Assessing The Utilization of Virtual LEGO® Blocks within a Group Design Project

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Abstract

The practical application of the philosophies of concurrent engineering stresses the importance of geometric data within design processes. Three-dimensional data generated from computer-aided design (CAD) applications are shared within concurrent engineering models to facilitate design ideation, simulation, prototyping, and production. To help implement this approach to design, Product Data Management (PDM) applications are utilized to control the exchange of critical data. Product data management applications have the ability to manage CAD and other engineering data while facilitating design communication. This paper describes the integration of a PDM focused design project within a sophomore level CAD course. Within this design project, student groups utilized virtual LEGO® blocks to meet specific design requirements. Unlike the traditional use of LEGO toys, blocks were pre-modeled in a CAD system and stored in a PDM application. Groups fabricated their designs within the CAD system's assembly module. This virtual representation of LEGO blocks was implemented in this manner to simulate the electronic sharing of design data that is typically encountered within a manufacture/vendor relationship. Within the project, students were required to follow a defined design process to include problem identification, ideation, selection, modeling, and simulation. Topics covered within this paper will include: 1) principles of concurrent engineering, 2) PDM capabilities, 3) design project requirements, and 4) student feedback.

Introduction

Information technologies are revolutionizing modern businesses. Apparent to most users of the Internet are e-Business tools that allow for the electronic marketing and selling of products. The Internet is also useful for the exchange of design data. A typical product has to be conceptualized, analyzed, engineering, manufactured, distributed, and maintained. A design such as an automobile requires multiple tiers within its manufacturing supply chain. These tier companies have to share and communicate design intent throughout the time span of a product's life. Data sharing technologies have spurred on the growth of Product Data Management applications that allow for the concurrent exchange of data across extended enterprises. These applications help to link different stages of a product's lifecycle. Advantages to such design communication include faster time-to-market, cheaper initial manufacturing costs, and increased product customization

With the introduction of the ASME Y14.41 Digital Product Definition standard during the summer of 2003, technical blueprints could become a thing of the past (ASME, 2003). Evolving communication approaches utilize Computer Aided Design (CAD) digital models. CAD has evolved into a powerful communication tool that promotes collaborative design, manufacturing, and service applications. Utilization with emphasis directed towards a product that is conceptualized, designed, manufactured and marketed in a paperless digital enterprise is only limited by industries' motivation to use it as a cost reduction tool.

In the systems supporting design and product development that are commonly in use today, stakeholders typically do not share information concurrently during the design, manufacturing, and service stages. Product Data Management (PDM) and Product Lifecycle Management (PLM) technologies provide a centralized repository for all information from the conception stage through product retirement. With a centralized repository vault, redundant databases and the potential for erroneous data are minimized. This powerful emerging knowledge base is used as a tool to improve the current product and enhance development cycles of future related products.

The center of a concurrent engineering design team may be a product data management system for managing design data. PDM software systems are emerging as new technology enablers for design and data management. Large companies in the aerospace and automotive industries are advocates of technology that adds value by improving the product realization process and managing their part and assembly files. PDM and PLM developers such as Dassault, Unigraphics, EDS, and Parametric Technology Corporation (PTC) have made large expenditures to develop and expand their software's capabilities to meet the needs of industry.

Product data management systems, as first conceived in the late 1980's, are design-centered packages used to manage product data. This is accomplished by using the following functions: 1) data vault management which provides information storage and retrieval, 2) process and procedures management which provides product data handling procedures, 3) product structure management which handles the Engineering Bill of Material (EBOM) and product configurations, 4) part classification management which provides information on reusing standard designs, and 5) project management which provides structure and allows coordination between process, resource, and project tracking (Fan, 2000).

The central product data repositories (vaults) maintain the master data and can only be modified by the current acting engineering authority according to established permission levels. Other data is stored and duplicated in many different repositories for specific uses by selected parties such as process, quality control, or suppliers. Sometimes specific data cannot be found or the data might not be usable due to an incompatible software version that requires translation. Often, data must be stored in a neutral format. As the product lifecycle progresses, authority is transferred from engineering disciplines to a neutral change authority to make any necessary product or process modifications.

Product data management technologies form the backbone for PLM approaches to engineering design. PLM has evolved naturally from philosophies of concurrent engineering Concurrent engineering is a non-linear team approach to design that brings together the input, processes, and output elements necessary to produce a product (Bertoline & Wiebe, 2003). It was implemented to shorten new product design times by involving all players in the product's design cycle. Conceptually, a product's life may be comprised of six phases: need recognition, design development, production, distribution, use, and disposal. Concurrent engineering helps to ensure that these phases are kept in constant consideration during product development (Asiedu & Gu, 1998).

