DMU Maturity Management as an Extension of the Core Product Model

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Abstract. Reverse Engineering (RE) of mechanical parts consists in creating a 3D virtual model using data that are often gathered by 3D measurement systems like laser scanners. The resulting point cloud is then transformed into a geometrical model. The purpose of RE activity is to make maintenance or redesign operations easier. The boundary of the literature is the component, isolated from its product assembly. Because of on-field maintenance, a long time running in-use product may not reflect its Digital Mock-Up (DMU) anymore. In order to maintain an efficient lifecycle, the changes made have to be considered. This paper focuses on the development of a knowledge-based RE methodology to support the DMU maturity management: to identify the maturity defaults, which correspond to unreported changes, in the CAD assembly model in order to make it matching the real product. That approach is supported by a Core Product Model data model extension.

Keywords: DMU maturity, product Reverse Engineering, product assembly, CAD, PLM, PDM

1 Introduction

Long lifetime products, in most cases, imply many actors with different expertise and often located in different places. The development project is lead in an extended enterprise way. To support that project, the Digital Mock-Up (DMU) is at the center of all exchanges flows. A DMU is not only a geometrical view of a product assembly; it is composed of several views, generally related to the different expert domains involved. Thus, DMU can capture geometrical and topological information, parameters linked to geometry, constraints and knowledge such as component manufacturing processes, assembly requirements or functional specifications.

In the Product Lifecycle Management (PLM), the DMU is intended to be the reference representation along the different development phases (as designed, as manufactured, as maintained, etc.). For new derivative product design or improvements, this representation is re-used to accelerate the beginning of the design process. But the DMU is hardly consistent when addressing maintenance or modification phases. Indeed, changes made on the in-use product may not be reported to the DMU which hence becomes obsolete. There is a gap between the real product and its virtual representation. This gap is a problem for the development contributors who need an up-to-date view. The differences between the two models are known as DMU maturity defaults.

Redesign or new design activity based on existing physical product is a matter which is treated in the scientific literature as Reverse Engineering (RE). RE consists in digitizing a real part in order to create a virtual model. Many application domains are related to it: competitive analysis, virtual prototyping, old product remanufacturing, maintenance or dimensional control. The classic way to RE activity is the geometric approach. The resulting model is often "frozen": it is made of surfaces or volumes that are not easy to modify and hardly propose parameterization. Redesign is then tedious; according to designers, the retrieved models are not suitable. Moreover, the actual RE methods only focus on one isolated component, not on assembly of components.

This paper describes a new RE approach to identify the DMU maturity defaults. The final aim is to replace the DMU at the center of the product development, as a reliable representation, as it is intended to be. After describing the context, a brief review of the RE technics is proposed in section 2. Then, the approach is detailed in section 3. In section 4, a data model as an extension to the Core Product Model (CPM) to support our method is discussed.

2 DMU Maturity in PLM and Reverse Engineering

In PLM (Product Lifecycle Management), one industrial need is to keep the DMU as representative as possible of the in-use product design. Indeed, as all the product development actors are distant, in terms of location or time, the DMU is the referential for insuring an efficient collaborative design. Some new products are close to previous ones, on the functions and/or the manufacturing process for example. A clever approach is to reuse the previous studies in the new product development, to accelerate the development process. But differences may exist between the DMU of the product and the in-use one, motivated by improvements or maintenance activities. They are important information that has to be considered for insuring an efficient product lifecycle management and for developing new derivative products. These changes are DMU maturity defaults. Two kinds of maturity defaults can be identified: the "natural deviation" before the product launch and the "on-field modifications". The paper purpose considering that problematic is illustrated in Fig. 1.

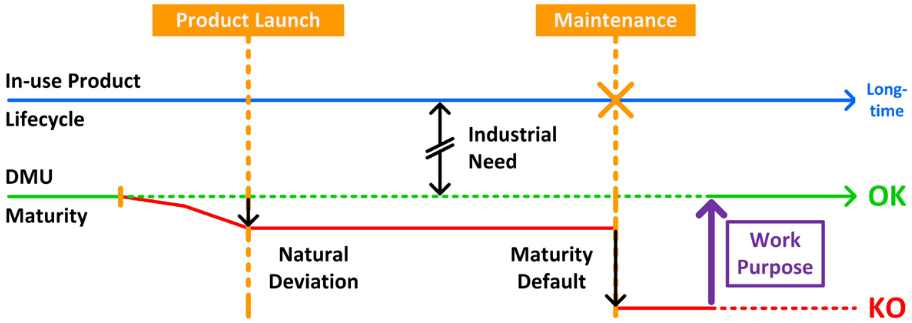

Fig. 1. The paper purpose: identifying DMU maturity defaults.

