Title:
An Approach to Support Model Based Definition by PMI Annotations

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Introduction:

Nowadays, the necessity to implement the paradigm of the Model-Based Enterprise (MBE) is a very common issue in many industries [6]. The development of hardware and computer graphics technologies allow to view a 3D model with a set of digital annotations and information throughout the product lifecycle [5]. The introduction of digital annotations marks the transition from 2D drawings to 3D representation in manufacturing and design companies. A 3D CAD model is considered as a source for delivering documentation and knowledge sharing [2]. Several ISO and ASME standards provide the specifications concerning the Model Based Definition (MBD) related to all extended 3D annotations such as Views, Product Manufacturing Information (PMI) and Geometric Dimensioning and Tolerancing (GD&T) [1, 4]. Generally, the task of adding annotations is assigned to designers. Before the introduction of digital annotations, the designer put dimensions and tolerances only in 2D drawings during the engineering phase. A CAD system was mainly considered as a tool to support the generation of 2D technical drawings [3]. Today, with the introduction of digital annotations, the designer has to add product lifecycle data on the 3D model in the modelling phase. Additionally, the digital information regards not only dimensions and tolerances but the whole product lifecycle (i.e. manufacturing, disassembly, energy consumptions, impacts, cost, etc.). Therefore, it is very important for the designer to pay attention and to take time when he defines the annotation in a digital model. Indeed, when the designer copes with similar 3D models, the definition of digital PMI annotations and GD&T could become a repetitive task.

The aim of the proposed work is to provide a method to generate PMI annotations in a 3D document by inheriting an existing PMI structure from a database of similar geometrical models. The database of 3D models with PMI annotations can be considered as a knowledge repository because much of implicit and explicit knowledge can be added through digital annotations. For example, in literature how to retrieve design intent in CAD models from digital annotations has already been evaluated [3]. Additionally, PMI tags can contain details and specifications regarding product design or manufacturing. Usually, they are attached to specific geometrical entities such as faces or edges, and the 3D workspace of CAD system is the domain of every annotation. However, commercial CAD systems do not provide tools to replicate a PMI annotation's structure from a 3D model to a similar one. Actually, many CAD systems fail to manage the updating of PMI annotations after the replacement of related components because they do not manage it. Furthermore, many researchers have proposed studies to enhance the use and implementation of digital annotations [3, 5]. Some examples show how to use 3D annotations for knowledge sharing [2], other works describe the limits of PMI annotations and how to improve their usability throughout the lifecycle management [6]. Nevertheless, in the literature studies about the possibility to inherit annotation's structures from similar models is lacking.

The described approach can be applied in all cases where the designer tends to reuse CAD models, but for different reasons cannot reuse annotations added in old documents. When a designer modifies/reuses a CAD model, there are several situations that limit the preservation of a PMI structure. As cited before, generally the replacing of an assembly component deletes the connections between annotation and geometry. Another case is when a designer models tailored components for a custom application but the delivered shapes are very similar to previous works. In all these cases and more, it would be useful to reuse a PMI structure already defined in previous digital models. The main advantage of this approach is the absence of the definition of knowledge-based rules because know-how is already intrinsic in annotations.

Main Idea:

The paper focuses on a geometrical analysis to define a tool to support the reuse of existing 3D annotations during the design phase of new models, such as parts or assemblies. The main idea is to inherit an annotation structure from a similar model collected in a database of previous CAD documents with PMI. Therefore, the proposed approach aims to enhance the reuse of knowledge in digital documents and reduce the time due to the modelling of annotations. A two stages analysis has been proposed. The first stage concerns the matching of similar 3D models using a geometrical and topologic analysis. The second stage regards the searching of equivalent geometrical entities to re-build PMI annotations in the new 3D model.

Fig. 1 shows the proposed workflow from a user point of view. The input is a new 3D model that could be a simple part, a sheet metal, or an assembly model. A geometric analysis gets the main information from geometry by a developed tool, in order to match it with data extracted from the database of CAD models. The database of models collects 3D digital documents with PMI annotations, as cited before.

