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Design Decision Automation Support through Knowledge Template CAD Model

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ABSTRACT

Today industries and companies are trying hard to reduce lead times and costs for new products, in order to satisfy customer requirements and maintain design quality. This paper presents the procedure and methodology to develop Knowledge template CAD model. This template is an "intelligent" CAD model which replaces the design library usually in the form of database. In this work the Knowledge Template (KT) is designed using Knowledge Base Engineering (KBE) elements such as design constraints, design rules, expressions, Graphical User Interface (GUI) and programs. The proposed KT gets automatically configured to fit for specific context (best design solution) according to the user input. The proposed methodology provide decision support system and tool to help the customer to choose promising design alternatives from KT according to their needs and desires. Design of wheel rim is presented, as an example, to validate the proposed concept of KT. With the proposed KT, it is possible to achieve direct interaction between the user and the CAD model so as to simplify design process and avoid re-design and re-modeling of product.

Keywords: knowledge template, knowledge base engineering, computer aided design, decision support system.

1. INTRODUCTION

Product design is an ill-defined, iterative and complex process of fulfilling continuously changing design specifications in order to meet varying customer demands. Today, industries and companies are trying hard to reduce lead times and costs for new products, in order to satisfy customer requirements and maintain design quality. Traditionally, manufacturing industries merely considered offering products with high quality and low cost as it was a "supply-push" era [21]. In order to capture competitive global market today, customer preference and satisfaction has been of prime importance for manufacturing industries. Customers' preferences, perceptions and life styles are too different and diverse [20]. Therefore, to satisfy continuously varying customer requirements, it becomes imperative that the manufacturing companies develop awareness about customers' preferences. A product development process is the sequence of activities to conceive, design, fabricate and commercialize a product [18]. The Product design process starts with identifying customer needs and ends with final design concept (solution) with complete product specifications. Present Computer Aided Design (CAD) systems include only final product specifications, and do not take account of other stages of the 'design' process [11]. There is a need to provide computational support to incorporate customer requirements, concept development, concept selection and other stages of design process, in CAD systems, so that the designer can take better informed decisions and effectively explore domains of early stages of design. Designer is forced to learn methods to use computational tools, as CAD systems are driven more by computer than by design [1]. There is a need of future CAD system to be driven more by design rather by computer [17]. Goel et al. [5] propose that next generation CAD system should support collaborative design, conceptual design, and creative design and it should be based on cognitive accounts of design. To effectively solve limitations of present day CAD systems, the present work uses Knowledge template CAD model.

This paper attempts to incorporate customer requirements/preferences into CAD environment through Knowledge Base Engineering (KBE) approach i.e. knowledge template (KT). The proposed KT CAD model gets automatically configured to adapt for

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specific context (best design solution) according to the user input. This helps the customer to choose best product alternative according to his/her requirements. The proposed computer supported framework includes providing customer requirements in a CAD environment and generate the best design solution based on customer needs. The proposed approach allows the designer to capture competitive market segment and addresses several key issues which are as follows;

- Identification of the important design parameter to segment competitive market,
- Examination of customer preferences and perceptions for generating product variants and assessment of these alternatives in customer-oriented manner,
- Development of new ideas for next-generation products by extracting customer perception of marketing demands,
- Assessment of the interrelationships between design parameters and customer requirements to help designer to understand their inherent dynamics.

2. RELATED WORK

The template based approach described in this work belongs to the domain of KBE. The usage of KT allows the designer to reuse the previous design knowledge and design solutions, so as to simplify design process and avoid re-design and re-modeling of product. The following two sub-sections presents the relevant research in the domains of KBE and KT respectively.