An ideal DMU management is to keep it as a parallel representation of the in-use product. The "Natural Deviation" stands for the differential between the "as-designed" product and the "as-manufactured" at the product launch. This is particularly true for products in automotive or aeronautic industries. The supply chain is one of the main causes of that differential: the subcontractors are no longer expected to assume specific components manufacturing but are expected to take an entire function in charge. For example, the "lighting" function of a car: the corresponding subcontractor will provide a sub-assembly bloc insuring that function. The car manufacturer just has to plug and settle it in the car; he doesn't need to know exactly the intern design. The "on-field modifications", identified as "Maintenance" in the Fig. 1, regroup all operations that affect the working product's design compared to the initial one in the DMU. As an example we can cite the replacement of an original connecting rod by a new one with an improved geometry. As it can be more significant changes, the deviation compared to the original design in the DMU is wider. In a concrete way, maturity defaults are considered as relative to the components: lack of, replacement, position changes, etc. This paper proposes leads of research for identifying the gaps caused by the modifications that are not reported in the DMU in order to update it.

The problematic can be compared to a Reverse Engineering (RE) activity which consists in retrieving information and representation of an existing product in order to reuse it in a new product development. The new development is then accelerated and more robust as expressed in [1]. Designers need to capture an "as-built" view from the real physical product. Reverse Engineering (RE) methodologies from scientific literature propose answers to that need.

The first historical studies are about retrieving surfaces in a point cloud [2]. The process is still used in some recent works. As an initial step, a point cloud is generated by scanning the physical model. Then, after sampling and filtering methods applied on the cloud, it is segmented in sub-clouds. B-rep surfaces are fitted on the sub-clouds. Sewing the surfaces is the final step to get a rebuild 3D model. That kind of approach is more suitable for artistic models because of the lack of parameterization: the resulting model is generally frozen and redesign activity is tedious. The rebuilt model is not suitable in a CAD context.

Considering that, some methodologies more appropriate to industrial context are then proposed. [3] for example, through the REFAB (Reverse Engineering-FeAture-Based) project propose to use a feature-based method. The principle is to recognize manufacturing features in a 3D model for process planning. A feature is then a collection of geometrical elements representing a specific manufacturing operation. The input data is still a point cloud. The user, after having defined the manufacturing features, specifies their locations on the input cloud. The system allows some relationships between features, mainly geometrical ones: concentricity, parallelism, etc. The features, as they are based on geometrical elements, allow some parameterization, which is seen as redesign possibility. But these approaches are limited to specific manufacturing domains.

More recently, another further step is proposed by adding knowledge to the RE process [4]. The principle to fit features on the point cloud is also kept but the features definition is extended. In [5], the authors assume that all the geometry of a mechanical part can be justified by a manufacturing process consequence or a functional specification. The approach is to combine geometrical description with design intents. The design intents are extracted from the knowledge embedded in the component. It's a two-step method. First, geometrical features, describing functional surfaces or manufacturing consequences, are identified in a 3D point cloud. Then, using a segmentation technic, the parameters of the geometrical features are valued by the fitting of the features in the cloud. Skin surfaces are finally generated on the features. As a main goal, the resulting model is closer to a CAD model from market software applications: features collected into a design tree driven by parameters allowing more redesign possibilities. Further technics propose to handle more heterogeneous data for knowledge extraction as pictures for example to conduct the RE activity [6].

The literature proposes lots of work but most of them are centered on a single component. RE for assembly products is not a well-covered domain. In the next section, we propose a RE inspired approach to support the DMU maturity management.

3 Research directions and methodology

To solve the problem of DMU maturity management, our approach consists in rebuilding an assembly model based on CAD parts used in the existing DMU that fits in the digitized in-use product. As expressed previously, maturity defaults correspond to areas where no matching is identified. We propose to determine an indicator of potential maturity defaults.

