A FRAMEWORK OF CONTEXTUAL KNOWLEDGE IN THREE DIMENSIONAL COMPUTER AIDED DESIGN FOR MECHANICAL ENGINEERING UNDERGRADUATES

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time. To the greatest woman in my life my wife, thanks for all the love and the endless support for completing this PhD journey. Without you, it would have been impossible for any of this to happen.

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ABSTRACT

Today's industries demand engineering graduates who are equipped with good knowledge and skills in using modern Three Dimensional Computer Aided Design (3D CAD). However, the recent research findings show that there is a lack of contextual knowledge among Mechanical Engineering Undergraduates when utilizing 3D CAD modeling software to develop a good product design. Most of them are not able to contextualize their created model in the aspects of manufacturing and user applications. This study was conducted to explore the essential contextual knowledge elements in the process of developing 3D CAD models among practitioners in manufacturing industries. The constructs of digital product modeling were established for this study, known as the contexts of Model Creation, Model Manipulation, Model Visualization and Model Transfer. A transcendental phenomenology approach was used as the main research design of this study. The participants of this study were practicing engineers from a shipbuilding company in Peninsular Malaysia. They have been purposefully selected to explore their experiences in utilizing the elements of contextual knowledge in 3D CAD modeling applications in their daily design works. All collected data were analyzed using phenomenological analysis. The textural and structural descriptions were gathered to capture what and how the essential contextual knowledge elements from each practicing engineer in the application of 3D CAD modeling within four digital product modeling contexts. Relevant documents were analyzed from practicing engineers to triangulate the main data for this study. The study has successfully developed a framework of Contextual Knowledge in 3D CAD modeling, which consists of three main elements: Realization, Design Intention and Normalization. By injecting these three elements in teaching and learning 3D CAD modeling, students can be expected to develop a creative and innovative product design and may lead to better usability of 3D CAD software in the product modeling process.

ABSTRAK

Industri masa kini menuntut graduan kejuruteraan yang dilengkapi dengan pengetahuan dan kemahiran yang baik dalam menggunakan Reka Bentuk Berbantu Komputer Tiga Dimensi (3D CAD) moden. Walau bagaimanapun, dapatan kajian terkini mendapati bahawa terdapat kelemahan pengetahuan kontekstual dalam kalangan pelajar Sarjana Muda Kejuruteraan Mekanikal semasa menggunakan perisian pemodelan 3D CAD untuk membangunkan reka bentuk produk yang baik. Sebilangan besar daripada mereka tidak dapat mengkontekstualisasikan model ciptaan mereka terhadap aspek pembuatan dan aplikasi pengguna. Kajian ini telah dijalankan untuk meneroka elemen-elemen pengetahuan kontekstual yang penting dalam proses pembangunan model 3D CAD dalam kalangan pengamal industri pembuatan. Konstruk pemodelan produk digital telah dibentuk untuk kajian ini, yang dikenali sebagai konteks Model Penciptaan, Model Manipulasi, Model Visualisasi dan Model Pemindahan. Pendekatan fenomenologi transendental telah digunakan sebagai reka bentuk penyelidikan utama bagi kajian ini. Peserta-peserta bagi kajian ini adalah jurutera terlatih dari sebuah syarikat pembinaan kapal di Semenanjung Malaysia. Mereka ini dipilih secara bertujuan untuk meneroka pengalaman mereka dalam memanfaatkan elemen-elemen pengetahuan kontekstual dalam mengaplikasikan pemodelan 3D CAD dalam kerja-kerja reka bentuk harian mereka. Semua data yang dikumpulkan telah dianalisis menggunakan analisis fenomenologi. Huraian *"textural"* dan *"structural"* dikumpulkan untuk mendapatkan apakah elemen-elemen penting pengetahuan kontekstual dan bagaimana elemen-elemen tersebut dipraktikkan oleh setiap jurutera terlatih dalam pengaplikasian pemodelan 3D CAD berdasarkan empat konteks pemodelan produk digital. Dokumen-dokumen yang relevan daripada jurutera terlatih juga dianalisis untuk menyokong data utama kajian ini. Kajian ini telah berjaya membangunkan kerangka Pengetahuan Kontekstual dalam pemodelan 3D CAD, yang terdiri daripada tiga elemen utama: *"Realization"*, *"Design Intention"* dan *"Normalization"*. Dengan menyuntikkan ketiga-tiga elemen ini dalam pengajaran dan pembelajaran pemodelan 3D CAD, pelajar diharapkan dapat membangunkan reka bentuk produk yang kreatif dan inovatif dan dapat mendorong penggunaan perisian 3D CAD yang lebih baik dalam proses pemodelan produk.

