Application of Computer Aided Design (CAD) In Knowledge Based Engineering

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Abstract

The impact of globalization on business has forced most industries to become more innovative and implement newer strategies to retain market leadership and growth with the desired profitability. The retention of corporate engineering knowledge and rules is also critical because of the aging workforce. Knowledge based engineering is a concept that allows for the retention of corporate knowledge as initiate-level engineers and designers enter the workforce. Knowledge based engineering is a complex concept that increases the productivity and product quality in any industry. Computer aided design (CAD) is one of the main roots and plays an important role in knowledge based engineering. This paper addresses the role of computer aided design at its integration with knowledge based engineering to make it more flexible, transparent, and standardized while working in a corporate environment. To motivate the discussion the authors have used a setting that is used to design a new product in a plastic manufacturing plant.

Introduction

Knowledge based engineering originated from a combination of computer aided design (CAD) and knowledge based systems but has several roles depending upon the context. In a design process, computer aided design is considered as the basis of the generative design with many expectations for hands-off performance along with the knowledge based engineering which would result in a limited human involvement in the design process. Today, the application of knowledge based engineering includes design (CAD), analysis (FEA), simulation (CAS), optimization, manufacturing, and support (CAPP) where CAD is the foundation for the rest of the cycle. In this paper, the authors start with discussing the traditional process, its pros and cons, how knowledge based engineering is revolutionizing today's design capability, and finally, the role played by CAD in synergizing knowledge based engineering.

The Traditional Design Process

The traditional design process accounts for 75% of total production costs [1]. Traditional design departmentalized as the engineers would develop the product design and any working and detail drawings associated within the conceptual design [2]. The design is then passed to other departments within the organization (manufacturing for process and material selection, marketing, purchasing, etc.). The design may then be sent back to the design team for rework and revision. The traditional design process tends to be exceedingly tedious and resource inefficient. This tedious and inefficient nature can lead to increased lead time and loss of profit. The following figure shows the product life cycle of a typical product.

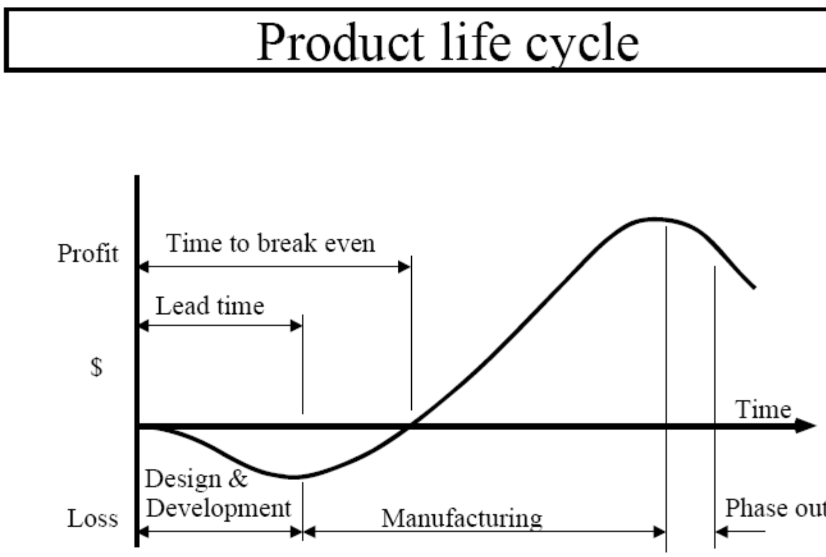

Figure 1: The Traditional Product Life Cycle [2]

As you can see from Figure 1, design and develop account for most of a production life cycle. This wastes time and resources, which calls for a more efficient way of designing a production. Knowledge based engineering is an alternative. In short, the objective of knowledge based engineering is to maximize the resource utilization.

Knowledge Based Engineering

The traditional (and wasteful) design process along with an increasingly skilled and global market calls for systematic and concurrent design development. Such a system that applies a systematic and concurrent design process is knowledge based engineering (KBE).

