Conceptual Knowledge in Three Dimensional Computer Aided Design (3D CAD) modeling: A literature review and conceptual framework

[a]Mohd Fadzil Daud, [b]Jamaludin Mohd Taib, [c]Rio Sumarni Sharifudin

[a, b]*Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Skudai Johor, Malaysia*
[c]*Faculty of Education, Universiti Teknologi Malaysia, 81310 Skudai Johor, Malaysia*

Abstract

The advancement of computing technology and widespread adoption on the use of 3D CAD modeling system has led the development of techniques and approaches to facilitate learning of relevant techniques in virtual modeling. This paper presents a review of literature on knowledge representation in CAD and proposed a new framework of conceptual knowledge in 3D CAD modeling. Findings of studies reviewed suggest that conception of knowledge representation in 3D CAD modeling has been dominated by approaches stressing on the development of a model within a single platform, not on variations of the modeling techniques and the way the system is used. A new knowledge representation in 3D CAD modeling is proposed to assist students to become a capable engineer.

Keywords: 3D CAD, Conceptual Knowledge, Knowledge Representation in CAD

1. Introduction

It has been observed that the use of 3D CAD system in manufacturing industries has gained popularity since the advancement of computer technology (Choi et al., 2009). The importance of the system in the context of digital product modeling is supported by published literature (Mi et al., 2006; Hwang et al., 2007; Choi et al., 2009). The recognition of the importance of the modeling techniques affirms the needs to align the teaching of the modeling system with the need of the industries (Duan, 2004).

This article is conceptually structured around knowledge representation in 3D CAD modeling, and will provide a review and synthesis of the key literature on the types of knowledge in virtual modeling. Furthermore, framework of conceptual knowledge in the modeling process will be addressed. According to Kondoh et al. (2004), 3D CAD has been gaining popularity as a method of choice for product modeling. The utilization of the modeling system has become the key competitive factors in the era of globalization. Advancement in computer technology in the last decades has led to the more complex modeling system we see today. Thus, conceptual understanding on the utilization of the modeling system need to be recognized due to recent developments and evolving techniques of computerized modeling. In general, the interrelatedness of the features and tasks in creating workable virtual models need to be addressed within the context which it has been applied in the manufacturing industries. The purpose of this conceptual review is to inform engineering education research community about the presence of conceptual knowledge in the modeling process. Drawing on literature from digital product modeling, constructs of conceptual knowledge in 3D CAD modeling are developed based on the fact that product modeling operations of all commercial CAD system are similar (Yang et al., 2008).

The focus of this article is on establishing the constructs based on the common features provided by the software and the general tasks that the user can take advantages of the modeling system. The proposed framework seeks to build on the invaluable contributions of the current literature on the utilization of 3D CAD system in the area of

* M. F. Daud. Tel.: +6-07-553-4672
E-mail: fadzil@fkm.utm.my

product modeling. Specifically, the article discusses the context of knowledge representation in 3D CAD modeling techniques as it relates to the need to understand the types of knowledge in the creation of a digital product model and the implications on managing complex design models.

In the early development of the modeling system, the field of knowledge representation in CAD modeling was dominated by command, declarative, strategic and procedural types of knowledge (Lang et al., 1991; Bhavnani, 2000). However, with variations on the types of modeling techniques, supported by the advancement of computer technology, common features in the functional approach to develop a virtual model need to be highlighted. It is due to the fact that there is growing realization of the importance of 3D CAD modeling, as it is nowadays widely used modeling system in the development of a product model. Manufacturing industries rely on the application of the modeling system to support their product development process. Past research on the use of CAD system has already identified several types of knowledge in the development of a virtual model. Some of these were based on two dimensional CAD system when it was first introduced. A review on knowledge representation in the use of the modeling system is intended to examine the issue of the type of knowledge creation in the utilization of the modeling system, as the technology evolves rapidly. Recognizing knowledge representation in 3D CAD modeling techniques enable us to constructively enhance, refine and compose new strategies in teaching the applications of the modeling systems in higher educations. As such, newly graduated engineering students are better prepared for entry level jobs related to engineering product development process.

The need to recognize the existence of conceptual knowledge in the utilization of the modeling system is due to the fact that the technology has become more complicated by having various modeling techniques with different capabilities to carry out different functions. The techniques are different because of different vendor products use different kind of technologies resulting with various kinds of software features. A review on the topic of interest will provide an understanding of the need to recognize related component of conceptual knowledge in 3D CAD modeling. Constructs common to all commercially available CAD modeling system will be discussed to highlight the need to recognize valuable facilities provided by the vendor to create virtual models from the complex modeling system.