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CAD	-	Computer Aided Design
CAM	-	Computer Aided Manufacturing
MC	-	Model Creation
MM	-	Model Manipulation
MV	-	Model Visualization
MT	-	Model Transfer
2D	-	Two Dimensional
3D	-	Three Dimensional
PDS	-	Product Design Specification
ABET	-	Accreditation Board for Engineering and Technology
NSF	-	National Science Foundation
ISO	-	International Organization for Standardization
ANSI	-	American National Standards Institute
UTM	-	Universiti Teknologi Malaysia

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Advances in Computer Aided Design (CAD) systems have contributed much to society as a whole. CAD systems have been recognized as essential tools in the product development process. This system was first introduced in the colleges and universities curriculum since the 1960s. In the beginning stage, the CAD system has been used in engineering education to replace the conventional hand-drawn method in producing an engineering drawing. Then, after CAD software has been well established in the market and becomes more affordable, this system has found their way to be injected into the engineering curriculum. CAD system has extensively been used in teaching and learning Mechanical Engineering program. In the current curriculum, students will learn how to use CAD software in engineering design subjects. The utilization of these CAD systems in the learning process has helped students a lot in visualizing and presenting their design ideas professionally. This introduction chapter will start with a discussion on the background of this study and then will be followed by the problem statement section, research objectives and research questions sections and significance of this conducted study section. Later, the theoretical framework and conceptual framework underpinned for this study will be discussed. Then, it will be followed with the definition of terms section to explain all the terms used in this research study. The last section of this chapter will then list all the limitations of this conducted study.

1.2 Background of Study

In one of the public universities in the south of Peninsular Malaysia, 3D CAD software has been taught as a supporting tool in producing engineering drawings among Mechanical Engineering undergraduates. The focus of teaching and learning of this software generally to utilizes it as a supporting tool in the development of product design. Students will learn how to employ the 3D CAD software to produce engineering drawings, creating design ideas, presenting the design project and the most important thing, this software will be used for the final year capstone design project.

Similarly with other higher institutions practices, CAD modeling software has also been integrated into their Mechanical Engineering curriculum. This was based on what has been reported by McConnell (2006), Hill Jr (2008), Hughes et al. (2014), Marschner and Shirley (2018) and Zalilov et al. (2020). They have mentioned that the use of this 3D CAD modeling software is commonly be embedded in the Engineering Design or Computer Graphics courses. Nevertheless, it was contrasted with what has been reported by Garcia et al. (2005) and Hamade et al. (2008) in their institutions practiced. They have stated the existence of a particular subject on CAD modeling course in their Mechanical Engineering curriculum.

However, this particular subject has not been offered at this study university and the knowledge on how to use CAD software will be taught along with the Engineering Drawing subject. In this Engineering Drawing subject, students will learn about technical engineering drawing by using a conventional hand-drawn method and at the same time, they will learn on how to employ the 3D CAD modeling software to develop engineering drawings from the created 3D models. The main focus of teaching and learning this 3D CAD modeling software is just to ensure that all students would be able to produce engineering drawings from the created 3D models. Typically, the instruction of solid model development is based on procedural and command knowledge. This procedural and command knowledge have been identified as two primary knowledge representations that typically been emphasized by instructors or lecturers in teaching and learning 3D CAD model development process Lang et al., 1991; Bhavanani, 2000; Chester, 2006; Hamade and Artail, 2008; Johnson and Diwakaran, 2011; Peng et al., 2012).

In order to assess the students' understanding of the application of this CAD software, students have been assigned a task to complete the final engineering drawing project. They need to re-draw real solid models by using Solid Works software and then extract the models into a complete engineering drawing. In a preliminary study on the final year Mechanical Engineering undergraduates project, the researcher has summarized that most of the students are able to complete their engineering drawings by using 3D CAD modeling software.

This result was shown that most of them have good procedural and command knowledge in using 3D CAD modeling software. However, when detailing the produced drawing into the aspects of good engineering design based on the Pugh (1990) Product Design Specifications (PDS), the researcher has found that there are problems with their created product design and need to be improved. Most of them were just focused on how to re-draw the models without thinking about the applications of the models within the contexts. They actually are not able to contextualize their created product design or, in other words, they are just drawn back the models without putting themself as the user or the manufacturer of the models that they produce.

This problem has also occurred among the fresh graduate engineers when they are newly entering into the real work situation in manufacturing industries. In the preliminary interview with the practicing engineer in one of the manufacturing industry, he admitted that he had made a lot of mistakes when he got a task to design a ferry toilet. As a consequence of his design errors, his company had to bear substantial losses. This mistake happened because of his design does not think about the ferry users' application. He does not put himself as the user of the toilet and this has caused him to not being able to think about what would happen to the users when they use the toilet while the ferry is moving or in other situations context. These problems actually relate to what has been reported by Ma and Zhang (2010) in their study. They have reported the most frequent mistakes that are commonly performed by the product designers in manufacturing industries. There were mistakes that have caused some designed parts not to be able machined during the manufacturing stage. These mistakes occurred because mainly the designers are more considered on the product function rather than the aspects of product manufacturability.

From the researcher's point of view, these problems have occurred due to the lack of fundamental knowledge representation in 3D CAD modeling that the engineer needed when utilizing 3D CAD modeling software for product design development. According to Kals (1997), having a lack of fundamental knowledge when developing a CAD model will effect the final quality of the product design. Thus, the advancement of this 3D CAD modeling knowledge representation is needed among engineering students to increase their competencies in the 3D CAD modeling system (Daud,2012). Besides, having a high competency level in the use of 3D CAD modeling systems is crucial when students are facing various 3D CAD modeling techniques practices in manufacturing industries.

Recently, CAD technology has been changed rapidly. Therefore, the CAD instructors and lecturers always need to keep updated the curriculum on the specific knowledge and skills required in the industries practices (Yuen, 1990; Zeid et al., 2015). In addition, Yuen (1990) Adnan et al. (2015) have also emphasized the necessity of CAD instructors and lecturers to prepare mechanical engineers for manufacturing industries' needs. It was due to note that the “CAD system is nothing more than a tool in the engineers' hands and that computer cannot draw by themselves".