KBE is defined as “the process of combining engineering knowledge, methodologies, rules and best practices with process knowledge and best practice to create product models that describes how product designs are created or engineering analyses are undertaken" [2]. KBE combines past design knowledge and practices with rules of design. KBE has origins in CAD. However, CAD differs from KBE because CAD personifies the "what" of a product design [3]. The "what" of a design includes product dimensions, geometric and surface contour, product materials, etc. KBE, on the other hand, personifies the "how" and "why" of a design [3]. The "how" of a design consists of manufacturing systems and processes involved with product conception and production. The "why" of a production model captures the engineering rules, governmental/corporation regulations, etc. of a design. KBE has roots in the aerospace engineering and automotive design industries. These oligopolistic markets tend to have high economies of scale, leading to large cost to implement a KBE approach. The benefits of a KBE approach typically outweigh the initial cost of implementing KBE system.

Contemporary KBE allows for the firm to retain critical design knowledge and intent behind the design. Engineers can input their past design experiences, engineering rules, rules of thumb, and corporate and governmental regulations in the form of logical constraints. These inputs are normally referred to as domain knowledge [6]. KBE helps to maintain the reuse of corporate knowledge and design experience [4]. Any reused design knowledge can lead to adaptive or variant design depending on the context [5]. This knowledge recycling leads to similar designs that can perform related functions. Similar designs can be created by applying new ideas and constraints to a single base model [1]. Applying knowledge and reasoning to design can eliminate rework and repetitive tasks [3].

A typical system also allows for hands-off product design and planning by using rules-based and constraint driven design algorithms. A conflict resolution and a constraint verification module may also be added to the system. The rules for the system tend to be the rules and functions initially entered by the engineer. Rules are stored within a relational database that creates dependency between rules [3]. Design rules are generally structured in an if-then format [6]. They may also be structured using and-or Boolean algebra [1]. Rules based systems permit for low level automation that can provide a foundation for more complex automation tasks [4].

Case-based reasoning (CBR) can be combined with rules-based reasoning to lead to higher levels of automation. CBR uses past design knowledge to create new designs based on domain knowledge and newly refined inputs; thus, redesign is eliminated and time to market is shortened. CBR is also beneficial because performance of the case situation is known [7]. A CBR algorithm uses a similarity algorithm to search for similar cases. Semantic similarity searches for similar names or part numbers [6]. Function similarity may also be used. This similarity concept compares key dimensions [6]. Parameter similarity uses input parameters from the user [6]. Similarity searches may or may not use Boolean logic.

Rules-based and case-based reasoning can lead to an object-oriented design environment. The initial computer aided design model or other geometric model is used as the class operator. Changes can be made to the class operator based on inputs and constraints applied by engineers. These changes create an instance (object) of the class operator. The instance will retain attributes associated with the class operator and will also contain its own attributes. An object-oriented environment is useful when only a small amount of changes need to made to an already completed design. Repetitive tasks are eradicated from the design work, leaving time for idea development. This helps to enable a feature recognition algorithm. Feature recognition requires a feature database. The database is searched using surface feature patterns [8]. Feature recognition helps to provide for a design for assembly (DFA) approach.

When using a DFA approach, constraints are applied to the various parts comprising the assembly. When a non-logical constraint is applied to a part there is a need for conflict resolution. Constraints help to aid in engineering development by applying known engineering rules [1]. Constraints typically aid in design for manufacture (DFM) by representing various manufacturing processes [9]. Conflicts are resolved using mathematical and knowledge based rules. These rules fall into four categories: equation constraints, qualitative constraints, implicit constraints, and knowledge constraints [9]. Equation constraints involve mathematical equations. These equation represent attributes, dimension constraints, shape constraints, etc [9]. Qualitative constraints involve relationships. Relationships are applied to variables. Variables represent post production factors such as cost, performance, and maintenance [9]. The post production factors take into account product life cycle management methodologies. Implicit constraints involve domain level constraints [9]. Knowledge constraints apply the domain knowledge and compare attributes and parameters [9].