2. Knowledge representation in CAD

Lang et al. (1991) identified knowledge in CAD as declarative and procedural knowledge. They stated that declarative knowledge consists of the facts of the situation and would include knowledge on the object being drawn and knowledge about the particular commands which can be used on a particular CAD system. They further elaborated that users should have access to facts about the objects being design such as the mechanical properties of the object, good engineering principles which can be applied to the object, and knowledge about other designs for similar kinds of objects which can be used as a reference for the designed object. In addition, the users must have declarative knowledge about the particular system such as syntax of the commands and the particular commands which can be used. Bhavanani et. al. (2000), explained the meaning of declarative knowledge in CAD as knowing what the software is all about and what it can produce. While Chester (2007), proposed a declarative command knowledge which is concerned with specific procedures used by individuals to secure familiar objectives such as extrude and revolve. He states that it is knowledge about the commands or algorithms that are available within 3D CAD. CAD procedural knowledge as mentioned by Lang et al. (1991), is similar to a subroutine that processes the particular information in the same way each time depending on the situation. They further explain that the strategies or procedures used for CAD tasks should be independent of the CAD platform and this should be usable on virtually any of the machine. Chester (2007), proposed quite similar meaning but in different term as specific procedural command knowledge which is concerned with specific procedures used by individuals to secure familiar objectives such as extrude and revolve Bhavanani et al. (2000), used the term command knowledge which refers to knowledge of the commands (algorithms or tools) and procedures to be adopted by those tools within CAD software. It is related to knowledge of knowing the relevant software command to achieve desired output. Meanwhile Chester (2007), reconceptualized command knowledge as specific procedural command knowledge which is the knowledge of how to execute the commands by the system to get desired output. He explains that this knowledge enables the operator to execute the necessary commands within specific CAD software. Bhavnani et al. (2001), stated that

expertise in complex computer applications such as CAD may be differentiated on the basis of 'command' and 'strategic' knowledge with expert employing greater amounts of the later knowledge. He explained that strategic knowledge is concerned with knowledge of the alternative methods by which specific tasks may be achieved and the process by which a choice may be made. Chester (2006), refers to strategic knowledge as the knowledge necessary to choose and apply the appropriate command knowledge in a manner that efficiently produces model and allows future design variation.

Procedural, Command and Declarative knowledge are the most basic knowledge in the modeling tasks. These types of knowledge only focus on the knowledge representation of the modeling system based on the operation of a single 3D CAD platform. These types of knowledge can effectively be used on a single type of CAD system as users' experience developed over time. However, in practice, this is rarely happened. Model developers need to recognize the necessities to understand the general features and tasks in the development of a model, as activities related to the development process affect other processes (such as design, manufacturing process planning and production). Furthermore, developed model are being utilized or interact with other type of software.

3. Conceptual Knowledge in 3D CAD modeling

This section briefly reviews the definition of conceptual knowledge provided by several researchers in the field of education. The section is not meant to provide a comprehensive review of the definition, but rather to highlight its existence in 3D CAD modeling, as the modeling procedures and prevalent tasks associated with the modeling techniques has well been documented (Ault, 2005; Nestorovic, 2008; Hwang et al.,2009; Nyirenda et al., 2009). Bloom et al. (1956) defined conceptual knowledge as the interrelationships among the basic elements within a larger structure that enable them to function together. The term was also defined by Groth and Bergner (2006) as a connected web of knowledge; a cognitive network in which relations between nodes are as important as the discrete pieces of information constituting these nodes. While In the case of 3D CAD, the technology itself has become more complicated by having various modeling techniques with different capabilities to carry out different functions. Knowledge in the interrelationships of this technology within and between them is important as the systems are nowadays being used as an essential tool in product development process. According to Hiebert and Lefevre (1986), this knowledge is needed to identify problems and generate new strategies or adapt known strategies to solve original problems. Constructivism and Schemata are two important ideas that underpin learning issues in relation to conceptual knowledge (McCormick, 1997). Constructivisms in 3D CAD focus upon individuals building up representation of their understanding of the systems' model development process. Students gradually developing their understanding of model development process by initially building up basic models of a part to a more complicated model structure, and eventually form a complete assembled model. They will attempt to fit their understanding of the concepts during model development process. Prior conceptual knowledge is essential during this process as it develops over time. Furthermore, numerous authors, such as, McCormick (1997), Rittle-Johnson et al. (2001), Heywood (2005) and Tabaran et al. (2007), have discussed the importance of the knowledge and its interaction with procedural knowledge. It is clear from these sources, the presence and importance of the knowledge in digital product modeling process.