2.1. Knowledge Base Engineering

KBE allows designer to store previous design knowledge and automate most of the design tasks which not only reduces cost, but also saves time in product development process. Tiwari et al. [16] described KBE as a system to collect, store and organize the design knowledge in order to make it available in the reusable form. They also described KBE as a computational support tool to the design process, specifically for standard parametric mechanical /engineering parts and assemblies. The approach is not suitable to elicit customer preferences as it works only when the designer is given strict criteria to meet certain design and company specific constraints. The reviews on existing technologies of KBE to establish its theoretical foundations were presented by Verhagen et al. [19]. They also identified relevant research issues within this domain. Chandrasegaran et al. [1] reviewed developments in knowledge capture and representation methods in product design and also addresses limitations of different KBE systems. Current knowledge structure is disorganized which necessitates the need of proper KBE systems. Reusing previous design knowledge becomes very difficult if existing databases, designs, thumb rules etc. are not maintained in order. Current knowledge structure is also not secure, as the databases for knowledge management that are not stored centrally are susceptible to changes by the other users and may also loose reliability. This work proposes to replace the design library usually in the form of database through the use of KT which is an "intelligent" CAD model containing many design alternatives. The main advantage of this type of template is that there is no need to maintain separate design library as large number of product alternatives can be stored in the same CAD model which significantly saves computer space and memory. A lot of research has been done in the area of KBE, but it is mainly focused in the area of automobiles and aerospace [19]. Examples of developments resulting from the use of KBE are presented in [2,4]. Despite large number of benefits that can be achieved through the application of KBE, only a few industries adopt this methodology in the design development of their products because of lack of standardization in implementation. KBE implementation includes extracting and storing knowledge from designers' minds and converts them into programming codes [13].

2.2. Knowledge Template

The aim of Knowledge-Template is to capture and reuse the design intent and product design knowledge through parameters, rules, formulas and automation techniques. Templates are based on KBE approach that allows the storage and reuse of know-how elements of design. KT can be updated automatically, according to given context based on inputs defined by the user. In addition to storing previous design solutions, templates provide standardized parts and assemblies for design activities, and incorporate previous successful designs into the future product development process [7]. Kamrani et al. [6] proposed an integrated design approach based on knowledge templates technologies that allows reducing the development time needed for novel products. Kuhn et al. [10] have presented an approach that provides engineers the correct order to update KBE templates. They had designed an ontology which allows knowledge representation about KT and assemblies. Kuhn et al. [9] proposed a framework that provides decision support system and tools to the designer during KT update process. Christ et al. [3] presented an approach to construct feature templates based on generic product structure, which provides knowledge about possible applications of templates. They had established design solutions by proper mapping of feature templates to product structure. Wei et al. [22] proposed knowledge template to combine KBE and CAD to generate intelligent design. They had established KT which is suitable for general part library development, and capable of providing product information, controlling automatically the part shape and size, and limiting topological structure of an assembly. To integrate the customer into the design process, Siddique et al. [15] had developed template which can adapt itself based on the given context. Proposed CAD template captures all the relevant information of a product family to provide instantaneous feedback to the user by automatically generating CAD models. The main limitation of the template proposed by Siddique et al. [15] is that client has to wait for the 2 to 3 minutes, until application on the server executes completely. The template developed in this work eliminates this waiting time as there is no need of design library (database server) or product database management system to store the product knowledge. The design library in this case consists of a Single CAD model which drastically reduces the waiting time for customer and there is no need to maintain a large server for product knowledge management. Lukibanov [12] made concerns regarding template maintenance and distribution of the latest versions of templates.

3. APPROACH

To develop a KT CAD model, customer target values (CTVs) are identified and elicited from customer and product domain. Product domain consists of product characteristic features and customer domain consists of customer needs. These product features and customer needs are converted into customer specific target values by suitable matching and mapping. Krishnapillai et al. [8] have described three types of mapping strategies, from customer domain to product domain, which may be through direct translation, through transformation function or through configuration table. Customer needs are linguistic and continuously varying with time. The review of classical techniques to elicit customer needs is done by Wang et al. [21] and they have described three techniques namely Quality Function Deployment (QFD), conjoint analysis and Kano model (KM) to analyze customer needs and convert them into suitable customer specific target values. To successfully achieve new product development, it is necessary to meet customer requirement even beyond their expectations. In this work, to generate product models (PM) from specific combinations of customer target values, dependencies of CTVs on design parameters i.e. geometry, topology and material properties of a product are identified. These dependencies are then converted into design equations (in the form of rules and constraints) to