3.1 The shape approach

Considering the problematic context, two input data have to be treated:

- The in-use product which is real,
- The product's virtual representation.

The aim is to determine a way to compare that input data. Even though they are available into two opposite ways (real and virtual), at least one common criteria exists between them.

First, the real product. As explained in sec. 2, a classic way to get a virtual representation of a real component is to scan it with some devices like a laser. We propose to adopt the same methodology: the assembly is scanned as one model. Thus, a point cloud can be obtained. The classic RE process then proposes to generate surfaces for example in order to acquire a 3D shape model from the scanned one. The surface may be a triangulated surface, a mesh.

Then, the DMU of the product. As the DMU is handled by typical CAD software, it is available in different kinds of representation. In fact, the product's envelope can be extracted as an apart 3D model. The envelope can be made of B-Rep sewed surfaces. These surfaces are suitable for a meshing process.

Assuming that we can generate a mesh on the input data, one common criterion is available: the *shape form*. The literature directly concerned by *shape description* is the *shape matching* domain. It is a well-covered literature span, offering lots of possible methodologies [7]. The main principle is to represent a shape by a compact and easy-to-generate shape signature based on different aspects of the considered 3D model as its geometry, its topology, its function, etc. Among them, the *Reeb graph* [8] presents some special interests.

A Reeb graph (RG) is a representation of the evolution of a mathematical function defined on a shape. It is a compact shape signature describing the topological connections between the 3D model parts of the considered model shape. These parts are defined by the level sets of the function. Reeb graphs can be displayed as 3D skeleton geometries made of nodes connected by edges or as 1D oriented graphs (Fig. 2).

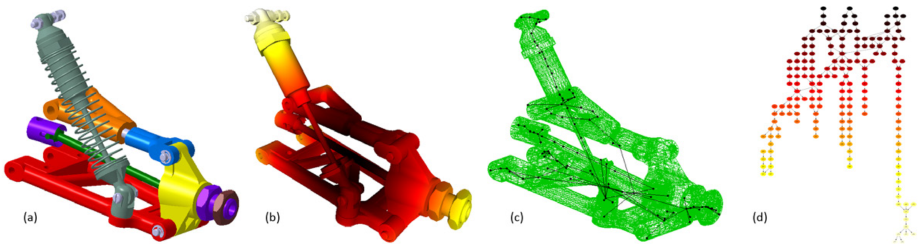

Fig. 2. Example of a Reeb graph generation on a suspension (a): (b) is the evolution of the function applied on the meshed shape, (c) is the 3D rendering of the RG and (d) is the 1-dimensional representation.

The RG has a key property: the appropriate choice of the function makes the graph insensible to the poses of a 3D model. The pose for a model can be seen as the relative positions and orientations of the parts composing the product assembly at the digitization time. As it is scanned as a single component, that property is suitable.

Digitizing assembled parts as a single part with laser scanning device implies a major drawback. As the resulting point clouds reflect the exterior envelope of the system, the internal contact surfaces between the different parts are not acquired. The notion of "component" does not exist in the RG generation context. The RG is inherently generated on the external envelope of a 3D model. The RG of an assembly of components is not the "assembly" of the RG of these components (Fig. 3).

