Associative modeling of manufacturing information in CAD-Systems

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Abstract

In current CAx systems, tolerance information can be represented within 3D models by 3D annotations. The way it is done now, the information is directly linked to the corresponding geometric zone. Therefore, when the structure of the 3D model is modified due to a topological update, the 3D annotations become instable. This is typically the case when the CAx system is unable to trace back the functional purpose from the previous structure of the model and transpose it into the updated structure of the model. As a consequence of this instability, the information held by the 3D annotations is either lost or turned into misleading information, e.g.: the 3D annotation can be linked to a wrong geometric zone.
In this paper a general methodology is introduced to increase the update stability of 3D tolerance flags in case of topological changes occurring in the 3D models of CAx systems. The methodology uses the template technology, which is an approach used in the automotive industry to support the Product Development Process (PDP). It is applied in the scope of a standard in CAD systems, at the level of the internal model for representing solid objects, namely the boundary representation (B-rep). A general algorithm is suggested. This methodology principally concerns the thin-walled parts and the face linked 3D annotations. A case study is exposed to demonstrate the performance of the methodology.
In conclusion, this methodology, by closely examining the behavior of B-rep elements during a topological update, sheds new light on the neglected issue of 3D annotations stability.

1 Introduction

In the automotive industry each manufactured component is meant to be assembled with other components. Depending on the machining process and the machines used, inherent variations from the ideal shape take place. Even though each component may be manufactured in a different location and by different machines, still the measurements and dimensions should fit with other mating components of the assembly. For this reason, these deviations must be varying within an acceptable range whose borders are defined by tolerances. [1]

Nowadays, CAx systems are used during different steps in the product development process (PDP) such as modeling, simulating, etc. When using CAx systems, all the dimensions are nominal and all the assembly simulations work out and show the expected results. [2, 11]

In the reality, manufacturing and machining processes are inherently imprecise. This means that the geometries present deviations from the ideal nominal shapes. If these deviations exceed the tolerance range, then mating parts may not be fitting to each other. If these imperfections are not controlled and taken into consideration, then during the assembly process, these issues have to be fixed, which will extend the time afforded to assemble the components and therewith cause additional unnecessary costs. [3, 12, 13]

Problems become even more severe, when the efforts dedicated so that the 3D annotations are correctly defined are wasted, because the information has become instable after a topological update of the CAD model. This

instability engenders either a loss of information or/and a distortion of other information by linking the wrong

information to the wrong geometric zone. Considering that a single part may convey hundreds of tolerances and manufacturing information, it becomes clear how tedious it is to manage this manufacturing information instability.

Section 2 gives some background on how the 3D annotations (tolerance and manufacturing information) are linked to the 3D model and describes how the 3D annotations can become instable. Section 3 introduces the template technology which is an approach commonly used by car manufacturers in order to increase the degree of maturity of components in the early stages of the PDP and increase the genericity and reusability of CAD models. The template technology is the backbone of the proposed solution to stabilize tolerance information. Then, section 4 describes the operating process of the solution which will enable us to fix the 3D annotations' instability issue. Subsequently, section 5 presents a case study. And finally, section 6 gives a conclusion.

2 3D annotations instability

The usual model in CAx systems for representing a solid object is called Boundary representation (B-rep). This model consists in a decomposition of a solid object's bounding surface into a structured set of different boundary elements (faces, edges and vertices). Then, the CAx system enumerates all the boundary elements in a manner that makes it impossible for the user to intervene on the enumeration process or even to predict it. This is the case for instance in CAD systems available on the marketplace, such as NX (Siemens) or CATIA (Dassault Systèmes), among others.

During the creation of a 3D annotation, the information is directly linked to the corresponding boundary element. This means that the link between the 3D annotation and the corresponding geometric zone is only depending on the boundary elements' enumeration which is generated internally by the CAx system. Because every boundary element is processed in the same way, the CAx system does a priori not differentiate the functional purpose of each boundary element.