Table 1: Advantages and Disadvantages of a Typical Knowledge Based System

Advantages	Disadvantages
1. Reduces time to market and lead time 2. Cuts production costs 3. Automates repetitive tasks 4. Allows for the reuse of critical knowledge and designs 5. Allows real-time design sharing using WWW, html, and hyperlinking protocols [1] 6. Suitable for analysis and simulation processes [10] 7. Reduces overhead costs [3] 8. Costs and time use can be reduced by 90% [4] 9. Compliments traditional CAx systems	1. Costly to implement 2. Initially requires large quantities of time to compile design knowledge 3. May only be justified if a problem is faced many times [10]

Computer Aided Design

A CAD software package is defined as "a process that uses a computer system to assist in the creation, modification, and display of a design" [2]. When paired with a knowledge based approach, CAD can do much more than display a design. A CAD model is generally the first geometry based input into a KBE system. CAD can also be used to reduce lead times and time to market.

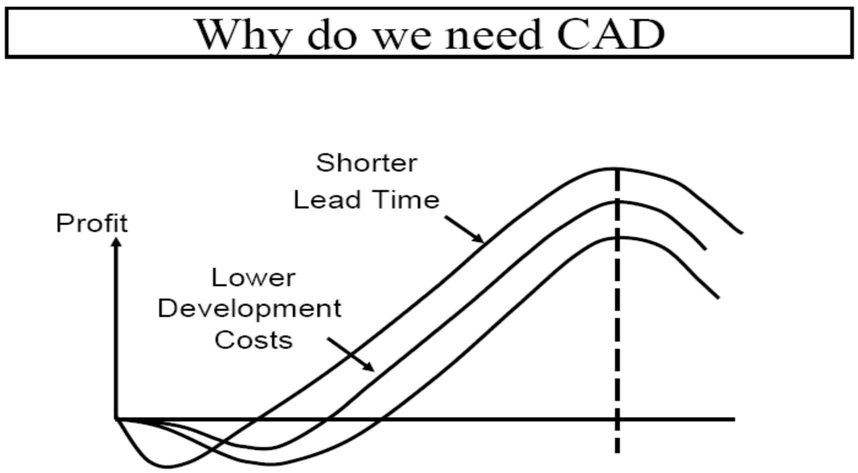

Figure 2: Product Life Cycle When CAD Is In Use [2]

CAD can be combined with a knowledge based approach by utilizing a database of standardized parts. These standardized parts can be ANSI, ISO, DIN, or Parker fasteners and bearing. Accepted standard corporate designs may also be utilized in a part database. These accepted standard parts and designs can serve as class operators in an object-oriented environment. Changes made to the class object inside a CAD environment would result in an instance of the class. This process helps to cut down time to redesign or redraw any standardized designs.

This object-oriented approach may also be used by creating derived parts inside a 3-D CAD environment. A derived part inherits attributes but will also be given new properties from the user. When creating a typical derived part, the CAD interface will prompt the user for inputs such as scale related to the class operator, material specifications, etc.