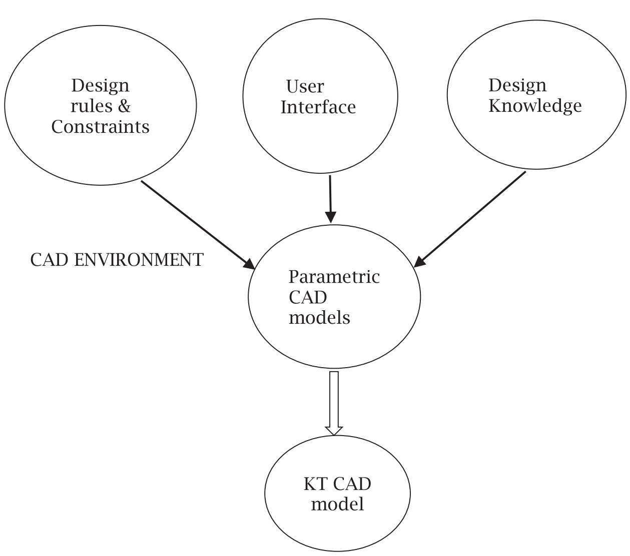

Fig. 1: Process of establishing KT in CAD environment

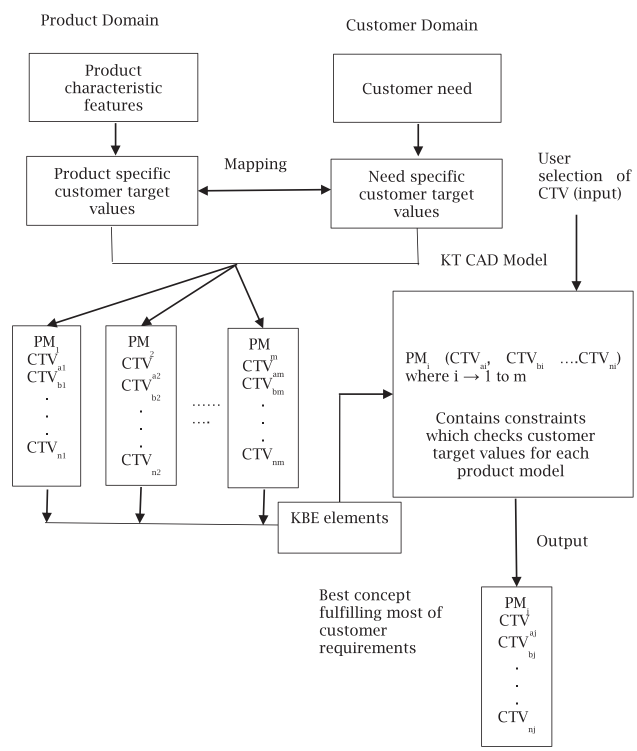

Fig. 2: Approach to develop KT CAD model.

Customer Requirements (CTV_i)	CTV_{i1}	CTV_{i2}	CTV_{i3}
Cost	Cheap	Medium	Expensive
Durability	Less	Medium	High
Weight	Light	Medium	Heavy
Performance	Low	Medium	High
Maintenance	Low	Medium	High
Appearance	Poor	Good	Excellent

Tab. 1: Customer target values for wheel rim.

generate parametric CAD models. These CAD models are linked with KBE elements to create KT CAD model. User interface is developed to provide the user the mode to input and assign the importance of their needs. Based on user input values, KT gets automatically updated to deliver the best design solution (concept). The information of customer target values,

Product model	Customer target values
Steel rim	PM_1 (CTV_{11}, CTV_{23}, CTV_{33}, CTV_{41}, CTV_{53}, CTV_{61})
Alloy rim	PM_2 (CTV_{12}, CTV_{21}, CTV_{31}, CTV_{43}, CTV_{51}, CTV_{63})
Chrome Rim	PM_3 (CTV_{13}, CTV_{22}, CTV_{32}, CTV_{42}, CTV_{52}, CTV_{62})

Tab. 2: Combination of target values for product models in KT.