In the previous studies, there were seven types of knowledge representations on CAD modeling that have been addressed by other researchers. There was the knowledge of procedural knowledge (Lang et al., 1991; Hamade and Artail, 2008; Johnson and Diwakaran, 2011; Peng et al., 2012), declarative knowledge (Lang et al., 1991; Rynne and Gaughran, 2008; Peng et al., 2014), command knowledge (Bhavanani, 2000; Chester, 2006), strategic knowledge (Bhavnani et al., 2001; Chester, 2007; Johnson and Diwakaran, 2011; Camba et al., 2016), specific procedural command knowledge (Chester, 2006; Toto et al., 2014), declarative command knowledge (Chester, 2006; Adair and Jaeger, 2014; Otey et al., 2018) and conceptual knowledge (Daud,2012; Khan et al., 2019). According to Daud (2012), all these CAD modeling knowledge representations have been more focused on the tasks related to the model creation using a specific CAD modeling software or known as "a single platform". Nevertheless, there is only one research that has been done by Daud et al. (2012) on the knowledge representation of users’ conceptual knowledge in the 3D

CAD modeling system, which is the knowledge that can apply to all commercial software, that means, “applicable to all” commercial CAD modeling systems. Therefore, the researcher was concerned that it is a necessity to conduct more research on the types of knowledge that can be applied to all commercial 3D CAD modeling software on the market and also be able to solve the Mechanical Engineering undergraduates problem in contextualizing themselves in designing a model by using any 3D CAD modeling software.

Since CAD modeling systems have been fully utilized by most of the manufacturing industries and the increment of system complexity as reported by Habib (2014), it has led the researcher to emphasize the importance of contextual knowledge enhancement among the engineers when using CAD modeling application for product design development. Furthermore, contextual knowledge is in a position to support user interaction and should lead them to raise the usability of the tool (Lohmann et al., 2006; Smith, 2019). Based on research works by Rulke and Galaskiewicz (2000), Yoshioka et al. (2001), Earl (2001), Tennyson and Breuer (2002), Johnson et al. (2002) and Pomerol et al. (2002), contextual knowledge are often defined as the individual's understanding to "use specific concepts, rules and principles within the knowing of why, when and where the knowledge should be wont to complete a specific task". As reported by Muhammed et al. (2011), the innovativeness of an individual's work can be enhanced positively by having a high contextual knowledge level. Furthermore, improving contextual knowledge can assist engineering undergraduates in being more creative, thus indirectly achieving one of the engineers' key attributes in 2020 (National Academy of Engineering, 2004).

Contextual knowledge was identified as one of the "key capabilities for engineering students" in a National Science Foundation (NSF) 1992 report (Bordogna, 2005; Goold, 2015). Bordogna (2005) has also mentioned that engineering students must be exposed to the functional core of engineering and able to integrate different types of knowledge for specific purposes in order to increase the essence of engineering. According to what has been emphasized by Ropohl (1997) and Maluleke (2019), contextual knowledge can positively increase the students understanding in learning technology studies.

According to ABET criteria for accrediting engineering programs outcomes, the most important attribute of engineering graduates has highlighted the engineering students "ability to use the techniques, skills and modern engineering tools necessary for engineering practice which are: Computer Literacy in Analysis Tools, Computer Literacy in Design Tools and Computer Literacy in Simulation and Modeling which include skills in the use of Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) tools" (Engineering Accreditation Commission, 1999). In the updated version of ABET, this criteria has been classified as "hard" skills, with engineering graduates required to have the "ability to use the techniques, skills and modern engineering tools necessary for engineering practice" (Brahimi et al., 2018). According to the accrediting bodies under Washington Accord for engineering qualifications, International Engineering Alliance (2014), they have also highlighted one attribute for the engineering graduates should be “create, select and apply appropriate techniques, resources and modern engineering and IT tools, including prediction and modeling, to complex engineering problems, with an understanding of the limitations”.

As a result, undergraduates should be equipped with contextual knowledge of 3D CAD modeling techniques to ensure they understand how to use the CAD software properly. Since the accreditation bodies explicitly expressed their criteria clearly, the existence of such expertise from the viewpoint of manufacturing industries would be critical. This study will help 3D CAD instructors and lecturers prepare students for the real world of manufacturing industries by focusing on the exploration of how the practicing engineers experienced the essential elements of contextual knowledge in the process of developing 3D CAD models. This study focused on exploring the essential contextual knowledge elements in the process of developing 3D CAD models among practitioners in manufacturing industries and then developing a Contextual Knowledge Framework in 3D CAD modeling for the Mechanical Engineering program.

1.3 Statement of the Problem

3D CAD systems have played an important role in introducing the new paradigm of product development. Most of today's industries are demanding to have university graduate engineers prepared with a good level of knowledge and skills in using modern CAD modeling tools. According to Peng et al. (2014), in the current highly competitive environment, they have made the not knowledgeable student using CAD modeling tools in a distinct disadvantage place after graduation. Therefore, the current engineering undergraduates are considered as mandatory to be equipped with their self with a good competency in the using of CAD modeling tools. Due to the need to equip the students with a good competency in using CAD modeling tools, there is a needs to review and updates the current curriculum in the higher education practiced and making an alignment with the current CAD practiced in the industries.