During a step by step modeling process, two types of updates can be distinguished for a 3D model. On one hand, there is the geometrical update which means that only the dimensions of the 3D model are updated, in this case, the boundary elements' enumeration will not be changed. On the other hand, there is the topological update (see Figures 1-a & 1-b). This update changes the number of boundary elements forming the 3D model. Therewith, the CAx system has to update the previous enumeration of the boundary elements as well. [4-5]

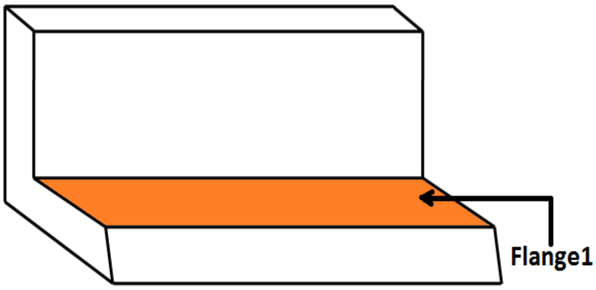

Fig. 1-a Before the topological update

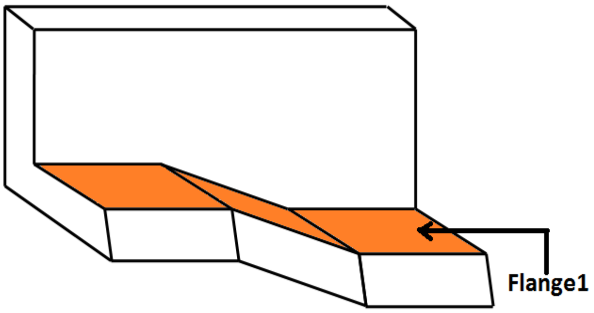

Fig. 1-b After the topological update

Since the relation between the 3D annotation and the related geometric zone is defined by the boundary elements' enumeration, a topological update over the 3D model will impact this relation. Considering the 3D model and the 3D annotation shown in Fig. 2, a topological update is applied to "Flange1" (See Fig. 1), which leads to a change in the shape of the 3D model as well as in the total amount of the boundary elements.

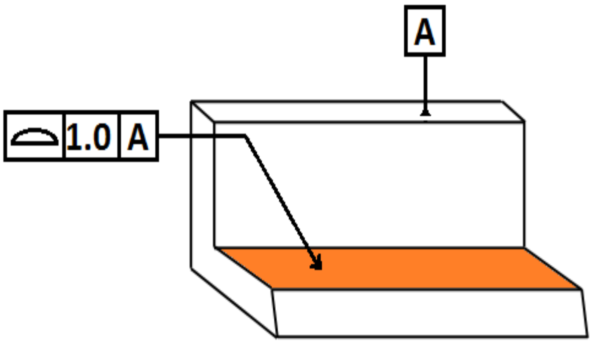

Fig. 2 Part before the topological update

The expected behavior in this case would be that the 3D annotation follows the shape update of the flange and consequently apply to the new boundary elements generated by the flange, even if its shape has changed (see Fig. 3-a which is the theoretical expected result). In the reality, due to how the 3D annotation is linked to the boundary element, the information will generally not follow the change. In this case, the information will be either lost meaning that it will not be pointing toward any boundary element (See Fig. 3-b). Or, the information will be pointing toward the wrong boundary elements (See Fig. 3-c). And in other cases the information will be pointing only partially to the related boundary elements (See Fig. 3-d). [6]

