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Constraint Conversion Method in Feature-Based Heterogeneous CAD Model Exchange

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Abstract: Feature-based method is the focus of heterogeneous CAD model exchange. In order to keep the consistency of design intent in heterogeneous CAD model exchange, a constraint conversion method was proposed. Firstly, Feature transformation ways were given to support the correct conversion of constraint. Secondly, the geometric certificate was improved to identify geometric elements and geometric element is the acting object of constraint. Thirdly, the constraint conversion method on level of feature was proposed corresponding to different types of feature and the global transformation method of constraint during heterogeneous CAD models exchanging. Finally, a transformation case of part model from CATIA to UG shows that the approach proposed above is effective.

Key words: Heterogeneous CAD, feature, constraint, transformation, design intent

INTRODUCTION

The exchange of CAD models between different CAD systems has become a significant industrial requirement and plays an important role in CSCW. Researchers or organizations provided us many different solutions to this problem. All the researches includes the STEP-based method, (Chen and Tan, 2001; Yang and Ning, 2005) the Brep-based method (Wang *et al*., 2005) and the mesh-model-based method (Liu *et al*., 2006). Whereas there is a common problem in these methodologies that the target model obtained is not editable. In order to solve the problem, a method based on feature was proposed and its basic thinking is to abstract features from CAD model according to design history and rebuild them corresponding to the modeling history (Liu *et al*., 2003; Kim *et al*., 2007; Pratt *et al*., 2005; Mun *et al*., 2003; Choi *et al*., 2002; Shao *et al*., 2007). This method ensures that the target model is consistent with the source one in geometry and editable too. However some information about design intent is lost as the method is used to transform CAD model.

Design intent is the relationship among functions of product, constraints, technique information and geometric information and it represents the decision of designers (Jiang *et al*., 2000). Kim *et al*. (2007) analyzed the loss problem about design intent in his study and considered that features, parameters, constraints and design history are the important impact factors to design intent. Furthermore, Wang and Yang (2007) used XML file to express 3D model for exchange and all the information in the XML file includes information about design intent. Both the researchers didn’t introduce the conversion methodology of information about design intent.

Thus, this study further researched CAD models exchange based on feature and proposed the transformation method of constraint which is considered the most important factor to the consistency of design intent.

PROBLEMS ANALYSIS

Kim *et al*. (2007) studied that constraints specify relationships between elements of a model that are required to be maintained if the model is edited. In other word, constraint is important to keep the stability of geometric and topology in CAD model and constraints in source model should be transformed into target model during heterogeneous CAD models exchanging.

Feature-based heterogeneous CAD model exchange should be viewed as the transformation of features one by one according to design history. Thus the transformation of constraints in this process is the transformation of the constraint on feature in fact. The constraint on level of feature includes geometric constraint, positioning constraint and topological constraint and is named as feature constraint simply. The problems on the transformation of feature constraint are as follows:

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- There are several different transformation ways for a feature. The constraint of the target model can't reflect the design intent, if an incorrect way is used to transform constraints
- Geometric constraint of feature includes implicit geometric constraint and explicit geometric constraint and the implicit one is added on feature by CAD system automatically (Shah and Mäntylä, 1995). Implicit constraint is often omitted during heterogeneous CAD models exchanging, which results in the target model being under-constrained
- Positioning constraint of feature is often substituted by the coordinate of base point, which makes the feature fixed
- Constraint is acted on geometric elements. If the identifier of geometric element is not exclusive, the rebuilding of feature constraint will encounter mistake

Furthermore, current CAD systems handle the under-Constrained target model in two different ways

- Under-constrained model is permitted in some CAD systems. If user edits the under-constrained model and changes parameters of it, the model's shape may be changed in all feasible ways
- In most of CAD systems, under-constrained model is not permitted. If the model is imported into this kind of CAD system, constraints will be added to it automatically and the model is made fully constrained

The two ways can not ensure that constraints in target model are same to that in source model, which will make the design intent of the two models inconsistent. For example, Fig. 1a shows the loss of implicit geometric constraint of the bottom, when BLOCK feature is decomposed into sketch feature and sketch-based extrude feature. While BLOCK feature is transformed into sketch feature and sketch-based extrude feature in Fig. 1b, the positioning constraint of the corner point is substituted by its absolute coordinate, which results in the loss of positioning constraint. The two examples show that if the constraint is often neglected in heterogeneous CAD model exchange. Thus the research on constraint transformation is significant in feature-based heterogeneous CAD model exchange.