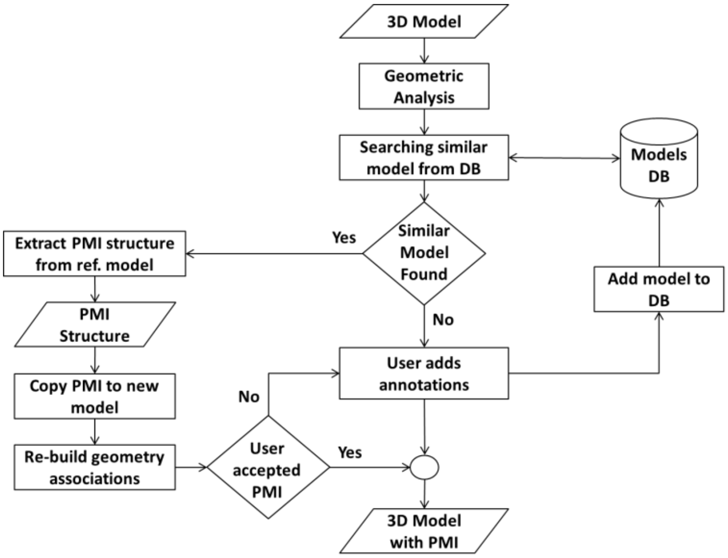

Fig. 1: The proposed workflow to re-use PMI structure in new models.

The comparison between parts is based on topology and geometry. It tries to recognize similar models without considering dimensions, because the searching aim is to find analogue models. Fig.2. describes an example of a short list of parameters evaluated in the proposed work. The comparison is between a reference model (Model A) and a geometry to compare (Model B). The score of similarity for each parameter is evaluated as the percentage of the absolute value Bn/An if Bn<An, otherwise An/Bn if An<Bn. In order to avoid numerical problems, the indeterminate form 0/0 has been evaluated with score 100% because that means the parameter analyzed is not present for both models. Otherwise, the form N/0 has been evaluated as score 0%. The total score is expressed such as the average percentage value of every similar score. As cited before, the approach compares the geometry of a model with many geometries collected in the database. A model is considered similar to another if these two conditions are true: it achieves the highest score of similarity and exceeds the minimum threshold value.

The conditions of similarity are experimental rules defined during the early analysis phase, where the algorithm was tested on different geometries regarding components like parts. The introduction of a minimum threshold value guarantees a level of reliability. This value has been considered like a parameter with a default value and the user can modify it. The minimum threshold is fixed to 90% for the matching of simple component parts. Thus, only similar scores higher than 90% were considered reliable, otherwise the model analyzed does not have similar geometries in the database. In this case, the annotations will be added by the user and then the 3D model with PMI will be added to the database of models.

List of parameters:	Model A:	Model B:	Score:
No. of edges	A1	B1	|B1 / A1|
No. of faces	A2	B2	|B2 / A2|
No. of hollows	A3	B3	|B3 / A3|
No. of convex edges	A4	B4	|B4 / A4|
No. of concave edges	A5	B5	|B5 / A5|
No. of pairs of parallel edges	A6	B6	|B6 / A6|
No. of perpendicular edges	A7	B7	|B7 / A7|
No. of right angles	A8	B8	|B8 / A8|
			% AVG

Fig. 2: Example of the geometric parameters analyzed for the matching of part models.

The case of the comparison between assemblies has been analyzed with additional conditions. In fact, an assembly model structure can be very variable. This implies a great difficulty in having a tailored PMI structure for many new CAD models to be generated.

The similarity analysis has been extended from a single part to the model tree structure. When two assemblies are compared, the components' structure of the one to be evaluated is matched with the reference one in order to obtain one of the four following options: the structure match is perfect, the reference model has less child components then the other one, the reference model has more different components then the reference one, or some components are in common but there are many differences between the two models. The proposed algorithm applies a weighted score in order to analyze all possible different cases. The matching analysis of an assembly model regards the analysis of three weighted scores: the similarity of the structures, the similarity of the parts' geometries, and finally the number of the leaf parts.

The extraction of a PMI structure from a reference model is performed by the tool developed during the research activity. Two matching analysis approaches have been analyzed. The first one used an advanced function based on a geometrical analysis in order to recognize entities between similar models. This algorithm takes into account the relative positions of entities inside the normal bounding box, normal vectors and alignments. The second approach aims to assign an identification (ID) tag to each face and edge. The ID assignment can be performed via programing language or manually on the CAD template models by the user.

Finally, the automatic assignment of a PMIs structure to a CAD document should always be reviewed by a technical user that validates the quality of the functions developed for the reuse of annotations. If a model requires some changes in the definition of annotations, it will be collected in the main database of models in order to enhance the further reuse of knowledge.