Concurrent Engineering is used to integrate product, process, and production engineering into one cross-functional team. A team is typically comprised of product designers, stress analysis engineers, the manufacturing process group, service, and any others that will contribute during the life of the product. Introducing the team to the design problem at the conceptual stage plays two important roles: it can serve as a filter for design decisions and it can also suggest alternative designs. As the team works together they can analyze and make tradeoffs between cost and functionality. Before the first design keystroke is taken, the product designer is aware of downstream issues in manufacturability, product costs, and serviceability. Actively soliciting and involving all the team members in the early stages may help to increase cooperation and reduce conflicts.

Instead of a counter-productive environment commonly found with linear design cycles, concurrent engineering promotes a complimentary environment. This is accomplished by building links into its system. It allows the user to have the maximum flexibility while allowing each team member to express his or her specific engineering expertise.

In the global market, manufacturers and sub-assembly suppliers are no longer constrained under the same building let alone in the same country. Sub-suppliers design components to meet the final assembly manufacturer's requirements. Consequently, design information is no longer contained by the OEM but is dispersed between it and the many supply tiers.

Manufacturing can make the most out of its resources by using its digital enterprise center. This can be accomplished by using CAD, PDM, and other digital-based technologies to conceive, build, and market products that are customer driven. In order to maintain or increase the competitive edge, the digital information must be accessible and available in a usable manner. The manufacturing companies that accept and use this new technology will have a leading edge over those that do not. The data accumulated within the network is more than information; it is knowledge.

Purpose

Educational modules demonstrating the interactions between CAD models and downstream applications using PDM applications are limited. Students with a firm, conceptual grasp on PDM should be able to enter the work force and be competent members of concurrent engineering teams. As team members, these players will be aware of the benefits of a single source shared data. The concepts of product, process, and production engineering creating a product will become common knowledge as CAD information creates CNC tool paths, Finite Element Analysis models, and plant layout scenarios. PDM is a key part to a fully functional PLM concept model and future product designs.

This paper describes the integration of CAD, PDM, and concurrent engineering principles within a group design problem. The purpose of the project was to allow teams of students the opportunity to conceptualize a design problem and solve it using existing vendor components. The design problem was based on a mechanism design project from LEGO®. For accessibility and ease of conceptualization, LEGO blocks were pre-modeled and stored in a PDM application. The solution to the design problem had to be solved with existing LEGO blocks and components; no part modeling was required within the project.

At the conclusion of the design project an evaluation was conduct to answer the following questions:

1. Can a design project using virtual components (LEGO® Blocks) be structured in a manner that improves student conceptual understanding of Product Data Management systems?
2. Can a group design project be structured in a manner that promotes teamwork and individual responsibility?

Course and Project Information

The group design project under consideration is a requirement for CGT 226 – "Constraint-Based Modeling" within the Department of Computer Graphics Technology (CGT) at Purdue University. The CGT Department (CGT) is known for developing graduates that are professionals in applied computer graphics. Currently, four degree options exist: animation, multimedia, construction graphics, and computer-aided design. Graduates of each option find careers in industries such as game development, simulation, film animation, web-development, architecture, drafting/design, manufacturing, product-data management, and computer-aided design. CGT 226 is required for Computer Graphics Technology and Computer Integrated Manufacturing Technology (CIMT) students; it is an elective for Mechanical Engineering Technology (MET) students. In addition, approximately twenty-five percent of students within the course are from Purdue's Schools of Engineering.

Students were placed into teams of three or four. The objective of group formation was to closely replicate a concurrent engineering approach to product design. Most groups had at least one designer (industrial design or CGT student), one engineering student (mechanical or aeronautical), and one manufacturing student (MET or CIMT). Students were given a formal design process to follow which included 1) Problem Identification, 2) Design Ideation and Conceptualization, 3) Design Selection, 4) CAD modeling, and 5) Simulation.

The design problem was derived from the LEGO company's Machine Design kit (LEGO, 2003). This kit consists of multiple LEGO pieces, motors, actuators, and pumps which can be used to solve various design situations. The situation used in CGT 226's design problem required the building of a pneumatic lifting device.