According to the ABET 2018-2019, Criterion 3 outcomes (Engineering Accreditation Commission, 2018), engineering students are required to have the "ability to use modern engineering tools necessary for engineering practice". In this study, 3D CAD is viewed as a modern engineering tool in the field of engineering. However, to what extent students contextualize the application of 3D CAD modeling within their engineering discipline remained unknown. Based on the literature review findings, the researcher has revealed that is no systematic research has been conducted on the exploration of contextual knowledge in 3D CAD modeling techniques either at the level of higher education institutions or manufacturing industries.

In the process of developing a holistic engineering education, Grasso and Burkins (2010) mentioned that future engineers need must be able to contextualize their work within the more significant needs of society in order to create creative, innovative and holistic solutions to the problems and challenges of the twenty-first century. According to Muhammed et al. (2011), contextual knowledge improves an individual's work's innovativeness. It will indirectly assist engineering students in being more innovative and achieving one of the National Academy of Engineering (2004) core attributes for engineers in 2020.

In identifying the need to conduct this study, the researcher has made the preliminary study with 20 students of final year undergraduates at the faculty of Mechanical Engineering in one university in south peninsular Malaysia and also with three practicing engineers in one shipbuilding company in Perak. Based on the preliminary study results, the researcher has found that most of the mechanical engineering undergraduates and the new entry engineers have a lack of contextual knowledge in the applications of 3D CAD modeling during the product design stage (Adnan et al., 2019). Due to this problem, it has caused the model designers not able to contextualize their developed models in order to make a good product design for the users' application. Two approaches have been used in assessing the Mechanical Engineering undergraduates in the preliminary study stage.

In the first approach, the researcher has given them a task to redraw back the solid 3D CAD model using SolidWorks software. The aim of giving this task is to assess the competency level of students in using CAD software to develop a solid 3D model. The results from this task also can help the researcher to see the student's level of procedural and command knowledge. Based on the findings, the researcher has found that most of them have a good competency in using CAD software and having a good level of procedural and command knowledge. The second approach is by assessing the engineering drawing of their final year project. From this preliminary study approach, the researcher has found that most of the students just focusing on how to re-draw the models using CAD software instead of thinking about the aspects of users' applications and also the aspects on how to manufacture that model has been designed.

Based on these findings, it has shown that most of them are not able to contextualize their created models or in other words, they just redraw the models without putting themself as the user or the manufacturer of the models that they produce. All the produced drawings also have a lack of information that can help others easily understand the overall view of the created product design. When the researcher has gone through with the practicing engineer preliminary study interviews, the researcher also has found that the same problems occur among the new entry engineers when they are newly entering manufacturing industries. This was based on their first experience when conducting a project that relates to a product design. As a result, this research explored another form of knowledge representation in CAD modeling called contextual knowledge. This contextual knowledge was described as understanding the principles governing 3D CAD modeling techniques either implicitly or explicitly. In addition, the interrelationships between essential elements that regulate the modeling techniques within a more extensive system, allowing them to cooperate together in producing workable 3D virtual models.

Since there was no comprehensive academic study has been conducted in addressing this type of knowledge representation in the 3D CAD model development process, the researcher feels that there is a responsibility to conduct an exploratory study on this type of knowledge. In order to clarify the essential contextual knowledge elements in the process of developing 3D CAD models among practitioners in manufacturing industries will be the main research activity and followed by the development of Contextual Knowledge Framework. Thus, this research was addressed to seek the answers to the questions: What are the essential contextual knowledge elements in the application of 3D CAD modeling within digital product modeling contexts from the perspective of practicing engineers and how have the elements been applied in product design modeling process?

1.4 Research Objectives

The objectives of this research are:

(a) To explore the essential contextual knowledge elements in the application of 3D CAD modeling within digital product modeling contexts (Model Creation, Model Manipulation, Model Visualization and Model Transfer) from the perspective of practicing engineers.

(b) To develop a framework of contextual knowledge in 3D CAD modeling for Mechanical Engineering undergraduates program.

1.5 Research Questions

The following research questions have driven this study based on the background and purpose of the study:

Research Question 1:

What are the essential contextual knowledge elements in the application of 3D CAD modeling within Model Creation context from the perspective of practicing engineers?

Research Question 2:

How do the practicing engineers employ the essential contextual knowledge elements in the application of 3D CAD modeling within Model Creation context?

Research Question 3:

What are the essential contextual knowledge elements in the application of 3D CAD modeling within Model Manipulation context from the perspective of practicing engineers?

Research Question 4:

How do the practicing engineers employ the essential contextual knowledge elements in the application of 3D CAD modeling within Model Manipulation context?

Research Question 5:

What are the essential contextual knowledge elements in the application of 3D CAD modeling within Model Visualization context from the perspective of practicing engineers?

Research Question 6:

How do the practicing engineers employ the essential contextual knowledge elements in the application of 3D CAD modeling within Model Visualization context?

Research Question 7:

What are the essential contextual knowledge elements in the application of 3D CAD modeling within Model Transfer context from the perspective of practicing engineers?

Research Question 8:

How do the practicing engineers employ the essential contextual knowledge elements in the application of 3D CAD modeling within Model Transfer context?

1.6 Significance of the Study

This research is significant and essential for a number of reasons. First, most of the research studies focused only on the knowledge that only can be applied to a specific commercial software of 3D CAD modeling and there is less research done on the knowledge representation in 3D CAD modeling that applicable to all commercial software has been done by Daud (2012) and Khan et al. (2019) on conceptual knowledge. For this reason, this study has been conducted to provide another knowledge representation type in CAD modeling and known as contextual knowledge. This knowledge can be viewed as another type of knowledge that can be applied to all commercial software in order to increase the level of competencies of Mechanical Engineering undergraduates in 3D CAD modeling.