CONSTRAINT TRANSFORMATION METHOD

Foundation of Constraint Transformation

Feature transformation: Feature transformation is the foundation of feature constraint transformation. Aiming at transforming feature constraint, feature transformation ways should be researched carefully. It is supposed that S_A and S_B are different CAD systems and M_A is model built by S_A. If M_A is transferred to S_B as M_B, the transformation ways of the feature F_A in M_A is as follow.

Let, FTS_A and FTS_B be the feature type set of S_A and S_B, respectively. As the modeling functions of S_A are same to that of S_B in some degree, $FTS_A \cap FTS_B \neq \Phi$. The definitions of basic feature type and extended feature type were proposed according to the relations between FTS_A and FTS_B.

Definition 1

Basic feature type (BFT): If FTS_A and FTS_B are the feature type set of S_A and S_B respectively, feature types in $FTS_A \cap FTS_B$ is defined as the basic feature types of S_A or S_B.

Definition 2

Extended feature type (xft): If FTS_A and FTS_B are the feature type set of S_A and S_B respectively, feature types in $FTS_A \oplus FTS_B$ is defined as the extended feature types of S_A or S_B.

According to analyze UG, CATIA and Pro/E, the scopes of $FTS_A \cap FTS_B$ and $FTS_A \oplus FTS_B$ are summarized.

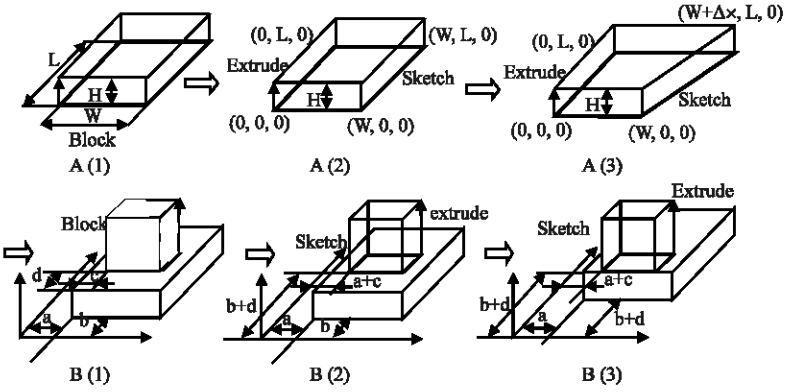


Fig. 1: Classical examples in feature-based heterogeneous CAD model exchange system

$FTS_A \cap FTS_B \subseteq \text{datum feature} \cup \text{spline or surface} \cup \text{sketch} \cup \text{sketch-based feature} \cup \text{simple design feature} \cup \text{detail feature}$. $FTS_A \oplus FTSB \subseteq \text{voxel feature} \cup \text{complex design feature}$.

Generally BFTs occupy most of all feature types in CAD system and can realize all functions of CAD system. XFTs are designed for special application fields of CAD system and their modeling functions can be substituted by the BFTs'. The method of feature transformation was put forward according to the relations between BFTs and XFTs and the method will be discussed in two cases.

BFT→BFT: For $\forall F_A \in M_A$, feature type of F_A is expressed as $FT(F_A)$. If $FT(F_A) \in FTS_A \cap FTS_B$, then $FT(F_A) \in FTS_B$. If F_A is transferred to F_B ($F_B \in M_B$), then $FT(F_B) = FT(F_A)$. The transformation from F_A to F_B is called as 1:1 transformation, tagged as $F_A \xrightarrow{1:1} F_B$. Since BFTs occupy most of all feature types in CAD system, 1:1 transformation is the main transformation ways.

XFT→BFTs: If $FT(F_A) \in (FTS_A - FTS_A \cap FTS_B)$, then $FT(F_A) \notin FTS_B$. Because $FTS_A - FTS_A \cap FTS_B \subseteq FTS_A \oplus FTS_B$, the modeling function of $FT(F_A)$ can be taken placed by BFTs in S_A. Thus, F_A should be transformed as $F_{B,k}(1 \le k \le m)$ and $FT(F_{B,k}) \in FTS_A \cap FTS_B$. The transformation from F_A to $F_{B,k}(1 \le k \le m)$ is called as decomposing transformation, tagged as $F_A \xrightarrow{\text{decomposed}} \{F_{B,k} | FT(F_{B,k}) \in FTS_A \cap FTS_B (1 \le k \le m)\}$. The following is the decomposing transformation ways presented in this study:

- $F_A \xrightarrow{\text{decomposed}} \{[F_{B,1}], F_{B,2}, F_{B,3}, [F_{B,4}] | FT(F_{B,1}) \in \text{datum feature}, FT(F_{B,2}) \in \text{sketch}, FT(F_{B,3}) \in \text{sketch-based feature}, FT(F_{B,4}) \in \text{detail feature}\}$.