4. Conceptual Framework of Conceptual Knowledge in 3D CAD modeling

The primary focus of this article is to propose a conceptual framework of conceptual knowledge in 3D CAD modeling. As mentioned earlier, the conceptual framework comprised of five constructs that represent students' conceptual understanding of related areas in the construction of virtual engineering models. Each of the construct represents a set of students' conceptual understanding of the modeling process in certain circumstances.

4.1. Model Creation

In 3D CAD, modeling activity usually starts with defining datum or construction plane that serves as the base plane to create the base profile. The construction of the base profile utilizes geometric entities, such as lines, arcs, splines, which are drawn as vectors in a single open or closed profile that will form base part (Silva et al., 2002).

Constraints are added at this point to the profile if parametric modeling is chosen for the modeling techniques. Further development on models' subfeatures are constructed by employing the same sequence through creating and positioning the construction plane at appropriate location. The user can add features to the parts' features. Completed model are treated as a single part in assembly modeling and additional parts can be further developed either in the same or separate files. In addition, standard engineering part can also be constructed through third party software or special programming script by specifying required parameter. These parts are then assembled using suitable software's specific command procedures. Models are regularly rotated and positioned in preferred location during the development process to assist interaction between the user and the models. The justification for this construct follows from the explanation given above. This construct contain essential concept related to the types of modeling techniques and their related elements of each techniques, such as, ruled, tabulated and revolved surfaces. This construct is conceptualized in the context of the construction of a single component or assembly type of modeling. This construct is considered to describe a conceptual understanding related to aspects of 3D CAD model creation process, regardless of the type of modeling techniques used.

4.2. Manipulation

Manipulation is a modeling activity which variations on the models are developed (Baba et al., 1998).The model is manipulated by means of modifying their geometry or features. Making use of the systems' facilities has great potential on reducing design time and design mistakes, enhancing consistency and ease of documentation (Wang et al., 2008). According to Wang et al. (2008), acquiring this knowledge gives the advantage by reducing the amount of time spend modifying designs ideas, subsequently helping design to manufacture more quickly. Any change made on any part or assembly is automatically generated in all associated parts and drawing sheet, so that all the related files will simultaneously been changed as the main part is being manipulated. The explanation described above indicates the relative importance of the task in 3D CAD modeling activity. Thus, this construct attributes to conceptual understanding of manipulation activity within the context of computer supported product modeling process to achieve a rich diversity of design variations.

4.3. Exploratory Visualization

Yoshimura (2007), stated that quantifying and visualization are the important factors in product development process provided by 3D CAD modeling system as such designers can make effective judgments or evaluations of created model. Created model presented by the system let designers inspect and judge the product naturally, eliminating the need for the designer to mentally infer real world aspects from a set of engineering drawings. Furthermore, understanding of CAD systems' visualization facilities would help users to speed up model development process (Fitzmaurice et al., 2008). It is necessary for the user to be able to navigate through simple or complex models structure such that features can be added or modified to form complete object (Jong et al., 2009). For instance, users can make use of feature manager to select directly desired entities in a complex model structure which would enable them to speed up modifying or correcting unintentional error. This explanation of the significance of the task related to 3D CAD modeling process, support evidence relevant to the proposed construct. Thus, this construct is used to denote conceptual understanding of tasks referred to visually explore a model which would help accelerate model creation process.

4.4. Model Transfer

This construct represents conceptual understanding of the need to share data (model transfer) for the purpose of transferring models to be used by downstream applications. Understanding and knowing data transfer in 3D CAD models development process is essential to every CAD users as created models are used for downstream applications (Pratt et al., 2001 and Kim et al., 2008). Such downstream tools are related to the analysis of the model, evaluation of productivity and generation of geometric data for machining (Kurimoto et al. (2002). The process of developing the models should include the needs of other users. Models would not be useful if it cannot be transferred to another platform. For example, related software system could not read related data due to inappropriate use of geometry or topology to develop a 3D CAD model. Therefore, it is important to develop models

that can be in grater use throughout the organization. Thus, this construct is established based on users' conceptual understanding of sharing and exchanging models' data across various platforms, enabling a progressive development of a product model, which include the transfer of data for downstream users.