Second, Muhammed et al. (2011) found that having a high degree of contextual knowledge improves an individual's ability to be innovative in their work. According to Grasso and Burkins (2010) in their book "Holistic Engineering Education," the advancement of contextual knowledge in 3D CAD modeling can also improve engineers' ability to develop creative and innovative product designs. Another important reason for conducting this research is that having a high degree of contextual knowledge can help to assist engineers in making the right design the first time in the product design development process and reducing product development time (Lohmann et al., 2006). According to Lohmann et al. (2006) and Smith (2019), contextual knowledge is one of the most important aspects of the product development process since it can support user engagement and improve tool usability.

The next significant are the findings from this study can be used to assist the curriculum developers or lecturers in reviewing and updating the curriculum of CAD courses in order to make the alignment between the manufacturing industries CAD modeling applications with the teaching and learning CAD modeling courses in the higher educations. Ye et al. (2004) posited that most of the current curriculum practiced by the instructors is more focused on CAD as a tool and skills development rather than the CAD theory and their application in engineering practiced. The information and results obtained from this study can provide an insight into the engineering curriculum developer to enrich and enhance the curriculum in Mechanical Engineering program. In a global view, knowledge has become the driver of economic growth of the country. Therefore, the advancement of knowledge in the design area needs to be improved in order to produce better products in the foreseeable future.

1.7 Scope of the Study

This conducted study was focused on exploring the essential contextual knowledge elements that mostly been utilized by practicing engineers in the manufacturing industries while applying 3D CAD modeling systems in the process of product design development. Since 3D CAD systems have been utilized as the primary design tools in the teaching and learning engineering design or computer graphics courses in all engineering programs at higher education, this conducted study has scoped its applications just in the pure Mechanical Engineering Undergraduates program only not specifically to other Mechanical Engineering program like Aeronautic Engineering, Industrial Engineering, Automotive Engineering or others. Therefore, the final framework that emerged from this study were be suited only for

3D CAD modeling applications for Mechanical Engineering Undergraduates program. In developing the final framework for this study, there were four contexts of digital product modeling in 3D CAD modeling that have been adapted from Daud's (2012) constructs. There are contexts on Model Creation, Model Manipulation, Model Visualization and Model Transfer. Based on these four contexts, the practicing engineers' contextual knowledge has been studied to understand on what and how are the essential contextual knowledge elements that been applied by them when developing a 3D CAD model. Therefore, the data for this study has been purposefully selected from practicing engineers in one of the shipbuilding company in Perak. All the practicing engineers are experienced mechanical engineers that daily used CAD software and have been experienced used more than one CAD modeling software. Thus, the findings from this study are represented the 3D CAD modeling applications from the mechanical engineering point of view. As been addressed in the background of this study, there are seven knowledge representations in CAD modeling that have been explored by others researchers. Therefore, this conducted study has been scoped to explore only on the contextual knowledge representation in CAD modeling without dependence on the others knowledge representation.

1.8 Theoretical Framework

The cognitive domain has been selected as the main domain to be explored in this study. The cognitive constructivism theory has been chosen as the underpinning theoretical framework. Piaget's work on individual knowledge construction was the foundation for traditional cognitive constructivism theory. According to Akar (2003), the process of cognitive analysis and interpreting experiences helps to construct individual knowledge. The theory of cognitive constructivism emphasizes the cognitive processes that individuals use to make sense with their surroundings (Amineh and Asl, 2015). Piaget focused more on how students construct meaning and understanding by actively exploring and discovering the world around them (Al Mulhem, 2014).

Practicing engineers have positively established their design knowledge based on their own experiences in previous projects through using 3D CAD modeling systems for the development of product design. They will reorganize their experiences and cognitive structures based on previous project experiences in order to accommodate the development of new 3D CAD models. Assimilation and accommodation are terms used by Piaget in cognitive constructivism to describe this process (Cholewinski, 2009; Schrader, 2015; Mărunțelu, 2020). The assimilation process occurs when an individual is faced with a new experience that must be integrated into an established mental framework (Piaget and Inhelder, 2008; Schuh and Barab, 2008; Tuncer, 2009). However, when existing knowledge needs to be modified or conflicted with new experiences and needs to be revised to suit new situations, this phase is referred to as accommodation (Can, 2009; Loyens, 2007; Slavin, 2012). According to Loyens (2007), individual ability to manage the assimilation and accommodation process will affect the construction of individual knowledge and meaning and it was crucial to Piaget.

The assimilation and accommodation process is significant in this study because it guides practicing engineers in improving their contextual knowledge during the 3D CAD model development process. 3D CAD modeling software was commonly used by practicing engineers to speed up the product design development process. Every project they receive usually has its own set of criteria, specifications, standards and requirements. They must ensure that everything has been completed. Therefore, in order to complete their task, they must assimilate and accommodate their existing design knowledge.