F_A is decomposed as $F_{B,1}$, $F_{B,2}$, $F_{B,3}$. In this transformation, features in [] is optional feature and $F_{B,3}$ is sketch-based feature. Sketch-based feature includes extrude feature, revolve feature, sweep feature and blend feature. If F_A can be transferred as different sketch-based features, the priorities are extrude feature, revolve feature, sweep feature and blend feature:

- $F_A \xrightarrow{\text{decomposed}} \{F_{B,1}, F_{B,2}, \ldots, F_{B,m} | (FT(F_{B,1}) = FT(F_{B,2}) = \ldots = FT(F_{B,m})) \wedge (FT(F_{B,k}) \in \text{simple design feature} \vee FT(F_{B,k}) \in \text{sketch-based feature} \vee FT(F_{B,k}) \in \text{spline or surface} \vee FT(F_{B,k}) \in \text{detail feature}) \wedge (1 \le k \le m))\}$.

Furthermore, CAD system provides special design features for designing injection mold, progressive die, machine tool and et al. Methodologies above will be combined, as these design features are transformed. The following is the transformation way of T slot which is used to design worktable of machine tool:

T slot $\xrightarrow{\text{decomposed}}$ {sketch, extrude, datum plane, sketch, extrude}

Figure 2 shows the transformation method of boss, cable, pocket and T slot.

In based-feature heterogeneous CAD model exchange, application of methodologies above is the precondition that feature constraints are transformed correctly.

Identifier of acting object of constraint-geometric element: As the boundary of feature, geometric elements are also constrained by feature constraints. In order to recognize and rebuild feature constraints correctly, geometric elements acted by feature constraints should be identified during feature-based heterogeneous CAD model exchanging. Thus the study proposed an identific-

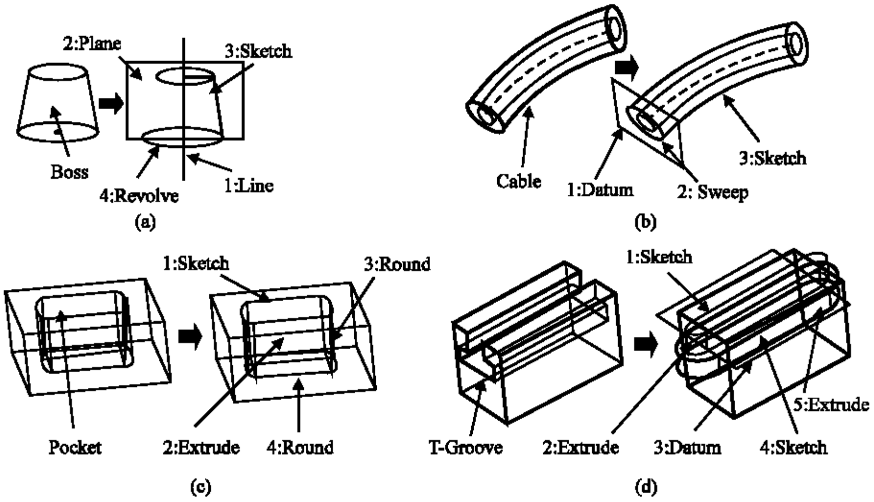


Fig. 2: Examples of feature transformation

ation method of geometric element based on advanced geometry certificate. Geometry certificate of geometric element was defined as triple (L, T, P) (Hoffman and John-Aringo, 1998). L is the sequence number of geometric element in list of point, line or face. T is the type of geometric element which includes point, line and face. P is the characteristic point of geometric element. While receiving CAD system is different from the sending one, the accuracy is bad and the efficiency is low if geometry certificate is used to identify geometric element. Thus this study improved geometry geometric element and use quadruple (F, L, T, P) to identify geometric element. F is the identifier of feature and the geometric element identified lies on the boundary of the feature. T is the type of geometric element. L is the sequence number of geometric element in T list of F. P represents the characteristic parameters, such as the coordinate of point, the coordinates and tangent vectors of line in ending points. As using this kind of geometry certificate to identify geometric element, the feature including the geometric element is found firstly by F. And then L, T and P are used to further find the correct geometric element. The usage of (F, L, T, P) limits directly the range of geometric element to the feature in which the geometric element lies. So the positioning efficiency of geometric element will be higher when using (F, L, T, P) to identify the geometric element. Furthermore, the positioning accuracy of geometric element will be promoted when the characteristic point is substituted by characteristic parameters. The identification method will be applied in feature constraint-conversion in heterogeneous CAD model exchange.