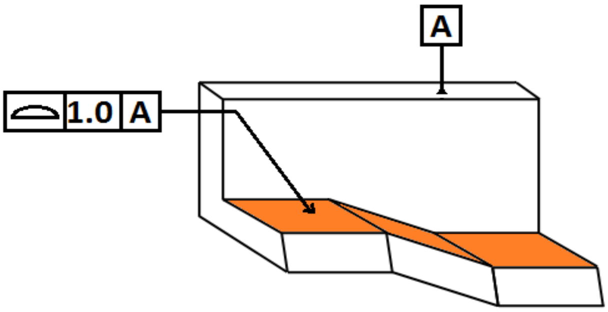

Fig. 3-a Theoretical result

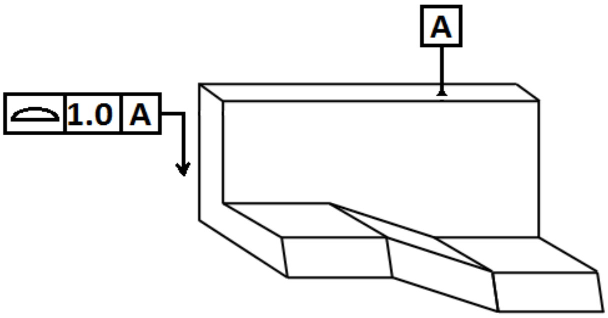

Fig. 3-b Total loss of information

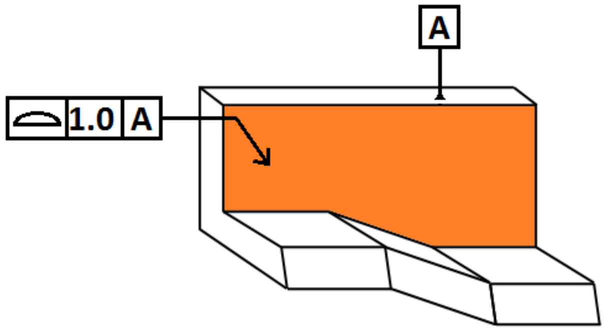

Fig. 3-c Wrong target faces

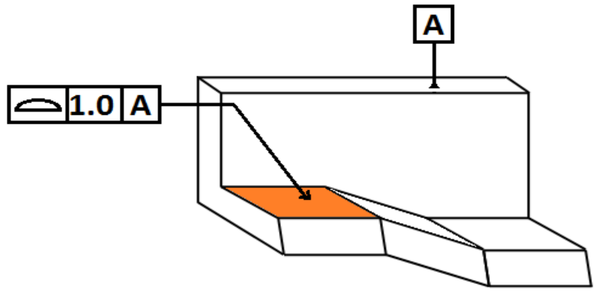

Fig. 3-d Partial loss of information

In any case, the tolerance information will be lost either partially or completely.

The obtained results show the need to double check all the tolerances after every topological update.

As just demonstrated, using the current process, consisting in annotating solely the B-rep model with tolerance information has proven to be unstable and inefficient.

The next section introduces the template technology which is used in the automotive industry in order to improve the product and development process by reducing the development time and cost.

3 Contribution positioning

Initially, feature recognition (FR) method was developed, in late 1970s, by L. Kyprianou at Cambridge University. Usual feature recognition techniques were used to test extract interesting regions of a CAD model, by using, for example, edge concavity as a shorthand way. Kyprianou developed a FR method decomposing models into sets of faces corresponding to a basic shape and various delimited sub-units called features. Later on, the method was improved by Anderson (1983) in order to allow overlapping features to be recognized.

Since then, many formal FR methods and algorithms have been developed such as:

-The syntactic pattern recognition approach, by Staley SM & al. (1983)

-Graph-based approach, by Floriani LD (1987)

-The logic-based approach, by Joshi S and Chang TC (1988)

-Expert system approach, by Luger GF and Stubblefield WA (1989)

-Volume decomposition and composition approach, by Wang (1990)

However, almost all the actual FR are mainly intended for linking CAD systems with Computer-aided Manufacturing (CAM) via Computer-aided Process Planning (CAPP) which means that the main focus of these methods is set to recognize and extract features from modelers.

Alternatively, some methodologies to automatically determine the Geometric Dimensioning & Tolerancing (GD&T) of machining volumes obtained by feature recognition emerged. By focusing on the features' properties and characteristics, standard tolerances can be inserted. Most of methodologies are mainly focusing on assessing whether there is a "feature" or not and according to the feature's semantic, standard tolerance information are determined.

It must be noted that these approaches are mainly located upstream of the tolerance process (see Fig. 4). However, when the tolerance process is established and specific tolerances are set, the usual methodologies are unable, in case of a topological update, to re-link specific tolerance information (non-standard) to their corresponding boundary elements.