When working on 3D CAD models, practicing engineers will come across new ways of representing a model's features or alternative procedures for creating an object. Therefore, in accommodating the new knowledge when creating the 3D model, they must construct and reconstruct their own mental models. It helps engineers in the generation of contextual knowledge about modeling techniques through the process of model construction and reconstruction. This illustrates how natural constructivism can be used to develop contextual knowledge in 3D CAD modeling. More complex models can be created as new knowledge is gained over experience. In this context, prior knowledge of modeling techniques, as well as contextualization of the model development process, influence the way practicing engineers represent their contextual knowledge in 3D CAD modeling. As shown in Figure 1.1, there are two main frameworks that have been referred to explore the cognitive constructivism process based on the constructs of contextual knowledge in 3D CAD modeling. There were the Aspers (2006) contextual knowledge representation framework and digital product modeling contexts in the 3D CAD modeling framework that has been adapted from Daud (2012). Detailed explainations on these two frameworks can be referred in Chapter 2. Therefore, this conducted study was aimed to explore the interaction between these two frameworks by focussing on the overlapping contextual knowledge elements that emerged when the practicing engineers utilized 3D CAD modeling systems in their daily design works. According to Aspers (2006), lifeworld and the province of meaning are the two main elements used to represent contextual knowledge activities. Thus, these two elements were explored in this conducted study to understand the essential contextual knowledge elements that have mostly been utilized by the practicing engineers while they are creating, manipulating, visualizing and transferring the 3D CAD systems in the process of product design development process. Figure 1.1 illustrates the structure of the theoretical framework.

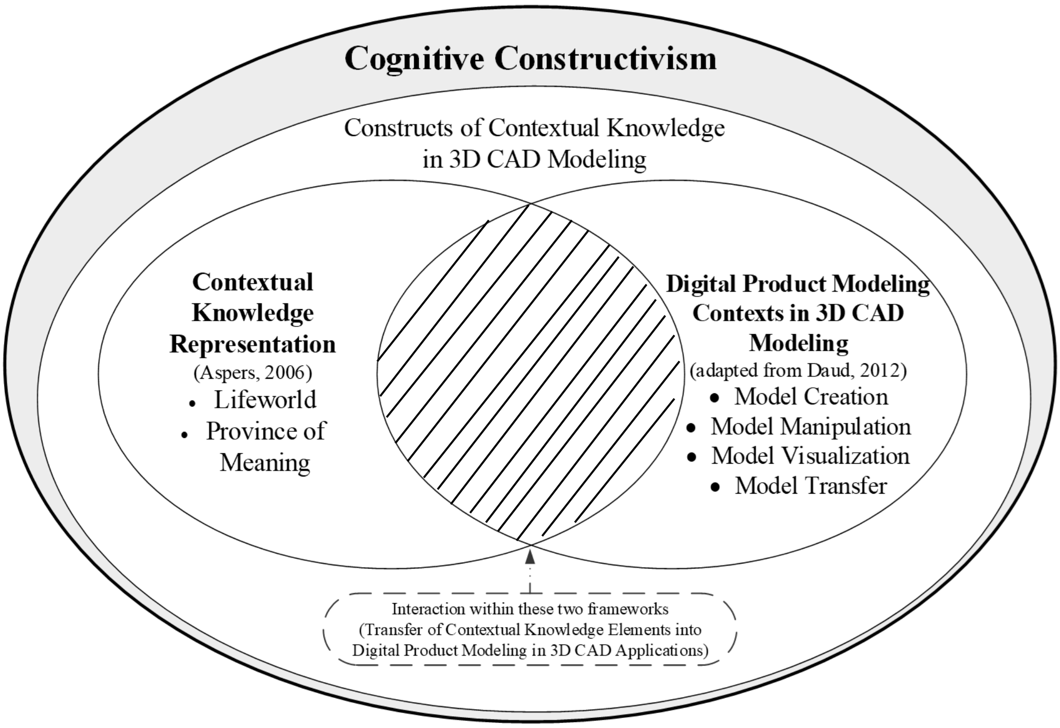

Figure 1.1 Theoretical Framework of Research

1.9 Conceptual Framework

This research was guided by four frameworks: a knowledge representation in a CAD modeling system, a digital product modeling framework adapted from Daud (2012), product design specifications (PDS) elements (Pugh, 1990) and Aspers (2006) contextual knowledge representation framework. This research has referred to the knowledge representation in the CAD modeling framework in order to understand the creation and utilization of knowledge in the process of developing a product model using a CAD modeling system.

A thorough review has been done by researcher in forming this knowledge representation in the CAD modeling framework. From the review, researcher has found that there were seven types of knowledge representations in CAD modeling has been done by the previous researcher. There are knowledge representations on procedural knowledge (Lang et al., 1991; Hamade and Artail, 2008; Johnson and Diwakaran, 2011; Peng et al., 2012), declarative knowledge (Lang et al., 1991; Rynne and Gaughran, 2008; Peng et al., 2014), command knowledge (Bhavanani, 2000; Chester, 2006), strategic knowledge (Bhavnani et al., 2001; Chester, 2007; Johnson and Diwakaran, 2011; Camba et al., 2016), specific procedural command knowledge (Chester, 2006; Toto et al., 2014), declarative command knowledge (Chester, 2006; Adair and Jaeger, 2014; Otey et al., 2018) and conceptual knowledge (Daud,2012; Khan et al., 2019).

These all knowledge representations in CAD modeling can be categories into two groups based on their application: i) knowledge that applicable to specific commercial software and ii) knowledge that applicable to all commercial software. However, six out of seven types of knowledge representations are focused on the knowledge that can be applied to specific commercial software or, in other words, “on a single platform”. Nevertheless, there is less research that has been done by Daud (2012) and Khan et al. (2019) on the knowledge representation of users’ conceptual knowledge in the 3D CAD modeling system, which is the knowledge that can be applied to all commercial software, that means, “applicable to all” commercial CAD modeling systems.