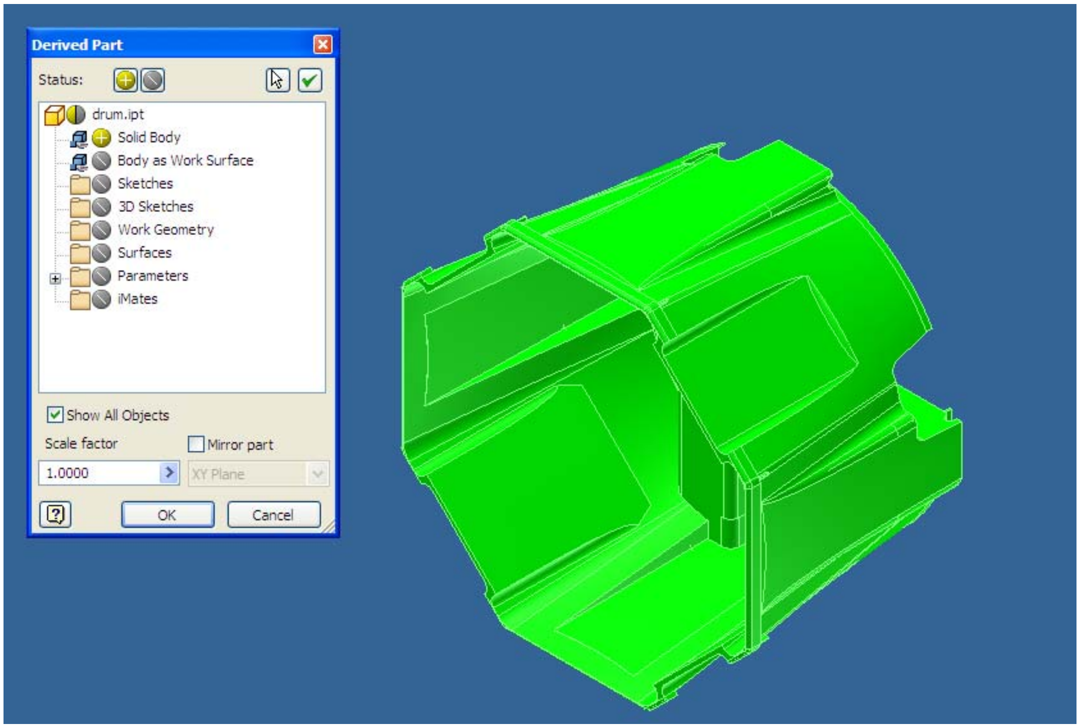

Figure 3: Derived Part Feature in Autodesk ® Inventor

CAD software is also incorporating the ability to gain useful engineering knowledge from the CAD interface. Many modern CAD packages include the ability to attach material properties to the model. These material properties, along with model geometry and features, can be used to automatically calculate engineering data such as density, volume, area, and moments of inertia. Engineering knowledge may also be obtained from CAD data by incorporating FEA and dynamic simulation into the CAD environment. This eliminates the tedious task of converting the CAD format into a NURBS based mesh. Data can then be readily obtained from the CAD format. The intended purpose of the product can be simulated digitally creating a digital prototype, thus eliminating the need for traditional physical prototypes (for many applications). Data such as wear points and thermodynamic information can be obtained while using real time digital simulation.

One of the most powerful and useful combinations of a CAD-KBE approach is the ability to export a CAD geometry to other CAx packages including CAS, CAPP, and FEA applications. A KBE system can be used to automate the repetitive simplifications of CAD geometry. The simplification makes the geometry suitable for other CAx systems [10]. Creating a mesh suitable for an FEA and CAS system can make up 80% of design analysis cost [10]. A contemporary knowledge based CAD system can perform automated mesh generation by supporting level 2 automation [4]. CAD packages can automatically convert geometry from its native format to formats suitable for FEA, CAS, CIM, and CAPP. Once converted, the CAD model can be used in the other CAx packages to obtain critical engineering and manufacturing knowledge. As discussed earlier, engineering knowledge can be obtained from the FEA and CAS packages.

Manufacturing knowledge can be directly obtained from CAPP. There are two types of CAPP: retrieval CAPP and generative CAPP [11]. Retrieval CAPP stores past data into families. When new data is entered, retrieval CAPP searches its family database to find similar data [11]. The related data is then output to the user. The other type of CAPP is generative CAPP. Generative CAPP searches its database to find similar instances and then uses manufacturing knowledge and rules to develop new manufacturing plans [11].

Application in Plastic Drum Production

The knowledge based approach to plastic drum production uses a KBE and CAD relationship. When both tools are utilized together, an effective design can be produced. The steps to utilizing both KBE and CAD effectively are stated in Figure 4.

