other design questions in a shorter time. Berman B. (2012) indicates '3D printer can produce simple objects, such as a gear, in less than 1 hour' (p. 155). Berman states the two important aspects that affect the RP process are cost and materials (p. 156). In spite of the advantages, some drawbacks

of RP made mention by Berman B., (2012) such as limited materials, limited surface finish, the high cost of materials and expensive RP system (p. 161). Although the RP process benefits the prototyping process in reducing the time, the drawbacks of RP process can affect Product Design students pragmatically.

Figure 2.3: Example of Rapid Prototyping (3DP) Materials.

(Source: Retrieved from https://3dprint.com/42417/3d-printing-material-strengths/)

2.4 Framing the issues.

Most of the researcher emphasis on the advantages of using RP as prototyping method. There were less information or research done in CMM process. Few researchers studies on the practice of model making and prototyping process in Product Design education. Previous studies discuss more on the transition from conventional process to utilise the latest technology and most focusing on processes that were practised in the industries. This can be seen clearly from most of the literature found while doing this research. Research gap is found concerning model making and prototyping process practised in the educational level and space parameter to expand more in this study.

Nevertheless, the researcher extracts some crucial evidence from previous studies to support this research. One of the crucial evidence found is the criterion that affects the CMM and RP process such as costs, time, materials, and space. As materials are related to costs, the researcher will look into costs and time. Space is one of the parameters that the researcher considers important to expand because, in this research context, facilities such as workshops are built to accommodate a minimum number of students.

2.5 Framing the Methodology

Having examined from several literature sources, the researcher discovers that case study, interviews, surveys and direct observations were used by some researchers as methods in their studies. Among them, there are few who conducted mix method in their research.

O. Diegel et al., (2006) uses a case study to compare RP and traditional process of prototyping in educational engineering. They conducted a project given to students to understand the difference in the component used, process, design time, making time and cost that affects both processes. The same as Orr, K., (2008), who also conducted a case study which using an architectural project given to students in understanding how architectural students conduct their projects and what parameters affect the process and the effect on students' educational process. Both case studies conducted starts from the beginning stage of design process until prototyping stage. In this research context, the researcher will only focus on the model making or prototyping process per se. Sketching, drawing, detail/technical drawing, or mock-up making are disregards in this research.

Documents' analysis was used in identifying parameters that affect prototyping and RP process by D.T. Pham and R.S. Gault (1998). Whereas Weller C., et al. (2015) conducted analysis on market structure models to discuss economics effects on Additive Manufacturing or RP. Vayre B. et al. (2012) suggests their own methodology in the process of designing by utilising RP. This method is used by conducting a simple project to look into the design process in order to approve or disprove their hypothesis. Validation is made by virtual manufacturing their design (p. 636).