Test case:

The proposed method has been validated in the context of an oil & gas application. A power gas turbine requires a design of inlet and exhaust ducts with many details. The functional design of each duct is a configuration of many items and levels. A duct is a collection of flanged items and each item is structured in different functional levels such as the insulation level, the casing level and the arrangement level. The sheet metal parts and assemblies, which represent the level of a metal casing of a duct item, can assume different tailored shapes, but there are always some typologies of common structures used in different power plants.

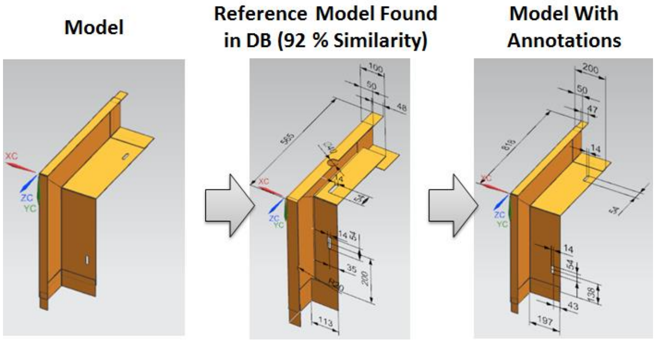

Fig. 3: Example of PMI inherited in an assembly model

The proposed method has been implemented as a prototypical tool within a CAD automation software called Duct Designer which aids the user to configure desired solutions of exhaust ducts by simplified layout. Fig. 3 shows an example of an assembly where the 3D annotations were reproduced by the proposed tool. Fig. 4 shows some examples of cladding components with PMI annotations. These parts were generated using the Duct designer software and the PMI structures has been applied using the PMI tool developed. The average success rate of the approach is about 85% for part components. An example of rectangular duct item is described in Fig. 5. The automatic generation of the annotations within assembly models has shown about 75% average success rate for assembly documents.

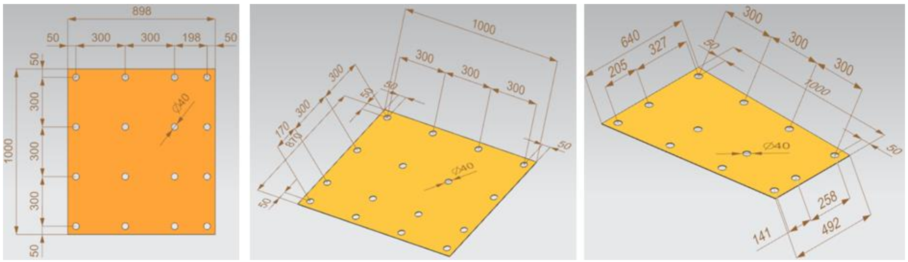

Fig. 4: Example of PMI annotations automatically added to cladding components.

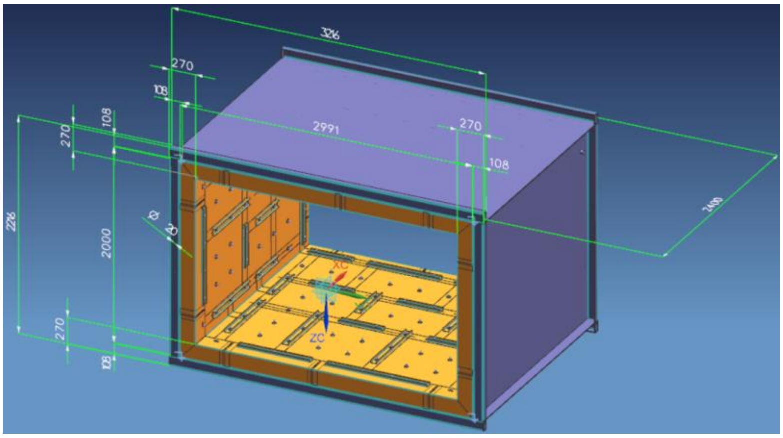

Fig. 5: Example of PMI annotations automatically added to a rectangular duct item.

Conclusions:

An approach to enhance the reuse of knowledge and best practices, held in digital 3D CAD annotations, has been proposed. The developed tool aims to overcome the limits of traditional CAD tools which are not able to add a PMI annotation's structure from one model to another one. The knowledge repository is represented by a collection of CAD models with annotations, thus the user is not required to define and formalize any design rules. A test case was performed on sheet metal parts and assemblies. The proposed method has been performed in combination with the design automation and configuration of oil & gas duct items, therefore the use of tools for adding PMI annotations has brought a great benefit in terms of reduced design time.

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