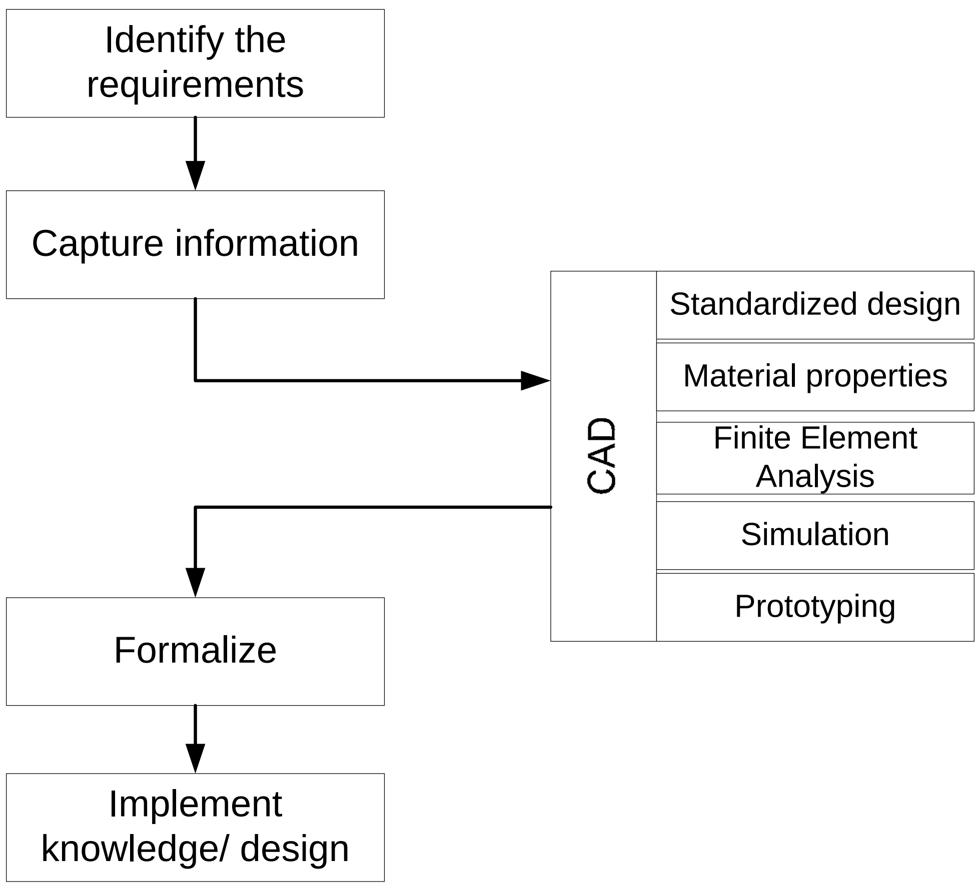

Figure 4: KBE and CAD Relation

The initial step in plastic drum production is to identify customer requirements. In this particular example, the customer(s) requested a pallet-less, 23 gallon grain storage drum. This design required that sets of four to eight drums be shipped together, but at the same time eliminating the use of a pallet. The drums would also need to be stackable. To eliminate the use of pallets, the drums would feature forklift channels at the base.

During the capture information phase, it was decided that the basis for the new design would be the company's original 23 gallon storage drum. The original drum features a rounded base with a ten side top. The new design retains the rounded base but reduces the top to eight sides. The new design would use a modified version of the original CAD model as a class.