Our concern is focused on tolerance information re-linking. It is tageted downstream of the tolerance process. The next paragraphs will be presenting a methodology solving this issue in the case of thin-walled parts and face linked 3D annotations. [20-25]

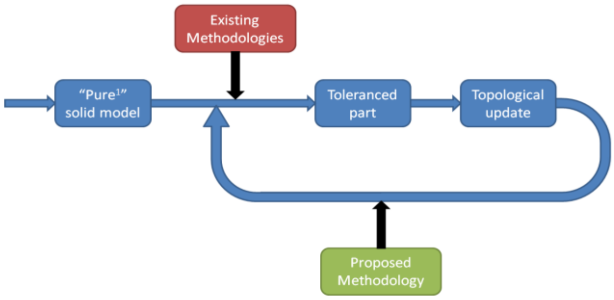

Fig. 4 Existing and proposed methodologies' position in a tolerancing process (overview)[1]

4 Template technology

Geometry templates are generic, parametric associative CAD patterns with reduced detail. These patterns are used as a pre-structured and reusable geometric location for the construction of individual parts and assemblies. [7]

In the automotive industry for instance, thin-walled parts in particular, the design process follows generally the same methodology, which makes sense insofar to divide the component into different functional units repeatedly used (e.g. flanges, cut outs, holes, etc.). Therefore, recurring characteristics over different car series can be gathered and built up as a parametric CAD pattern. It represents a reduced model which will be used for different car series in the development process by simply adapting its input according to each car series' characteristics. The purpose behind this operation is to ensure the possibility to replace or update these functional units (e.g. change the hole type, update a flange's form) without affecting the rest of the 3D model which offers a great handling and workability during the design process. Therefore, the designer begins with a higher degree of maturity in an early stage of the PDP instead of starting from scratch. [8]

[1] *A pure solid model contains no tolerances and no explicit dimensions.*

Template technology in the automotive industry can be divided into three groups, namely: Geometry Templates, Study Templates and Follow-up process Templates. In this paper, only the first group, namely "Geometry Templates" will be dealt with and referred to as templates.

The buildup process of a template pattern, for a motor hood for example, consists in making an adaptive surface for the left flange. This adaptive surface (functional surface) is made by assembling a set of basic surfaces, using a filet operation for instance. Each basic surface is fulfilling a function within the 3D model. Then the design surface of the motor hood, which is a class A surface, is assembled with the left flange. Afterwards, the resulting surface is assembled to other adaptive surfaces. Once the assembly operation is completed, a thickness is given to the surface. Then other machining operations such as holes, cuttings, etc. are realized and the obtained volume represents the instance of a template. [9]

In the next section, a new manufacturing information modeling approach based on templates is introduced.

5 Manufacturing information modelling approach

Section 2 demonstrated the problems of the tolerancing process based on the low level Boundary representation. The gaps in this method are principally due to the fact that the functional information is lost after operating a topological update. Thus, the answer to the crucial questions "How" and "Why" each information is linked to which boundary element is missing. Templates can solve this issue. Indeed, as explained in the previous section, templates allow to store and use the functional information and therewith the functional faces can be calculated and distinguished from non-functional faces.

The solution proposed in this paper combines the boundary representation and the template technology.

The boundary representation allows to decompose each volume into elementary boundary elements and to enumerate each one of these elements. Consequently, any boundary element inside the part can be pinpointed and targeted. Also, the CAx system provides the ability to calculate the distance between different geometric elements of the 3D model, while templates provide the possibility to identify every boundary element in the component.

In the following sections, the proposed methodology is described in terms of data model and in terms of process.

Suggested data model

The internal representation of the boundary elements in CAx systems procures a unique ID for every geometric element. This ID will be used in the following methodology to identify and pinpoint specific elements. These elements are the volume body and the functional surfaces of each 3D annotation. This unique ID will also help determining, for each 3D annotation, the list of the tolerance target elements which represent the collection of boundary elements that must be toleranced together by the same annotation. In this paper it will be referred to this list as “tolerance_list”. The reason behind considering the ID of the whole body and the whole functional surface instead of directly using the target faces is because of the impact of a topological update over boundary elements. While the ID of individual boundary elements separately considered is volatile and changing after a topological update, the ID of features in general remains unchanged after updating the existing elements even when it comes to a topological update. In addition to this data, the position of the leader of each 3D annotation is also required in order to check its conformity and, if necessary, re-orient it toward the right boundary element.

By specifying an offset value, the user can either tolerance the faces which are directly in contact with the functional surface or tolerance the faces which are located at the height of the offset value from the functional surface (hashed face - Fig. 5).