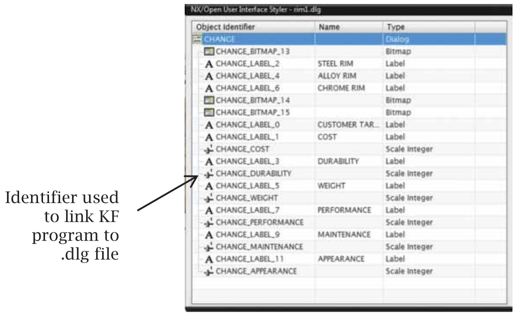

Fig. 3: GUI file (.dlg) of KT wheel rim CAD model.

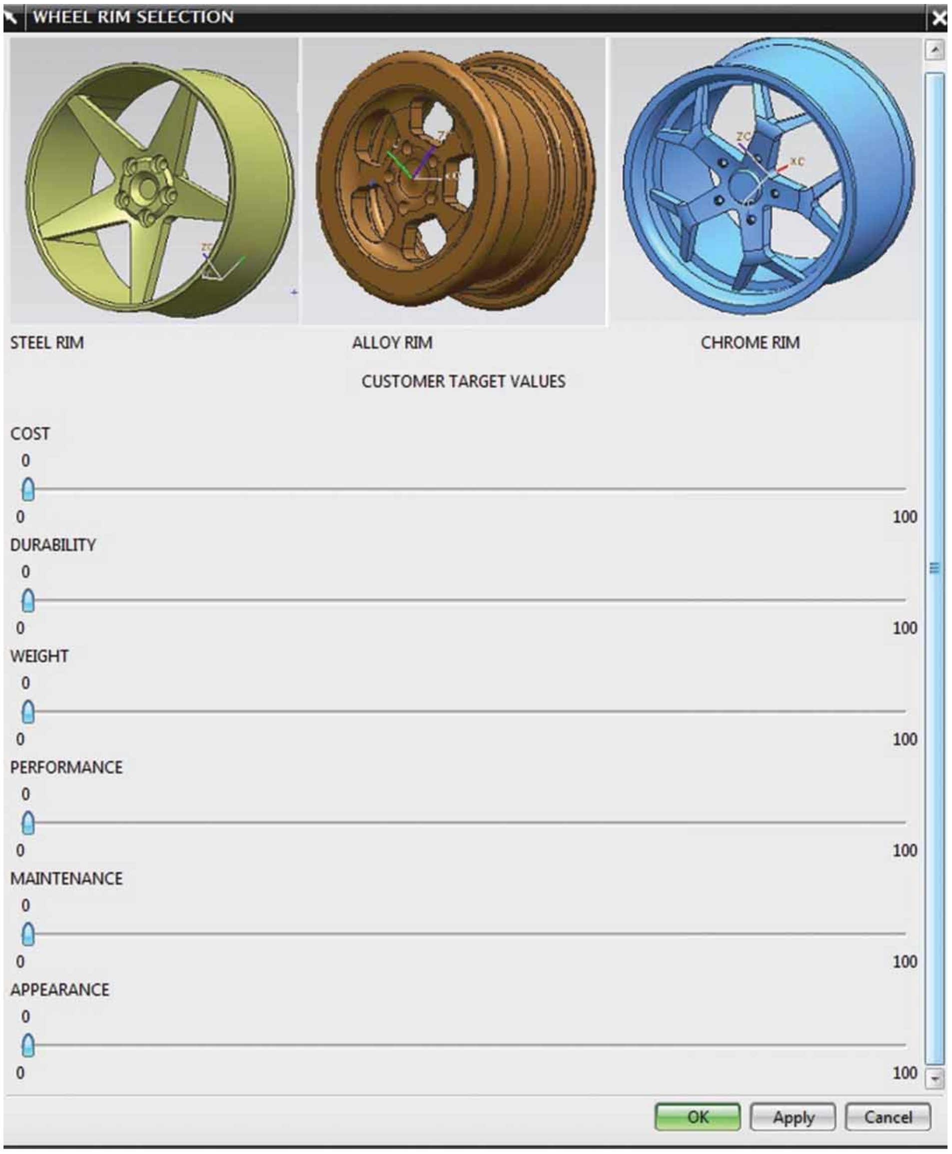

Fig. 4: GUI of KT wheel rim CAD model.