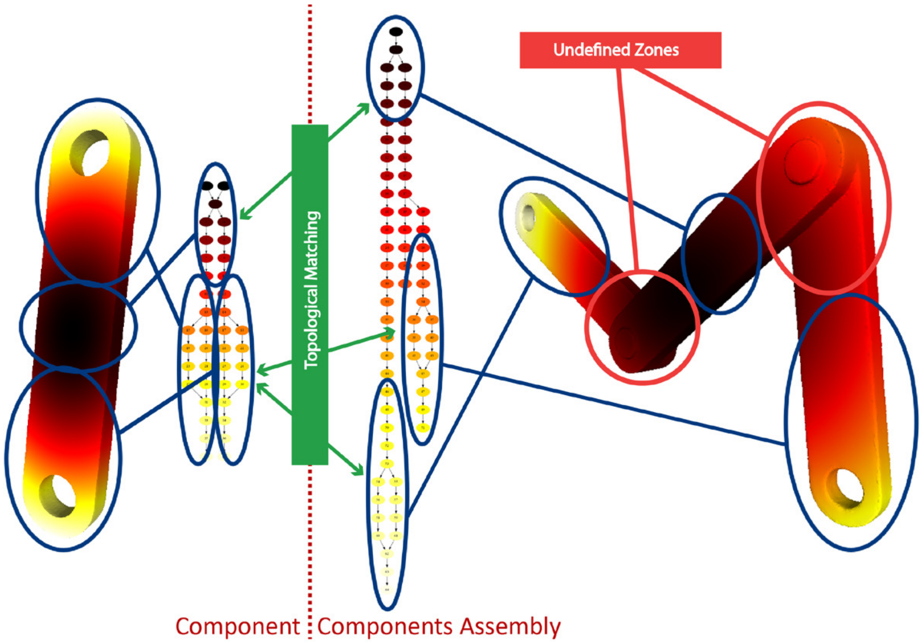

Fig. 3. Partial shape matching between the RG of a single connecting rod and the RG of 3 linked connecting rods.

3.2 The knowledge extraction

Using RG "as it is" is not a sufficient way to describe a mechanical system in DMU context and identify components within it: non-topological and non-geometrical information are not managed. Therefore, it is clear that the RG must be enriched with information that does not only belong to topology or geometry. We propose to add specific information to the shape description. The enrichment comes from "non-directly seen" characteristics that come from manufacturing processes, system functions, etc. This paper does not propose this enrichment but assumes that this enrichment is enabled. Knowledge can be extracted from relationships between components. Our actual research direction consists in describing and characterizing a mechanical system by its relative movements. As a matter of facts, it is often a requirement for calculating product characteristics such as efforts, speeds or paths. As we consider mechanisms, the products should have possible movements. The representation of the links between groups of components in our scenario will therefore be based on the kinematic chain. The kinematic chain is a representation of the knowledge relationships embedded in a mechanism. In our simple use case of 3 connected rods, the kinematic chain is composed of 2 mechanical links: 2 revolute pairs.

As shown in Fig. 4, the kinematic chain brings some information where the topological description is not useful. The kinematic pairs locations correspond to undefined zones of the meshed scan data.

We assume that using such kind of complementary information based on knowledge as additional criteria is a lead to perform an effective DMU maturity diagnostic.

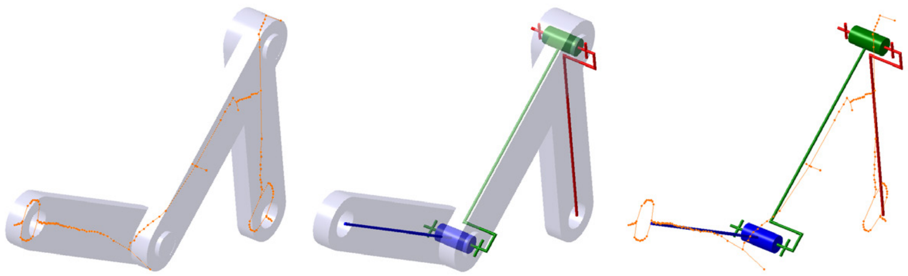

Fig. 4. Example of knowledge information addition to system description.

3.3 The proposition

A typical process scenario is shown in Fig. 5: a workflow illustrating the part recognition scenario in a meshed digitized as-build product.

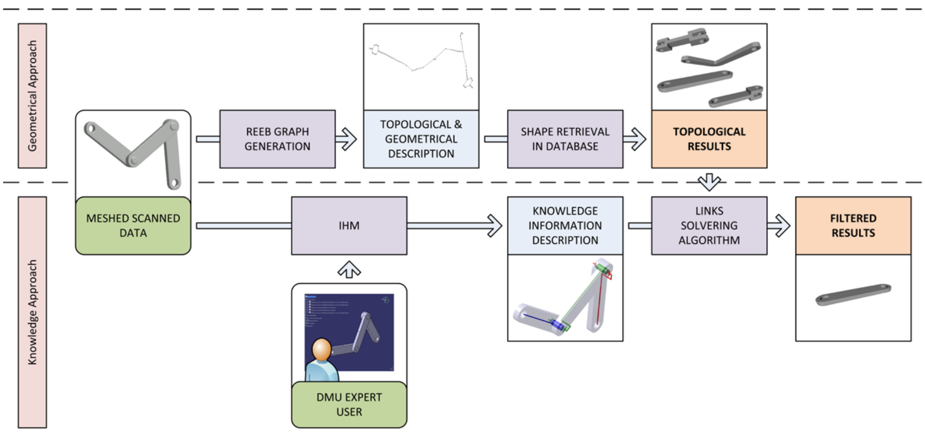

Fig. 5. Example of a process workflow for the proposed approach.