4.5. Collaboration

This construct consists of essential concepts of collaboration activities in 3D model development process. The construct concerns the understanding of various means of communication and collaboration in the development of a product model within any distributed teamwork environment. The framework of collaborative CAD in product development facilitates creation of a hierarchical product structure, with single and compound components by assigning tasks to team members (Janardanan et al. 2008). Each team member can have his own specific view on the product which is kept consistent by using a central product model. The actual design of a single component is supported by a web-client specialized in part design, whereas the specification of assembly relations among components is supported by a web-client specialized in assembly design (Bidarra et al. 2002). Some commercial CAD systems are incorporating functionality for multiuser facilities using client-server architecture in collaborative modeling. This construct is established based on users' conceptual understanding associated with the development of a product model within the context of collaborative CAD system.

5. Implications for Theory Development and Research

The most prominent implications is that the proposed framework now identifies a set of constructs that comprise conceptual knowledge in 3D CAD modeling pertaining to the discipline of Mechanical Engineering. Concerning about the nature of knowledge representation in CAD modeling, the framework explicitly describes the areas of interest in the study of 3D CAD modeling specifically related to the above mentioned discipline. Further refinement of the conceptual framework, based on research, could be undertaken by identification and incorporation of such contextual characteristics on the application of the modeling system in product development process. It would be premature to suggest that the proposed framework should be considered as another type of knowledge representation in 3D CAD modeling. The framework simply seeks to identify and describe the research areas that comprise conceptual understanding in virtual modeling. Thus, the conceptual framework at this point is purposely descriptive in nature.

6. Conclusion

The conceptual framework was proposed to address issues related to current understandings of conceptual knowledge in 3D CAD modeling. The framework suggests the complementary approach of engaging academic and community providers in knowledge representation of the modeling task. That is, the framework indicates how students can fully utilize the potential of the modeling system within the specified knowledge domain, such that instructors and engineering education community might be able to make informed decisions related to the teaching and learning of the modeling system. The benefits of conceptual understanding in a particular knowledge domain have been identified over years of research, yet little research addresses the existence of conceptual knowledge in 3D CAD modeling. In the new framework presented, research is needed to determine the potential advantages of understanding the knowledge, and also to clarify and test the interaction of the knowledge with other type of knowledge (Command, Procedural, and Strategic), in the construction of a virtual 3D CAD model. Future research in the areas of conceptual knowledge in 3D CAD modeling will be important to higher institutions in order to produce capable engineers of the future.

Acknowledgements

The authors wish to thank the Regional Centre for Engineering Education (RCEE) UTM, for supporting this research project.

References

Ault, H. K. and Giolas, D. T. (2005). An Investigation of Solid Modeling Practices in Industry. *Engineering Design Graphics Journal*. 69(1), 34-43.

Baba, Y. and Nobeoka, K. (1998). Towards knowledge-based product development: the 3-D CAD model of knowledge creation. *Research Policy*, 26(6), 643-659.

Bhavnani, S. K. (2000). Design conducive to the use of efficient strategies. *The 3rd conference on Designing interactive systems: processes, practices, methods, and techniques*, August 17-19, New York City, New York.

Bhavnani, S. K., Reif, F. and John, B. E. (2001). Beyond Command knowledge: Identifying and Teaching Strategic Knowledge for Complex computer applications. *CHI' 01Conference on Human Factors in Computing Systems*, March 31-April 5, Seattle, Washington, United States.

Bidarra, R., Kranendonk N., Noort A. and Bronsvoort W. F. (2002). A Collaborative Framework for Integrated Part and Assembly Modeling. *Transactions of the ASME*, 2(4), 256-264.

Bloom, B., Englehart, M. Furst, E., Hill, W., and Krathwohl, D. (1956). *Taxonomy of educational objectives: The classification of educational goals. Handbook I*: *Cognitive domain*. Longmans.

Chester, I. (2007). Teaching for CAD expertise. *International Journal of Technology and Design Education*, 17(1), 23-35.

Choi, S. S., Herter, J., Bruening, A. and Noh, S. D. (2009). MEMPHIS: New Framework for Realistic Virtual Engineering. *Concurrent Engineering,* 17(1), 21-33.

Duan, X. R. (2004). A Model Curriculum for Computer Aided Design (CAD) Associate Degree Programs. *Journal of Industrial Technology*, 20(2), 1-9.