design parameters, related product characteristic features and design analysis is collected and captured within KT CAD model, so that it can be easily updated and shared whenever required, throughout the design process. The customer needs obtained by evaluating market trends, and the associated product characteristics are supported by a set of KBE tools within CAD environment. Knowledge can be easily added, modified and stored within this support environment through the use of KT. The process of establishing KT in CAD environment is depicted in Fig. 1. The basic approach to develop KT CAD model as shown in Fig. 2 are described below:

a. Elicit product specific target values from product characteristic features,
b. Elicit need specific target values from customer needs
c. Generate CTV from product specific target values and need specific target values by suitable matching
d. Identify dependencies of customer target values on design parameters by direct mapping from customer domain to product domain
e. Define design rules and constraints based on these dependencies
f. Develop parametric CAD models from these design rules and constraints
g. Link all product variants (concepts) from specific combinations of customer target values, design rules and constraints through KBE elements to generate KT
h. Develop user interface
i. Link this GUI to KT with the help of KBE elements which will provide inputs to the user

4. DESIGN CASE STUDY

Based on the proposed methodology, a KT CAD model to select wheel rim has been developed within CAD environment (here, Siemens NX 6.0) through the use of KBE based Object Oriented module of NX namely, Knowledge Fusion (KF). The user interface is designed using module of NX 6.0 namely, User Interface Styler, which gives user an option to choose importance of his/her requirements. One of the major functions of the car wheel is to provide support to a load, which characterizes the design intent of the product being designed. For an automobile in static state, the essential requirements of a wheel rim are as follows: (i) sufficient robustness to bear the weight of a vehicle (ii) light in weight (iii) good appearance, (iv) statically balanced etc. The major parts of a wheel are rim, hub, holes, spokes and nuts. In this work a decision support system based on KT is developed in a CAD environment for selection of best wheel rim based on importance of customers' requirements. All the geometric parameters like size of the rim and hub, number of holes, spokes and nuts, etc. are kept constant. The material of wheel rim is changed and three product models, namely, steel rims, alloy rims and chrome rims are compared according to the importance of customer requirements. Product characteristic features are studied for the three product models (concepts) and product specific customer target values are identified. For example, *Chrome wheel rim weighs higher than alloy wheel rim as chrome finish adds more weight*. So, product specific customer target value for the characteristic feature *weight* is *'heavy'*. The trends of customer requirements are also studied for generating need specific target values so that user can easily choose the importance of his/her needs. Consider a customer need; '*cheapest wheel rim with high durability*.' Need specific target value for this customer requirement are *cheapest* (in terms of cost) and '*high durability*'. CTV are identified by matching of product specific target values and need specific target values. The task of establishing customer target values relies on design experts and intuition of engineers and designers. In the presented case study, six customer requirements are considered; they are cost, durability, weight, performance,