Unlike the LEGO kit, students did not have actual LEGO blocks with which to work. Before the start of the exercise, all the LEGO blocks from the kit were pre-modeled in Pro/ENGINEER and placed in a PDM system's common-space (PTC's Pro/INTRALINK). In addition, a parts catalog was created with detailed drawings of each piece. The intent of this catalog was to replicate a sub-supplier's relationship with an original equipment manufacture. Also, unlike the LEGO kit, students did not have a predefined solution to the design problem. The design groups were given the following specifications:

1. The positioning device will be designed with a platform deck size of: 2-1/2” and 1-7/8”.
2. The platform deck should hold an object with a minimal height of 3/8”. Maximum height is unlimited.
3. The mechanical lifting operation will incorporate a cylinder or cylinders in the design.
4. The cylinder/s may provide direct or indirect lifting action.
5. The positioning device will provide a minimum vertical lift of 2.00”.
6. The platform deck will remain horizontal (level) during the lifting process.
7. The lifting device must be capable of lifting a 50-gram object without tipping.

From these specifications, each group had to develop two valid and distinct design solutions through the use of ideation sketching (Figure 1). The solution for continued development was selected by the use of a weighted scoring table (Table 1). After a design idea was developed, a virtual model of the design was assembled in Pro/ENGINEER. Mechanism joints and drivers were also utilized within the virtual model to simulate the actual motion of the product (Figure 2).

Project Evaluation

At the conclusion of the design project, students in CGT 226 were given an evaluation to measure their opinions on the effectiveness of the current iteration of the LEGO group design problem (N = 45). The evaluation focused on group dynamics, the utilization of PDM within the course, and the format of the group project. A Likert scale was utilized to provide feedback (1. *Strongly Agree, 2. Agree, 3. Neutral, 4.Disagree, 5. Strongly Disagree)* to the following statements:

1. My group functioned well together.
2. All members of my group generally did their fair share of the group project.
3. I enjoyed the group project.
4. The group project was a valuable component of the course.
5. Pro/INTRALINK helped with the management of part and assembly files.
6. Pro/Intralink helped to give me an understanding of how PDM tools can be used in engineering design processes.
7. This project improved my concept of PDM.

One-sample t-tests were used to assess student perceived feelings about the effectiveness of the group project. Within the tests, the sample data were compared to a neutral response of 3.0.

All findings for group dynamics were significant. Students felt that their teams functioned well together, (M = 1.911, SD = 0.973), t(44) = -7.508, p = 0.000, with all members performing their fair share of the project, (M = 2.511, SD = 1.160), t(44) = -2.826, p = 0.007. The students also seemed to enjoy the project, (M = 2.333, SD = 0.929), t(44) = -4.812, p = 0.000, and felt that it was a valuable component of the course, (M = 2.222, SD = 1.064), t(44) = -4.905, p = 0.000.

Findings for product data management utilization were also significant. Within the project, students felt that Pro/Intralink helped with the management of computer-aided design data, (M = 2.400, SD = 0.939), t(44) = -4.286, p = 0.000. They also felt that Pro/Intralink gave them a better understanding of PDM, (M = 1.955, SD = 0.5203), t(44) = -13.466, p = 0.000, and that the project in general helped to improve their concept of product data management, (M = 2.468, SD = 0.929), t(46) = -3.925, p = 0.000.

Conclusions

The findings support the study’s first research question. A design project using virtual components can be structured in a manner that improves student conceptual understanding of Product Data Management systems. The intent of the group project was to replicate a scenario where design problems are solved using existing vendor components. The components in this project were Lego blocks that were pre-modeled and stored in the PDM system’s commonspace. The project was structured in this manner to require students to work with virtual components and a vendor catalog in hopes of improving their conceptual understanding of PDM utilization.

The second research question was also supported. A group design project can be structured in a manner that promotes teamwork and individual responsibility. The group project was structured in a manner that required groups to self-manage their teams. Each group had to establish group rules and member responsibilities. In the end, students did generally feel that their groups functioned well together and that the project was enjoyable and valuable.

Product Data Management implementations and Product Lifecycle Management philosophies are changing design processes practices within manufacturing enterprises. Appropriately applied PLM tools allow engineering and CAD data to be shared and controlled within an enterprise and within an enterprise's supply chain. The ability to control and communicate engineering data allow decisions to be made earlier in the design cycle which in turn decreases cost and time-to-market.

In addition, by leveraging the data vault capabilities of common PDM applications with the recognizable catalog of LEGO components student were able to focus on the process of design and documentation without an unsuitable overhead of 3D part modeling. The PTC applications used in the course described in this paper serve well the needs of establishing this cognitive understanding of product data management. Other 3D modeling applications, such as Solidworks, have the means of establishing a catalog or data vault of pre-constructed forms that the student can mate into an assembly that solves a particular design problem. In either case, the student is left with more time to discover the knowledge aspects important to PDM utilization.

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