Feature constraint conversion method: This study proposed the method of feature constraint conversion, This method will play an important role to keep consistency of design intent in heterogeneous CAD model exchange. This study will only discuss the method of feature constraint conversion while F_A is decomposed into different types of features $F_{B,k}(1 \le k \le m)$. In order to guarantee that the design intent expressed by $F_{B,k}(1 \le k \le m)$ is same to that of F_A, the principles about feature constraint conversion was proposed.

Principle 1: There must be equivalent constraints to the feature constraints of F_A in $F_{B,k}(1 \le k \le m)$

Principle 2: While $F_{B,k}(1 \le k \le m)$ is edited, $F_{B,k+1}$, $F_{B,k+2}$, ..., $F_{B,m}$ must change with $F_{B,k}(1 \le k \le m)$

Principle 3: $F_{B,k}(1 \le k \le m)$ must be constrained completely

The conversion methodologies of geometric constraint, positioning constraint and topological constraint are provided, according to these principles. The conversion method of positioning constraint and that of topological constraint will be discussed together because of the mutual transformation relationship between positioning constraint and topological constraint transformed.

The conversion method of geometric constraint: Geometric constraint is used to constrain the position relationship between geometry elements of sketch. This study discusses the constraint conversion in two cases:

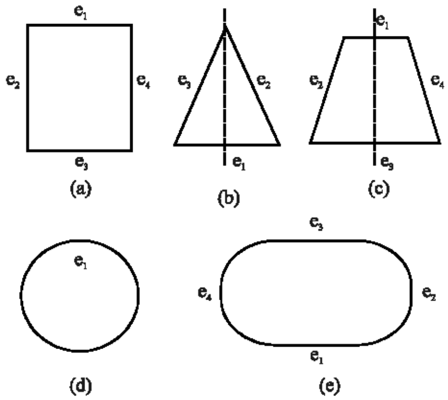
- The section of F_A is regular geometries. For example, the section of boss is ladder
- The section of F_A is irregular geometries and there are chamfer or in the section. For example, the section of pocket is a rectangle with fillets

Aiming at simplifying the profile of sketch, fillets and chamfers should be removed from the section of F_A, while F_A is transformed into $F_{B,k}(1 \le k \le m)$ and sketch feature is included in $F_{B,k}(1 \le k \le m)$. All the fillets and chamfers should be transformed into detail features. The basic profiles of sketch were got by analyzing all kinds of sections of feature and these profiles of sketch are showed in Fig. 3.

The following geometric constraint s will be added to the basic profiles:

- Perpendicular $(e_1, e_2) \cap$ perpendicular $(e_2, e_3) \cap$ Perpendicular (e_3, e_4)
- Equal $(e_2, e_3) \cap$ angle(e_1, e_2)
- Equal $(e_2, e_4) \cap$ angle$(e_2, e_3) \cap$ angle(e_3, e_4)
- No geometric constraint
- Tangent$(e_2, e_4) \cap$ angle$(e_2, e_3) \cap$ angle(e_3, e_4)

Conversion method of positioning and topological constraint: The conversion method of positioning and topological constraint is discussed in two cases.



(a) (b) (c) (d) (e)

Fig. 3: Basic profiles of sketch feature

- If the section of F_A is parallel to the link face of F_A, the sketch feature transformed from F_A will attach on the face corresponding to the link face of F_A. The transformation way of F_A is as follow:

$$F_A \xrightarrow{\text{decomposed}} \{F_{B,1}, F_{B,2}, \ldots | FT(F_{B,1}) \in \text{sketch feature}, FT(F_{B,2}) \in \text{sketch-based feature}, \ldots\}$$

All the positioning constraint and the topological constraint of F_A will be conversed to sketch feature, since the positioning constraint and the topological constraint between sketch-based feature and sketch feature are added through the dependent relationship. Sketch feature $F_{B,1}$ succeed the topology of constraint of F_A and sketch attaches on the face corresponding to the link face of F_A. The level and vertical positioning constraint of $F_{B,1}$ are transformed from the positioning constraints of F_A, the reference geometric elements of positioning constraint are corresponding to the reference elements on which the positioning constraints of F_A attach