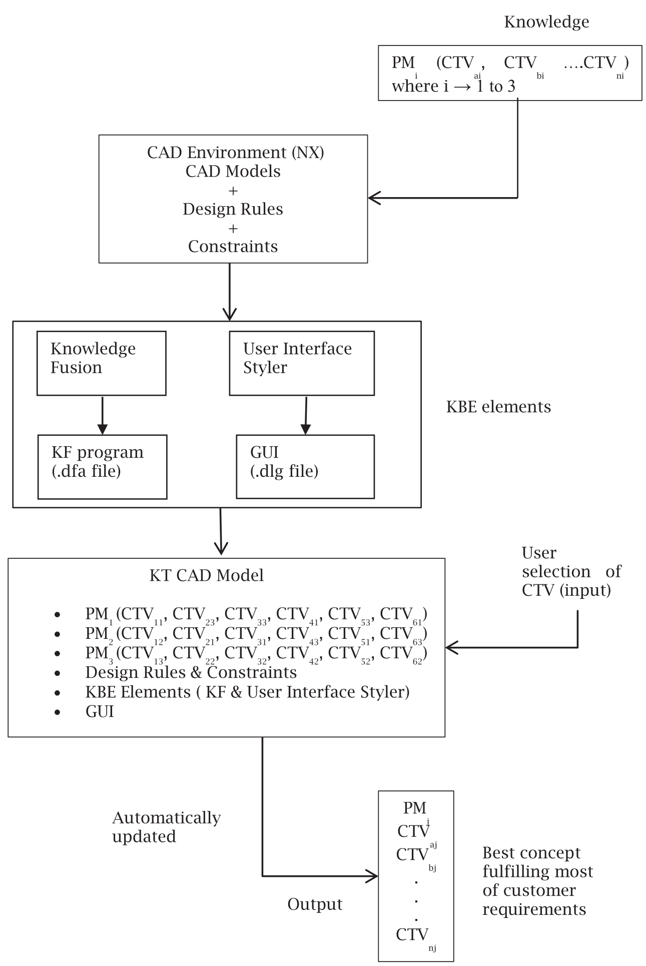

Fig. 5: KT framework and update process of wheel rim.

maintenance and appearance. There is always a scope to add more customer requirements. Target values of each customer requirement are defined based on product characteristic features and customer needs as in Tab. 1. CTVs are mathematically expressed as CTV_{ij}, where 'i' represents customer requirement number and 'j' represents target value as defined in Tab. 1 for the design of wheel rim.

Design rules and constraints are identified and developed for each product model based on specific combination of the target values. These rules are developed by mapping CTVs to product design specifications. In order to represent imprecise information of customer requirements in the product domain, direct mapping of CTVs to design specifications is used in the present work. Methodologies described by Nayak et al. [14] and Yu et al. [23] helps to identify fixed platform parameters and scalable platform parameter for product families. Scalable design parameter can be varied to achieve different performance constraints [8]. For the case study presented, all the geometric parameters of wheel rim like size of the rim and hub, and number of holes, spokes and nuts are considered as fixed parameters and material is considered as a variable design parameter (scalable design parameter) to achieve customer specific target values. Design rules are developed for each product model based on dependency of customer target values on variable design parameter (material, in this case). For example, '*if cost* = CTV_{11} *then material* $(M_1, M_2, M_3) == M_{1'}$ where M_1, M_2, M_3 are steel, alloy and chrome respectively. Tab. 2 represents combinations of customer target values used for the product models. A target value showcases the importance of each customer requirement to the user.

The design rules and constraints are then used to build KT in CAD environment through the use of KBE elements (KF and User Interface Styler, in this case). In this work, KF program connects target values, rules, constraints and functions of user interface to KT. KF is object oriented module in Siemens NX, which supports KBE. The main advantages of using