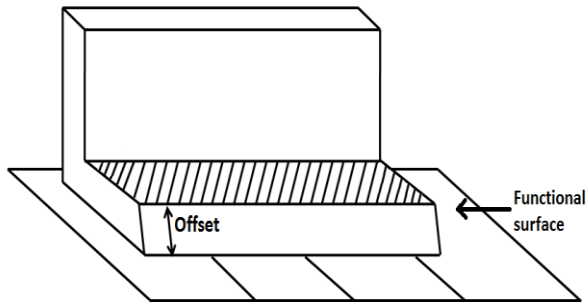

Fig. 5 Offset value

Suggested process

The first step of the suggested process associated to our methodology consists in determining the ID of both the volume body and the functional surfaces for each 3D annotation. Then, a database linking each 3D annotation present on the part with the respective IDs of its related volume body and functional surfaces is created. This database can be stored either within an external file (e.g. XML file) or embedded within the part model itself. When a topological update is applied to the 3D model, the ID of the boundary elements affected by this update will be adapted as well. As explained in section 1, the consequence of this update is the destruction of the link between the tolerance information and the tolerance target elements. Therefore, the second step of this methodology consists in reconstructing this link by first retrieving the IDs stored during the previous step in order to determine the actual volume body and functional surface related to each 3D annotation. And then, for each 3D annotation, the contact boundary elements between the volume body and the functional surface will be determined. In order to determine these contact elements, by taking advantage of the boundary representation’s structure, the volume body and the functional surface will be decomposed into elementary boundary elements (for clarity purposes the faces derived from the functional surface will be referred to as “functional faces” while those derived from the 3D model will be referred to as “body faces”). Then the body faces are also decomposed into body vertices. Afterwards a loop over the functional surface is generated in order to measure the distance from each functional face to all the body vertices (the measurement operation in this study is carried out according to the minimum distance function, see Fig. 6).

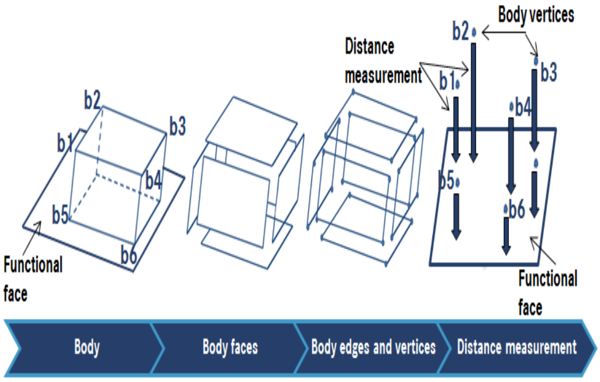

Fig. 6 Brep decomposition + distance measurement

All the distances assessed in this step are stored in a list conventionally called in this paper “distance_list”. Then, each value in the “distance_list” is assessed and checked if it is within the range centered at zero with CAx system’s internal tolerance value as radius. If a body face’s set of vertices is within the range, then the corresponding body face is stored in a list conventionally called in this paper “contact_list”. This operation goes on until all the functional faces’ distance from the body have been assessed. The elements stored in the “contact_list” represent the right elements that must be toleranced by the related 3D annotation.

The next step is to compare the actual toleranced faces with the newly acquired elements from the “contact_list”. If these two sets of elements are fully corresponding then no change is needed. However, if they are not fully corresponding, then it means that the tolerance information has been lost and that the target faces are either wrong or incomplete. Comparing both elements (old tolerance target elements and the new tolerance target elements obtained in the “contact_list”) in order to determine the missing faces would be both performance and time consuming without relevant benefit. That is why the proposed solution consists in directly replacing the tolerance target elements by the new elements stored within the “contact_list” without determining the missing features. This operation will re-orient the tolerance information toward the right boundary elements by updating the tolerance target elements. Whereas, the leader of the 3D annotation will still be pointing into the wrong directions (see Figures 2-b, 2-c, 2-d). In order to re-orient the leader, the distance between the old position of the 3D annotation’s pointer and the new related boundary elements is measured. These measurements are then assessed so as to determine the nearest boundary element from the old position of the leader. Therewith the new position of the leader will be re-oriented toward the coordinates extracted from the nearest boundary element.

It also happens that the user wants to tolerance boundary elements which are located at a certain offset distance from the functional surface. In this case, the range, which was centered on zero and had a radius equal to the CAx system’s tolerance value, will be centered on the offset value instead of zero. [10]

The overall process is summarized in Fig. 7.