- If the section of F_A is perpendicular to the link face of F_A, the sketch feature transformed from F_A must attach on a datum plane. The transformation way of F_A is as follow:

$$F_A \xrightarrow{\text{decomposed}} \{F_{B,1}, F_{B,2}, F_{B,3}, \ldots | FT(F_{B,1}) \in \text{datum plane}, FT(F_{B,2}) \in \text{sketch feature}, FT(F_{B,3}) \in \text{sketch-based feature}, \ldots\}$$

One of the positioning constraints of F_A will be transformed as the positioning constraint of the datum plane and the other will be transformed to position the sketch feature in one direction. The topological constraint of F_A will be conversed as the positioning constraint in the other direction which is vertical to the former.

Some of the methodologies are used in the examples in Fig. 4 which shows that the design intents are kept in the transformation examples.

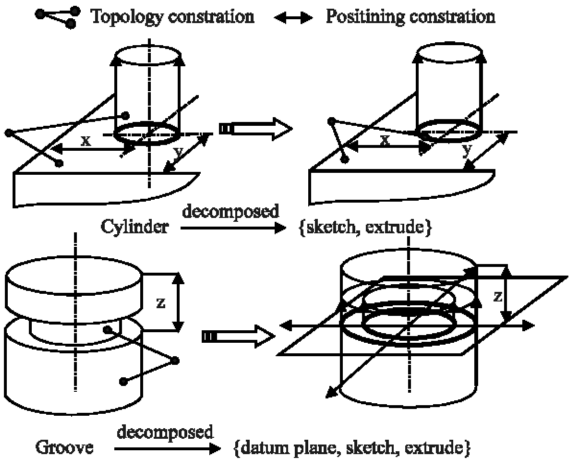


Fig. 4: Examples of feature constraint conversion

Global constraint conversion in model exchange: Global constraint conversion in model exchange is not to simply converse constraints one by one with features transforming and it is relative to the context of model exchange. This study proposed a method of global constraint conversion. In order to describe the method, some definitions are given. For arbitrary geometric element e, ID(e) is defined as the identification function e. The following is the definition of identifier mapping set.

Definition 3

Identifier mapping set: For an arbitrary geometric element $e_A \in M_A$, e_B is its corresponding geometric element in M_B. There must be an injection f from M_A to M_B, so that $ID(e_B) = f(ID(e_A))$. The mapping relationship from $ID(e_A)$ to $ID(e_B)$ is represented as ordered couples $<ID(e_A), ID(e_B)>$ called identifier mapping about e_A and all the identifier mappings form the Identifier mapping set in the transformation from M_A to M_B. Identifier Mapping Set is simply denoted as IMS.

Two functions are defined on IMS:

- Push($<ID(e_A), ID(e_B)>$ & IMS). The function is used to add $<ID(e_A), ID(e_B)>$ into IMS and return the refreshed IMS simultaneously
- Find($ID(e_A)$, & $ID(e_B)$). The function is used to search for $<ID(e_A), ID(e_B)>$ by $ID(e_A)$ in IMS and return $ID(e_B)$

The method of global constraint conversion is as the following steps:

Step 1: M_A is imported into CAD system S_A and all features and feature constraints are gotten by traversing the feature tree

Step 2: For an arbitrary feature $F_A \in M_A$, all features after F_A are scanned one by one. If there exists feature constraint referencing the geometric element e_A of F_A, the type of the feature constraint should be obtained. If the feature constraint is positioning or topological constraint, the feature the feature constraint lying in and all its successors are depressed. If the feature constraint is geometric constraint, all successors of F_A are depressed. As the identifier of e_A, $ID(e_A)$ is constructed

Step 3: e_B is the geometric element of M_B and it is corresponding to e_A. The identifier of e_B is gotten by f and $ID(e_B) = f(ID(e_A))$. The identifier mapping $<ID(e_A), ID(e_B)>$ is inserted into IMS, Push($<ID(e_A), ID(e_B)>$ & IMS)