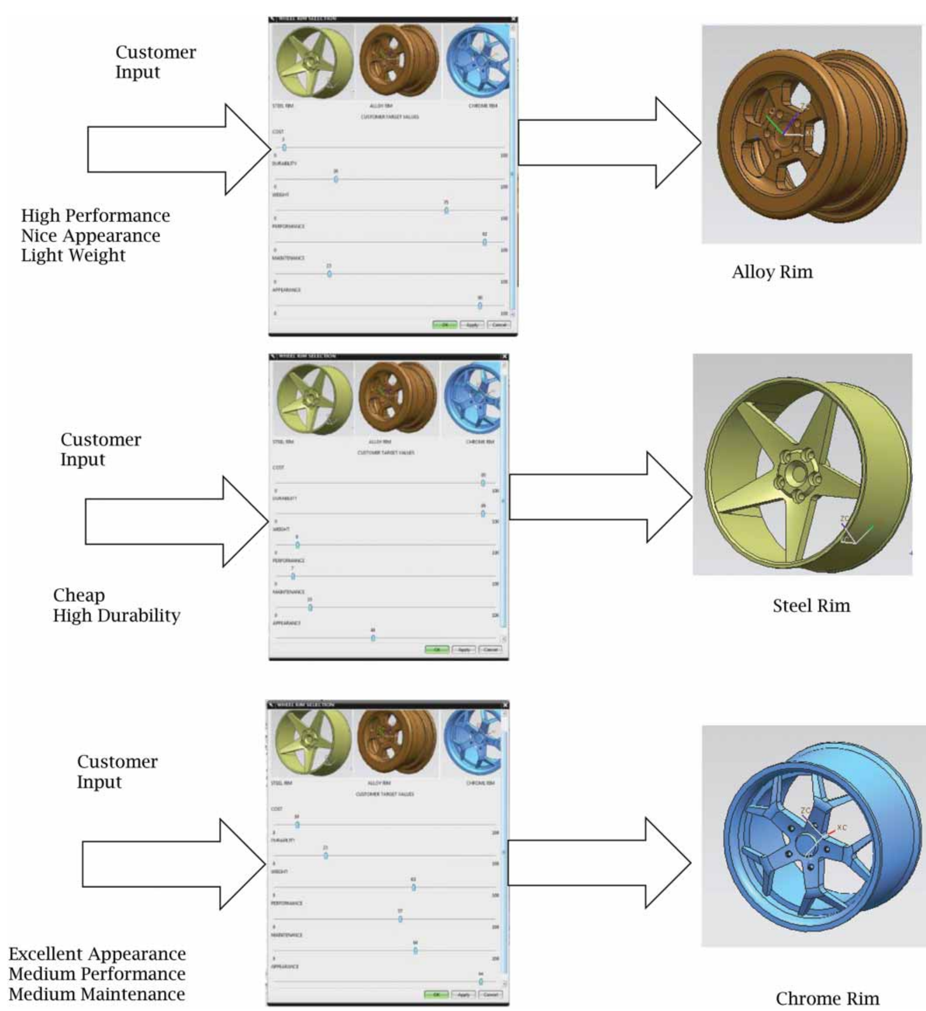

Fig. 6: KT updates for three different Scenarios.

the KF are: (i) it allows to preserve critical knowledge, design intent and design rationale during the design process, (ii) it allows quick automation of repetitive design tasks and (iii) it has the abilities to store and capture workflow process through the use of scripted file which can be programmed in many automation languages. KF program is developed in a text editor (Notepad) with .dfa extension. KF program is added to KT with the help of DFA manager. Graphical user interface (GUI) is designed in User Interface Styler of NX 6.0 with .dlg extension which assists the user to select the target values of various customer requirements. Wheel rim .dlg file is depicted in Fig 3. GUI of wheel rim selection KT CAD model is depicted in Fig. 4. The user selects the target values, in the range of 0-100, which shows the importance of each customer requirement to the user. Zero represent minimum importance and hundred represent maximum importance. In this manner, the ill-defined customer requirements can be easily expressed in descriptive and qualitative terms. Fig. 5 depicts the KT framework for wheel rim and its update process. Part models of three wheel rims are parametrically modeled in CAD environment through the knowledge of CTVs. These CAD models are then converted into KT with the help of KBE elements. According to the selection of user's importance, KT updates automatically to generate the wheel rim that satisfies most of the user requirements. Fig. 6 depicts KT updates for three different cases of customer inputs. There is no need to maintain large database server as KT CAD model act here as a design library and can store as many models as possible. The developed KT in this work saves significant memory space and updates within seconds so that the user can see changes immediately according to his requirements.

5. CONCLUSIONS

Design engineers spend most of their time to make crucial decisions under uncertain trends of customer requirement. In this paper, a KT CAD model is proposed to incorporate customer preferences and perceptions into CAD environment for decision-making process during concept evaluation. To validate the applicability of KT CAD model, an example of selection of wheel rim based on customer preferences is demonstrated. Through KT, comprehensive representation for product design process knowledge is included in CAD environment. This would simplify design process and avoid redesigning of any product from scratch when the customer requirements change. Through proposed KT, it is possible to replace design libraries, and eliminates many difficulties that are associated with maintaining large database. The designer's intent is also captured by the use of KT, which can be extended to construct design rationale framework. This paper attempts to demonstrate the following:

1. learning the importance of customer preference and perception to segment competitive global market,
2. evaluating product variants (concepts) in a market-oriented manner
3. capturing knowledge from later stages of design to make it available for early stages of design
4. developing computer supported tools for early stages of design
5. uncovering new ideas for future product development through clear understanding of customer perception
6. recognizing the complicated relations between customer requirements and design parameters to offer managerial insights to designers

The KT developed in this work incorporate only the importance of customer requirements in CAD environment. Future work will also include integrating current KT with other design automation methods to depict designer's intent and rationale as why user preference impacts the selection of a particular design alternative.

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