Therefore, in this conducted study, the researcher has taken the initiative to address these issues by focusing on the contextual knowledge elements representation in CAD modeling systems. This type of knowledge representation has been considered as the knowledge that can be applied in all 3D CAD modeling systems. Besides, the digital product modeling framework oriented towards manufacturing operations by Yan et al. (2006) has been explored to understand the prevalent modeling tasks or activities associated with using the CAD modeling system in developing a product design. According to Bauert et al. (1990) and Lam (2001), the CAD modeling system application in the manufacturing industries has facilitated the complex model propagation by registering all the product knowledge and integrating all the production processes. This framework has also been selected in this study because nowadays, computer supported modeling has been widely used in the manufacturing industry (Johansson and Detterfelt, 2006; Vuletic et al., 2018).

The CAD modeling system has been recognized as a "leading tool in the product development process (Mi et al., 2006; Vaai, 2014; Lin and Chiu, 2017). As a result, for construct development, all of the common tasks and activities within the framework of the digital product modeling approach are used. Based on the literature, the researcher discovered that there are several contexts involved in digital product modeling. However, in this research, four contexts of CAD in digital product modeling have been focused on and are known as "Model Creation, Model Manipulation, Model Visualization and Model Transfer" as adapted from Daud (2012) conceptual knowledge framework. Further discussions about these four digital product modeling contexts will be discussed in the following section.

Product Design Specifications (PDS) framework by Pugh (1990) has been reviewed in this study to overlook its elements application during the model creation process in 3D CAD modeling. PDS is a list of the critical parameters, specifications and requirements for the product design. It contains with 32 elements that have been listed by Pugh (1990) and might appear as product design specifications and it is not intended to be all inclusive in one product design. There are the elements of performance, environment, life in service, maintenance, targeted production cost, manufacturing facility, size, weight, aesthetics, materials, ergonomics, customer, quality and reliability, safety, company constraints, installation, environment and other elements. In this study, the appropriate elements that can be applied in 3D CAD modeling have been reviewed in order to understand the contextual knowledge elements interaction with this PDS framework and digital product modeling context framework. Detailed discussion on this PDS elements application in this study can be found in Chapter 2.

The contextual knowledge representation framework in this study has been adopted from Asper's (2006) contextual knowledge elements. According to Aspers (2006), two main elements can represent contextual knowledge: the lifeworld and the province of meaning. The word "contextual" implies a close connection to cognitive skills, which are referred to as "domain-dependent cognitive strategies" (Tennyson, 1994). The researcher redefined contextual knowledge as an individual's "understanding of why, when and where to apply specific concepts, rules and principles" in modeling activities within digital product modeling contexts in order to align the use of contextual knowledge in 3D CAD modeling. Therefore, this exploration study has been driven by the applications of practicing engineers on these two essential elements of contextual knowledge.

In this study, the practicing knowledge on real problems, situations and applications faced by practicing engineers when utilizing 3D CAD modeling activities within a digital product modeling context in their product design is known as the lifeworld element. For the province of meaning element, it has been known as the practicing engineer knowledge in having the same understanding on the application of 3D CAD modeling in their product design. Further discussions about how contextual knowledge framework representation are employed in 3D CAD modeling activities in various modeling contexts are discussed in the following chapter. In showing the contribution of this study into the body of knowledge representation in CAD modeling framework, Figure 1.2 has been structured for this study.