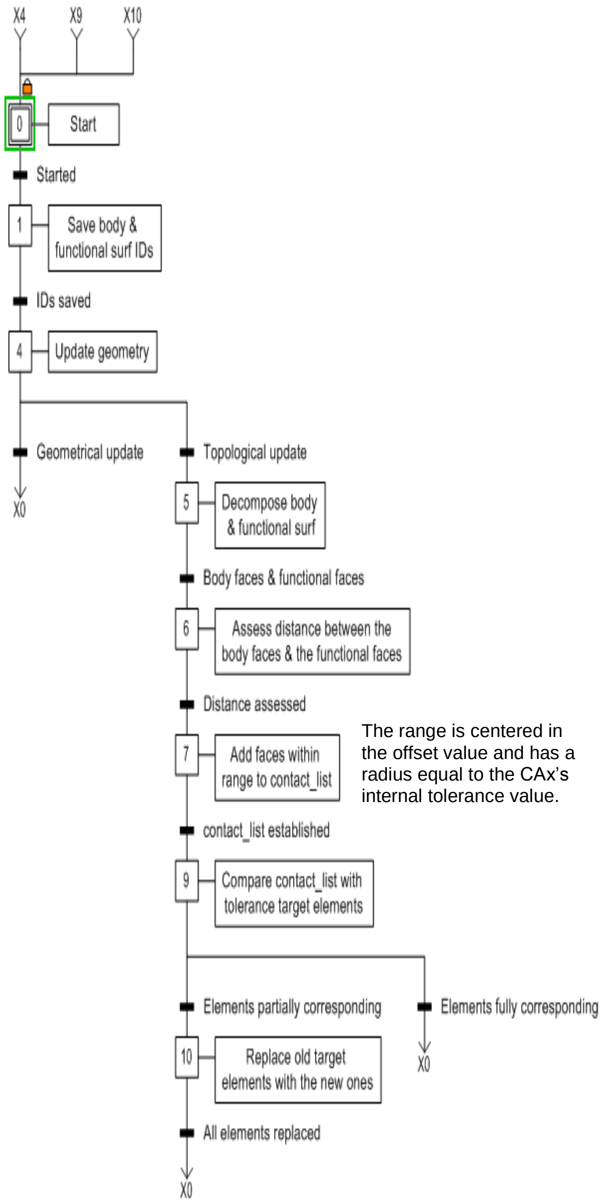

Fig. 7 Overall process of the methodology

6 Case study – NX Siemens implementation

This section is dedicated to expose how the new stabilized manufacturing information modeling approach was actually implemented in the scope of NX software (Siemens) and tested on a prototype thin-walled part undergoing topological changes. The 3D annotation studied is a Feature Control Frame (FCF) for surface profile tolerance (see Fig. 8).

The first step consists in retrieving the IDs of both the volume body and the functional surface. In NX, the ID of each geometric element is called “journal identifier”. Then, these IDs are stored within each corresponding 3D annotation’s properties (it is also possible to store it inside an XML file). Afterwards, a topological update is performed over the 3D model, leading to a change in the flange shape and consequently to a total loss of the tolerance information (see Fig. 8-b).

The second step is to retrieve the IDs of both the volume body and the functional surface from the FCF. Afterwards, the contact method explained in the previous section is executed. As a result, the "contact_list" is generated and contains the new boundary elements that must be toleranced. Once the "contact_list" is established, its content is compared to the actual tolerance target elements. These elements are stored in a NX collection called "associated objects" and which can be found in the properties of the FCF. Then, the comparison of the two sets of elements ("contact_list" and "associated objects") returns that the two sets are not fully corresponding. Indeed, Fig. 8-a shows that, by selecting the FCF, the geometric elements that are stored within the "associated object" are highlighted in red while Fig. 8-b shows that even by selecting the FCF, no face is selected; this means that the "associated objects" list is either empty or, in this case, that the list is filled with elements that are no more existing in the part. Consequently, the tolerance information must be updated and replaced with the new elements stored in "contact_list". This operation consists in linking the tolerance information to the appropriate boundary elements. However, it will not re-orient the leader of the 3D annotation's pointer to the right face. In order to correctly re-orient the leader's position, the distance between its actual position and the new tolerance target elements is measured; therewith the nearest tolerance target element is determined. Then its coordinates are attributed to the leader in order to re-orient it toward the nearest boundary element.