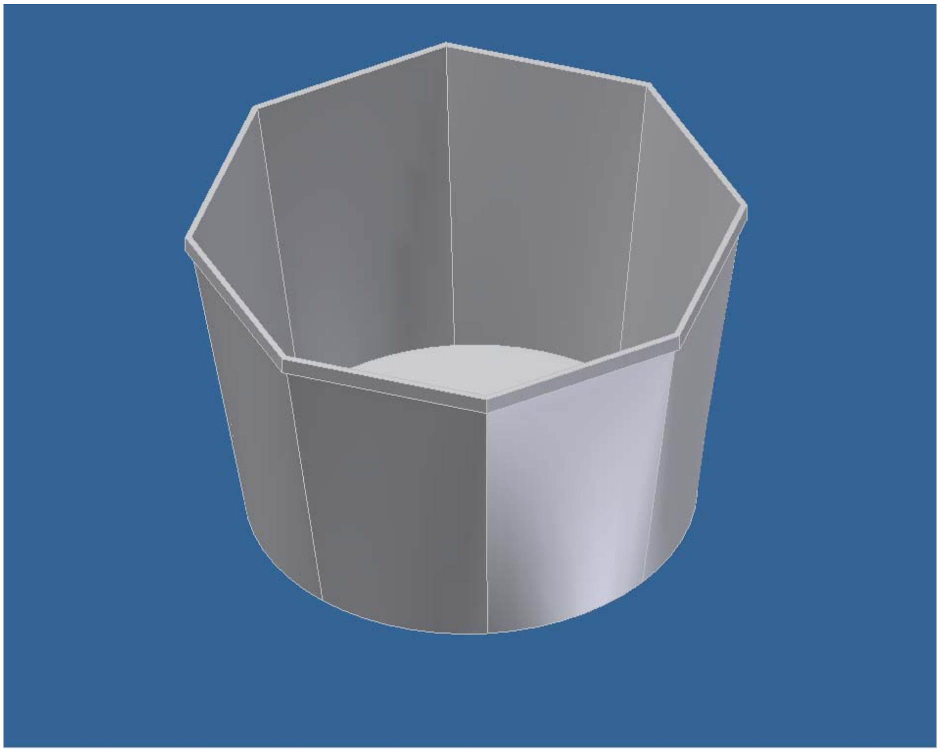

Figure 5: Modified Version of the Original Design

The third phase is to standardize the design. The new design utilizes attributes from the original design, which is already an industry standard design. Any new changes will be made on the class operator.

During the CAD drawing process, the initial change to the class model was to add forklift channels to the drum's base. Autodesk® Inventor was used to automate the addition of fillets to the sharp edges of the channels.