Groth, R. E. and Bergner, J. A. (2006). Preservice elementary teachers' conceptual and procedural knowledge of mean, median and mode. *Mathematical Thinking and Learning*, 8(1), 37–63.

Heywood, J. (2005). *Engineering Education; Research and Development in Curriculum and Instruction*. Wiley-Interscience, John Wiley and Sons, Inc.

Hiebert, J. and Lefevre, P. (1986). Conceptual and procedural knowledge in mathematics: An introductory analysis. J. Hiebert (Ed.). *Conceptual and procedural knowledge: the case of mathematics*.Erlbaum.

Hwang, J., Mun, D. and Han, S. (2007). Neutral reference model for engineering change propagation in global top-down modeling approach. *International Journal of CAD/CAM*, 7(1).

Hwang, J., Mun, D. and Han, S. (2009). Representation and Propagation of Engineering Change Information in Collaborative Product Development using a Neutral Reference Model. *Concurrent Engineering*, 17(2), 147-157.

Janardanan, V. K., Adithan, M. and Radhakrishnan, P. (2008). Collaborative product structure management for assembly modeling. *Computers in Industry*, 59(8), 820–832.

Jong, W. R., Wu, C. H., Lin, H. H., and Li, M. Y. (2009), A collaborative navigation system for concurrent mold design. *The international Journal of Advanced Manufacturing Technology*, 40(3-4), 215-225.

Kim, J., Pratt, M., J., Iyer, R. G., and Sriram, R. D. (2008). Standardized data exchange of CAD models with design intent. *Computer-Aided Design*, 40(7), 760–777.

Kondoh, T. and Suzuki, T. (2004). Using 3D-CAD Systems for Mechanical Design Innovation. . Proceedings of IEEE International Engineering Management Conference (IEMC), 2004, Vol.3, 954 – 957, 18-21 Oct., Singapore.

Kurimoto, H., Matsumura, M and Kobayashi, T. (2002). Strategic Aspects of Introducing a Virtual Product Development System: Focusing on CAD systems in the Japanese Auto Industry. *Asia Pacific Management Review*, 7(3), 329-348.

Lang, G. T., Eberts, R. E., Gabel, M. G. and Barash, M. M. (1991). Extracting and Using Procedural Knowledge in a CAD Task. *IEEE Transaction on Engineering Management*, 38(3), 257-268.

McCormick, R. (1997), Conceptual and Procedural Knowledge. *International Journal of Technology and Design Education*, 7(1-2), 141-159.

Mi, X., Shen, W. and Zhao, W. (2006). Research on Internet-Based System Architecture for Collaborative Product Development. *Lecture Notes in Computer Science*, 3865, 394-403.

Nestorovic, G. (2008). Principles of computer Modeling of the Solid Products Learning. *Interdisciplinary Description of Complex Systems,* 6(1), 67-73.

Nyirenda, P. J. and Bronsvoort, W. F. (2009). A framework for extendable freeform surface feature modeling. *Computers in Industry*, 60(1), 35–47.

Pratt, M. J., and Anderson, B. D. (2001). A shape modelling applications programming interface for the STEP standard. *Computer-Aided Design*, 33(7), 531-543.

Rittle-Johnson, B, Seigler, R. S., and Alibali, M. W. (2001). Developing conceptual understanding and procedural skill in mathematics: An iterative process. *Journal of Educational Psychology*, 93(2), 346-62.

Silva, J. and Chang, K. (2002). Design Parameterization for Concurrent Design and Manufacturing of Mechanical Systems. *Concurrent Engineering*, 10(1), 3-14.

Taraban, R., DeFinis, A., Brown A. G., Anderson E. E., and Sharma, M. P. (2007). A Paradigm for Assessing Conceptual and Procedural Knowledge in Engineering Students. *Journal of Engineering Education*, 96(4), 335-346.

Wang, S., Melendez, S. and Tsai, C. (2008). Application of Parametric Sketching and Associability in 3D CAD. *Computer-Aided Design and Applications*, 5(6), 822-830.

Yang, J. and Dou, W. (2008). Synchronized Collaborative Design with Heterogeneous CAD Systems Based on Macro Semantic Commands. *12th International Conference on Computer Supported Cooperative Work in Design, CSCWD,* April 16-18, Xi'an, China.
Yoshimura, M. (2007). System Design Optimization for Product Manufacturing. *Concurrent Engineering.* 15(4), 329-343.