Finally, in order to be able to tolerance the upper faces of the flange instead of the lower ones, the value of the thickness of the flange has been attributed to the offset value. Indeed, when the user selects the functional surfaces, the tool pops up a window asking for the offset value. [10]

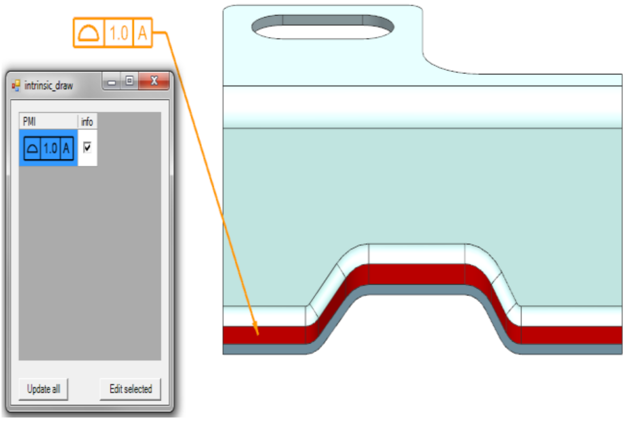

Fig. 8-a Before topological update

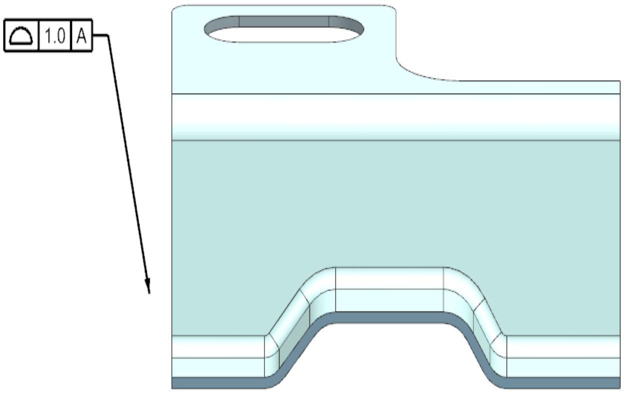

Fig. 8-b After topological update

7 Conclusion

This paper highlighted some stability issues in handling tolerance information within a 3D model. It has been exposed how the internal operating process of the CAx system can affect the stability of the 3D annotations, which is due to a lack of information about the functional purpose of each B-rep element. The different cases resulting from this instability were as well introduced (Fig. 3-b, 3-c and 3-d). An introduction about the template technology that is used to convey functional features about generic and reusable shapes was presented.

Hence, by exploiting the advantages of both the boundary representation and the template technology, we have proposed a solution able to fix the stability issue. Instead of considering direct links between tolerance information and individual B-rep elements with unstable references, we propose to connect this tolerance information to the B-rep elements that are derived from a template, this template provides a stable reference over subsequent part modeling steps. The general algorithm has been successfully embedded in NX Siemens software. It showed its ability to trace back the functional purpose behind each boundary element and exploit it in order to correctly reconfigure the unstable 3D annotations. By including the template technology, we were able to gloss over the boundary representation's disadvantages. Therefore, not only will it be possible to get all the functional aspects of the boundary elements but it will also allow keeping the internal representation of volumes used by the CAx systems. This will ensure that the 3D annotations will keep on being related and pinpointing toward the right boundary element even after topological updates.

Altogether, the solution allows the user to stabilize the 3D annotations within a 3D model after performing a topological update. Therefore, the main objective of this solution was to prevent information loss causing unnecessary cost and time waste at manufacturing time and to increase the design process productivity. An interesting asset of this solution is its portability, which means that it can potentially be applied to any CAx system. The implementation proved to be robust, not requiring the intervention of the user afterwards; this is unlike the actual methods which are specific to each CAx system and which require the intervention of the user to check the results after every update and correct it manually.

Currently, this solution has only been developed and tested over single parts. The current work is dedicated to expand the current solution into a more generalized context, able to handle assemblies by tracing the mating surfaces of different components.

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