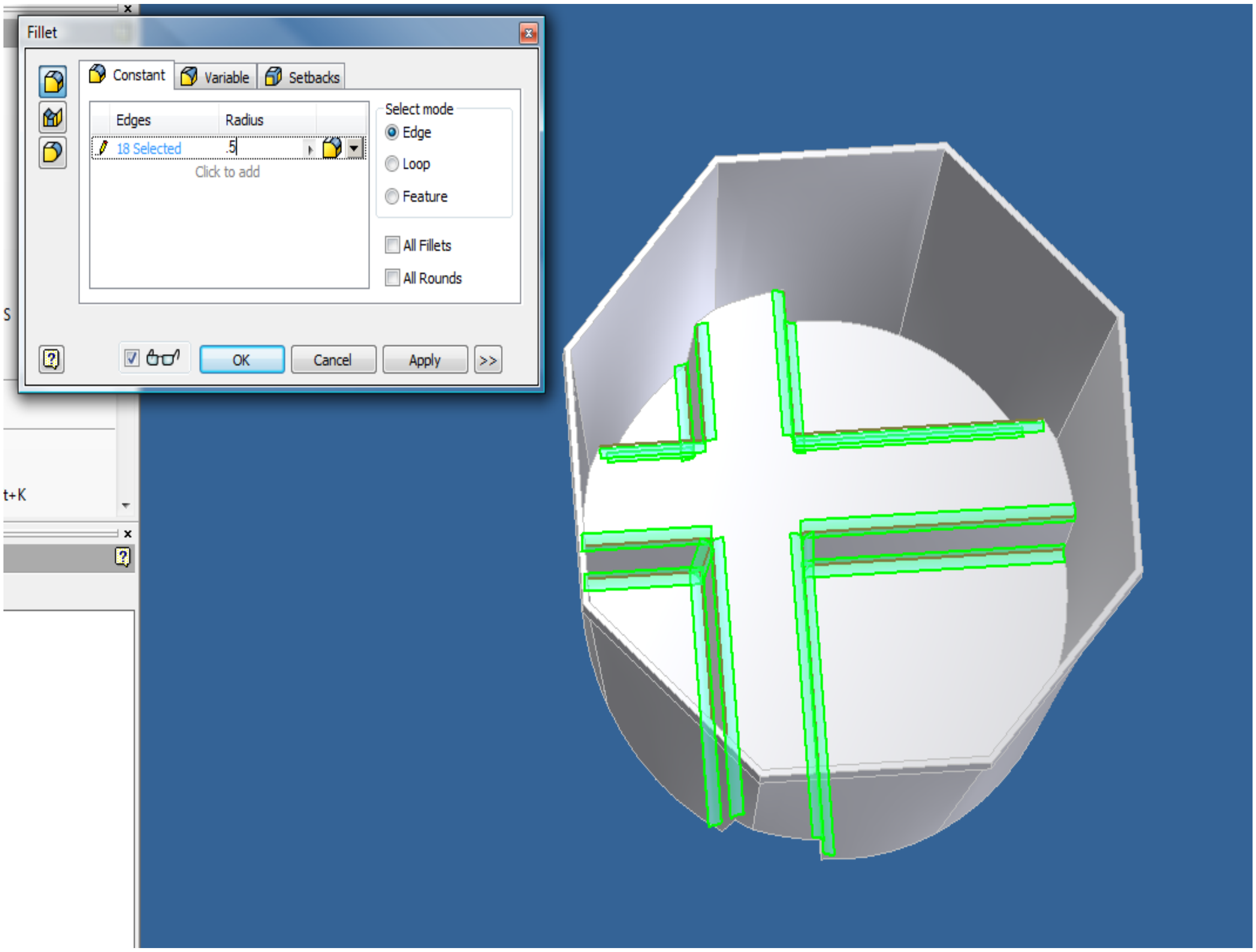

Figure 6: Automating Fillet Addition

The next phase in making the new CAD model was adding external drafts. This, again, was automated in Inventor by modeling one draft and then creating a circular pattern of the draft. Internal drafts and stacking tabs were created using the same automation process.

Design for manufacture was also automated. To obtain a consistent wall thickness throughout the drum, the shell feature was used to automate thickness changes. A consistent thickness, draft angle, ands rounded edges makes it easier to mold the drum. The automated filleting feature was also used to achieve an easier mold.

Materials properties were next added to the design. The material is high density polyethylene (HDP). Inventor does not include HDP as a material. The style and standards editor was used to add HDP. Adding HDP would make later FEA and simulation trials easier.

FEA was used to analyze whether the drum could loads of 250 pounds. FEA was automated using ANSYS® software. The analysis measures material fatigue, contact point stress, and deformation.