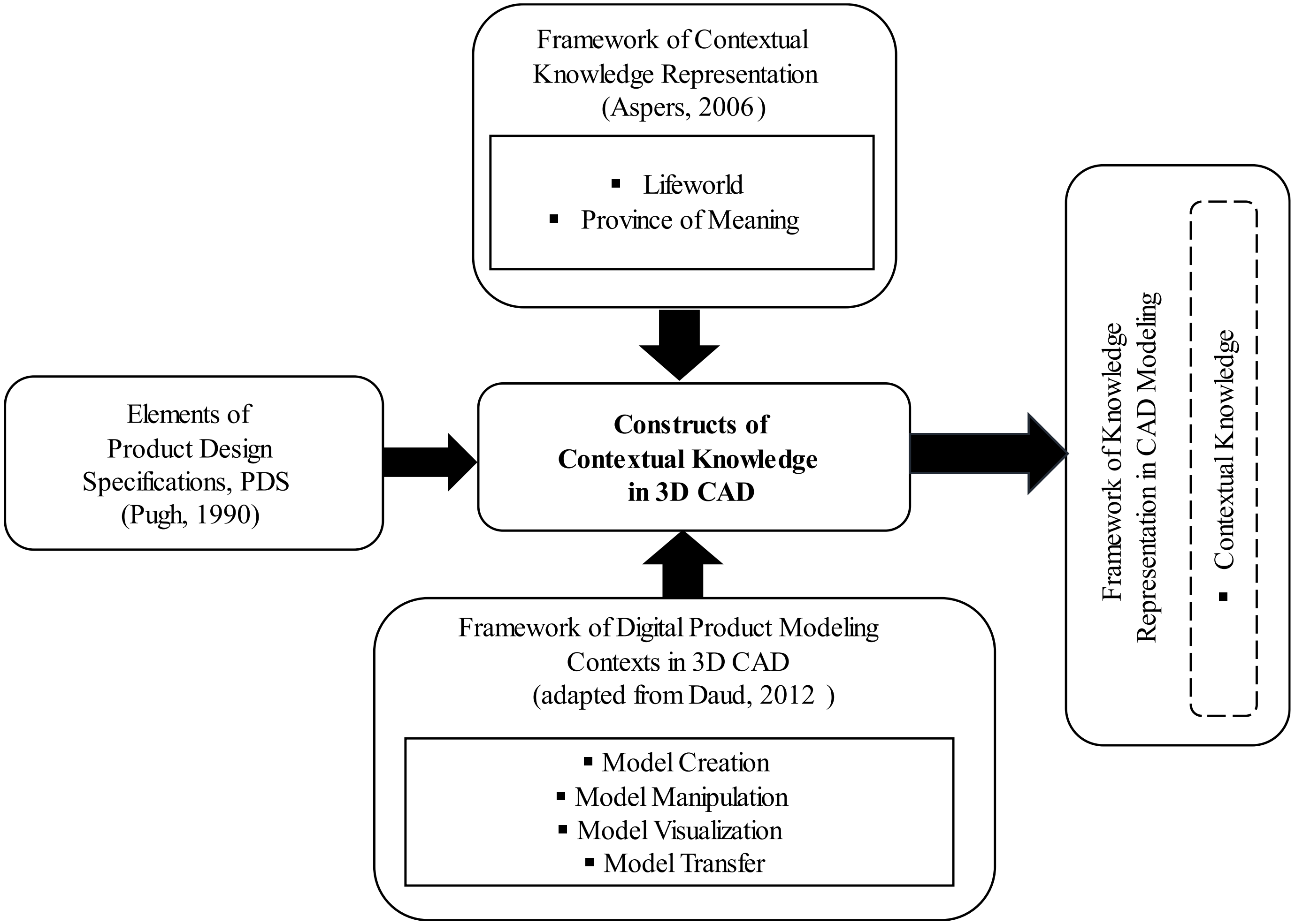

Figure 1.2 Conceptual Framework of Research

1.10 Operational Definitions

Computer Aided Design (CAD) - An engineering design activity in which the computer has been used to "create, modify, analyze, optimize and document" an engineering design (Kamrani and Nasr, 2009).

Manufacturing industry - An organization's primary function is to design and manufacture discrete products, capture design and manufacturing best practices for the optimal product life cycle (Khan and Hussain, 2014).

Digital Product Modeling - Provides an integrated framework for all aspects of design, allowing for the integration of downstream life cycle phases, including testing and certification, maintenance and operation and disposal into the conceptual design process (McEwan and Butterfield, 2012).

Model Creation – The activities of creating a CAD model based on the design intent of the part or product design and its subsequent use for the downstream applications (Bar-Cohen, 2019).

Model Manipulation – The modeling activity that reused and modified the created CAD model to meet new design criteria and requirements in practice (Zhu et al., 2010).

Model Visualization – The activity of utilizing the visualization tools in 3D CAD modeling system for displaying, sharing and communicating non-contextual information in the form of engineering drawings and product designs (Yassine et al., 2004; Terzi, 2005)

Model Transfer – Activity of transferring 3D CAD model data in the product development process for downstream applications (Pratt et al., 2001; Kim et al., 2008; Xie et al., 2013; Urbas and ukašino ić, 2019)

Contextual Knowledge - The ability of an individual to apply specific concepts, rules and principles in order to "understand why, when and where knowledge should be applied to complete a specific task" (Tennyson and Breuer, 2002). Contextual knowledge is redefined in this study as an individual's "understanding of why, where and where" to employ essential lifeworld and province of meaning elements in 3D CAD modeling activities within digital product modeling contexts, including the PDS elements such as safety, material, standard, manufacturing and others.

Lifeworld - According to Schutz (1976), the lifeworld is the "constantly pre-given" everyday world in which people exist with a natural attitude. The lifeworld element has been described in this study as the practicing engineer's "knowledge of the real problems, situations and applications" that they face while using 3D CAD modeling activities within the context of digital product modeling in their product design.

Province of Meaning - Aspers (2006) defines the specific province of meaning in the manufacturing industry as "understanding the meaning of an image or seeing it in the same way as anyone else as a result of shared experiences, schooling and other parallels". In this study, the province of meaning will be defined as the practicing engineer's knowledge of the application of 3D CAD modeling activities within the contexts of digital product modeling with other engineers in the same manufacturing firm, as well as their knowledge of what their customers need.

Product Design Specification (PDS) - A set of product requirements that need to be met at the end of product development (Sapuan et al., 2005; Dieter and Schmidt, 2012; Mat et al., 2020).

1.11 Limitations of the Study

This research was limited to the following conditions below:

a) The sample of practicing engineers for this study is restricted to those who have used any type of 3D CAD modeling software within three years and above.

b) The respondents for the preliminary study have been selected among Mechanical Engineering undergraduates were restricted to semester 2, final year Mechanical Engineering undergraduates (mainstream course) at the university for the academic year of 2012/2013 session.

c) 3D CAD programs were restricted to manufacturing-related disciplines in this study. Engineering design graphics, Computer Graphics, art design, Engineering Graphics and Geometric Design were not included.

d) This study was carried out only on practicing engineers at one shipbuilding company in Perak, Malaysia.

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LIST OF PUBLICATIONS

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