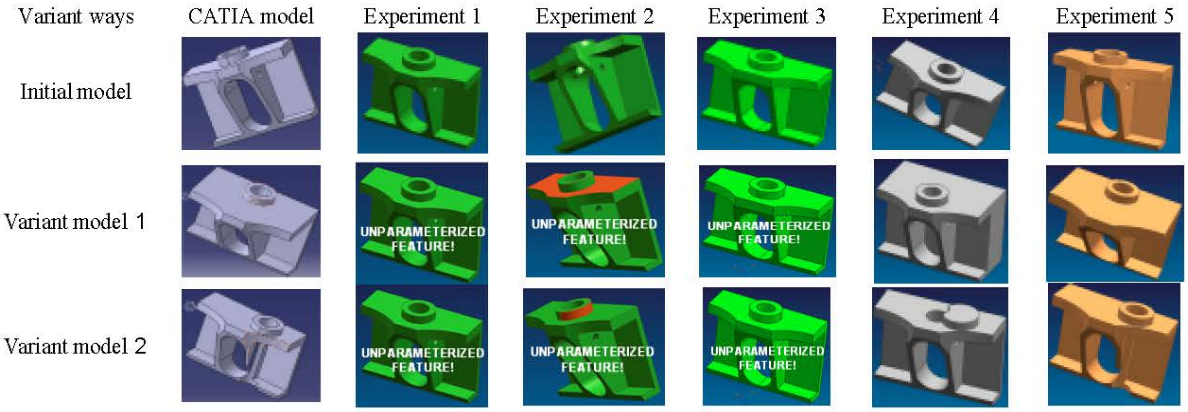


Fig. 5: Target models gained from 5 experiments and their variant models

Step 4: For an arbitrary feature $F_A \in M_A$, F_A is transformed to $F_b \in M_B$ according to FT(F_A) and all feature constraints of F_A is conversed into F_B. If the feature constraint of F_B references e_B and e_B is corresponding to e_A, ID(e_B) is obtained by Find(ID(e_A) & ID(e_B))

Step 5: Step 1, Step 2, Step 3 and Step 4 are executed circularly until the transformation from M_A to M_B is completed

The global constraint conversion from M_A to M_B is realized by following steps above.

EXAMPLES

This study applies the method of constraint conversion proposed in developing the model transformation interface from CATIA to UG by VC++6.0. A CATIA model of bracket is used as the transformation object and is transformed in five different transformation experiments:

Experiment 1: The bracket model is exported from CATIA by STEP AP203 and is imported into UG. The UG model of bracket composed of an unparameterized feature is obtained

Experiment 2: The bracket model is exported from CATIA by IGES and is imported into UG. The UG model of bracket composed of many unparameterized features is obtained

Experiment 3: The bracket model is exported from CATIA by *.model and is imported into UG. The UG model of bracket composed of an unparameterized feature is obtained

Experiment 4: The method proposed by Shao and Chen (2007) is used to develop the transformation interface from CATIA to UG. The CATIA model of bracket is exported from CATIA by the interface and is imported into UG. The UG model of bracket composed of a series of parameterized features is obtained

Experiment 5: The method proposed by this study is used to develop the transformation interface from CATIA to UG. The CATIA model of bracket is exported from CATIA by the interface and is imported into UG. The UG model of bracket composed of a series of parameterized features is obtained

The UG models of bracket obtained by these experiments above are shown in the first row of . 5. In order to study characteristics of these UG models, a further experiment is necessary. In the experiment, these UG model are required to be changed in the ways as shown in the first column of Fig 5. The 2nd and 3rd rows of Fig. 1 show the results of the experiment. Conclusions are drawn by results of the experiment:

- Uneditable target models are obtained through experiment 1~3 and design intent is lost seriously in the process of model transformation
- If constraint is ignored or conversed in wrong methods in feature-based heterogeneous CAD model exchange, variant characteristics of target model will be different from that of the source model. This will result in the loss of design intent in heterogeneous CAD model exchange
- If the transformation interface is developed in the method proposed, the variant characteristics of target model is same to that of the source model in heterogeneous CAD model exchange. This shows that consistency of design intent is maintained well and the constraint conversion method proposed is effective

CONCLUSION

This study put focus on the lost of design intent in heterogeneous CAD model exchange and proposed a constraint conversion method for keeping the consistency of design intent. This method was validated by model transformation experiments from CATIA to UG. The benefits of the method proposed are as follows:

- The method ensures that the variant characteristics and the editable characteristics of the target model are same to those of the source model
- The method can be applied in collaborative design among heterogeneous CAD systems and it is important to promote the interoperability among heterogeneous CAD systems
- The method is the supplement to the based-feature heterogeneous CAD model exchange and it is significant to guide to develop the model transformation interface between heterogeneous CAD systems

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