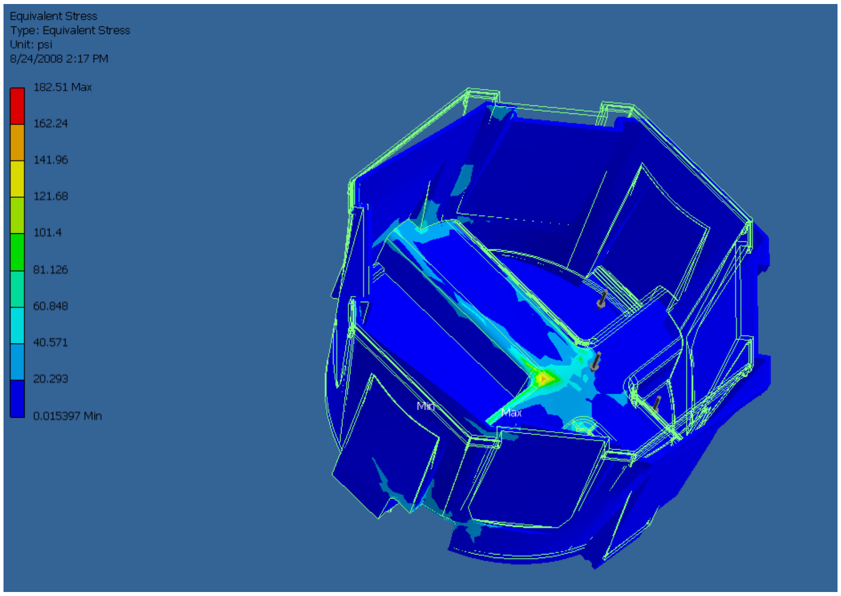

Figure 7: FEA

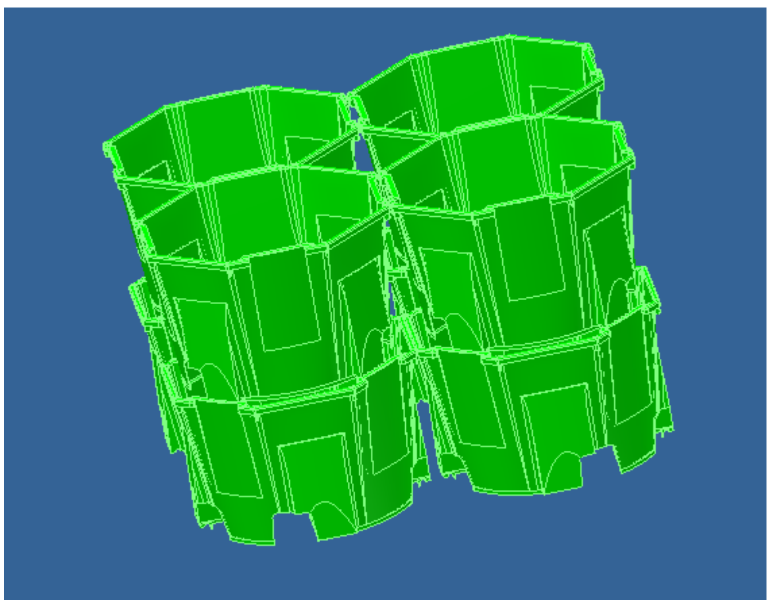

Figure 8: Stacking Simulation

Dynamic simulation was used to visualize the stacking abilities of the drum. Simulations provide a real effect of the course of stacking. The connection and locking between the drums were simulated to see if there was any mismatch between the drum while stacking.

A simulation video created inside the CAD software was used to show product capabilities to customers.

Prototyping was automated using Inventor. The native .ipt file was automatically converted to .stl file that is used by various stereolithographic machines to make prototypes.

Using the combination of KBE and automated CAD, compared to the traditional design process, cuts down on design time. The time that was saved was used to market the product and to get the product to market faster. The time saved was also used for developing new products.

Conclusion

In today's competitive and global market, new manufacturing and engineering techniques are being developed. One such technique is KBE. KBE allows firms to retain valuable engineering and design knowledge. This knowledge can then be used to automate the design process, leaving time for creative design thinking. KBE can then be used along with CAD to create a generative design environment, creating a foundation for other engineering processes. KBE techniques are especially useful in plastic design where molding techniques can be applied to the design. This technique allows for more time to be used in other aspects of production such as manufacturing. The time to market for the product is also greatly reduced.

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Biography

Jaby Mohammed received his PhD in Industrial engineering from University of Louisville in 2006. His research interest includes advanced manufacturing; computer aided design, six sigma, and enterprise resource planning. He is a member of IIE, ASQ, SME, POMS, ITEA, NAIT, KAS, and Informs.

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