We propose an assisted approach with an interactive interface. The user is an expert who knows the considered product. In this process, we assume that a previous comparison has been made by the expert user. In a macro way, the DMU RG and the scan RG have been compared. The similarity result is used as an indicator: he suspects the presence of maturity defaults. The current activity is to determine which parts are present and which are not, based on the Bill Of Materials (BOM), extracted from the DMU. With the approach described in sec. 3.1, using the mesh RG, potential suitable parts are retrieved from the PLM system database. The RG matching process gives an approximate location for each part. The identification criterion is topological with linked geometry. Then, with the interactive interface, the user adds knowledge information on the mesh, as detailed in sec. 3.2. In this case, the user generates the kinematic chain, identifying kinematic links and their location. Using that information, a linkage matching algorithm is executed with two inputs: the list of potential suitable parts and the kinematic chain. Based on the functional surfaces of each potential component, the algorithm determines a filtered list of potential parts and locates them in the mesh with the approximated locations previously identified. The algorithm emphasizes areas without corresponding parts. These areas correspond to part changes (because of a different geometry or a lack or a different location), the maturity defaults as we defined them.

4 Data model

The aspects discussed in the previous section have to be managed. In fact, the whole concept introduces a new object type to handle: the *abstraction*. An abstraction is a representation of a product (assembly or part) focusing on specific aspects isolated from the rest. Thus, two kinds of abstraction can be distinguished:

- The shape abstraction, based on geometrical and topological description,
- The knowledge abstraction, based on the knowledge extraction.

The CPM (Core Product Model) [9] data model is intended to be a basis-level product description for capturing all product information shared during a product development process. The main principle is to provide a generic, non-proprietary and expandable data model allowing interoperability with other models from market software or application in PLM and XAO domains as CAD for example. The Open Assembly Model (OAM) is one of the existing extensions of the CPM [10]. Its aim is to provide handling for assembly context, which is not managed in the original CPM. The proposition for a data model supporting our approach is shown in Fig. 6. The DMU is managed by the existing framework proposed by the CPM and its OAM extension. With the Shape Abstraction Model (SAM), we propose to support the DMU maturity identification by handling *product abstractions*. Only specific data relative to DMU maturity management have to be added to the original design of the data model. As it is a key element in our approach, **Abstraction** class is defined as a specialization of the **Artifact** class from the basic CPM. Its specialized classes dedicated to handle the two types of abstraction as described in section 3: the Reeb graph in the **ShapeAbstraction** class and the kinematic chain in the **KnowledgeAbstraction**. The first one is a signature description of a part or assembly shape. It allows making a direct link between the **Part** and **Assembly** form the OAM extension and **Form** from the CPM. With this signature, the parts and assemblies can be retrieved in a database as in classic 3D shape retrieval methods [8]. Defining the Reeb graph as a specialization from the **ShapeAbstraction** class permits to add other kind of shape descriptors. The second abstraction is a description of the relationships between the parts associations in a product assembly and the intended functions. In mechanical systems, the parts associations are designed for specific functions. Thus, the SAM extension proposes to link the **Function** class from the CPM to the **ArtifactAssociation** class from the OAM extension. As the aim is to identify and gathered the changes made on an in-use product and report them to the DMU, it is necessary to save the justification of the DMU updates. The SAM does not need to handle that information, there's already a product evolution management in the CPM with its PFEM (Product Family Evolution Model) extension. A link exists between the **AssemblyAssociation** class and the **DesignRationale** justification class from the PFEM extension.

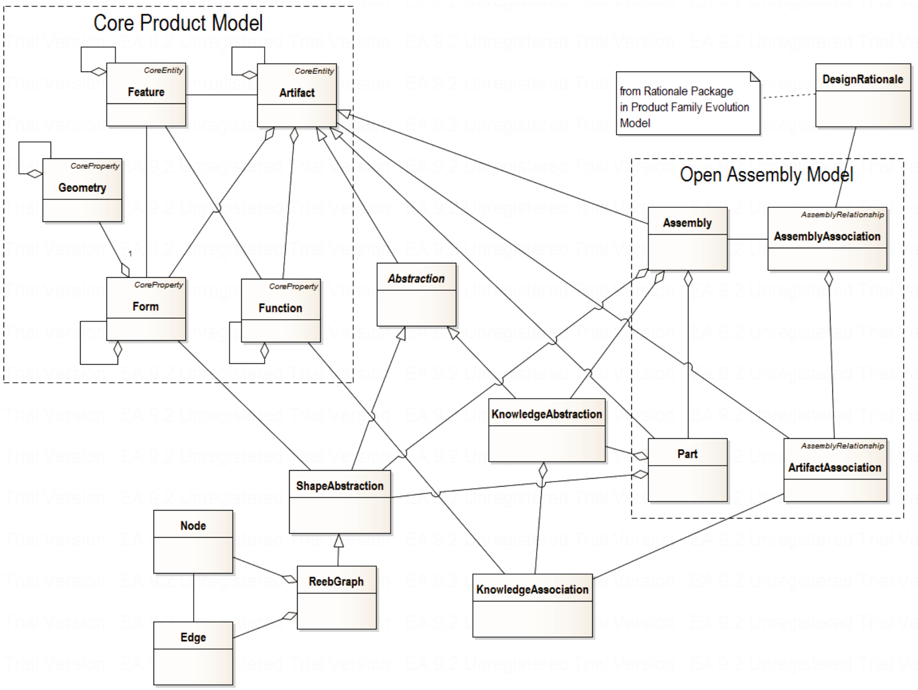

Fig. 6. The SAM (Shape Abstraction Model) extension supporting the proposed approach.

5 Conclusion

For maintenance, improving components or developing new derivative products, keeping an up-to-date view of in use long lifetime products is mandatory. The main advantage of using the DMU is to allow contextual design (each new component is designed considering its environment). The DMU maturity management is a scientific challenge that the approaches presented in this paper are intended to address. We assume it can be solved by an interactive RE activity driven by a product expert. The expert's aim is to identify the missing, moved or replaced parts by rebuilding the vir-

tual representation of the product from its digitization. The proposed methodology combines a geometric approach and a knowledge extraction in a reverse engineering way. The topological description is used as hint of maturity defaults presence. The methodology is supported by the CPM, its extensions and a new addition, the SAM extension, for managing the new kind of data handled: the abstraction.
Further works will focus on defining other kind of information to be extracted as knowledge. The application perimeter is another way of improvement to consider. The proposed method will be extended to systems that are not specifically mechanical ones but larger scale systems such as welded structures or factory implantations.

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References

1. Troussier, N., Bricogne, M., Belkadi, F., Durupt, A., Ducellier, G.: An extension of the Core Product Model for Reverse Engineering. In: 7th International Product Lifecycle Management Conference, PLM10. Bremen (2010)
2. Várady, T., Martin, R.R., Cox, J.: Reverse engineering of geometric models - An introduction. CAD Computer Aided Design, Vol. 29, No. 4, pp. 255-268 (1997)
3. Thompson, W.B., Owen, J.C., De St. Germain, H.J., Stark Jr., S.R., Henderson, T.C.: Feature-based reverse engineering of mechanical parts. IEEE Transactions on Robotics and Automation, Vol. 15, No. 1, pp. 57-66 (1999)
4. Fisher R.B.: Applying knowledge to reverse engineering problems. Computer Aided Design, Vol. 36, pp.501-510 (2004)
5. Durupt, A., Remy, S., Ducellier, G., Derigent, W.: A New knowledge based approach for the reverse engineering of a product. In: Marjanovic, D., Storga, M., Pavkovic, N., Bojcetic, N. (eds.) 10th International Design Conference, Design 2008, Vol. 1, pp.753-760. Dubrovnik (2008)
6. Laroche, F., Bernard, A., Cotte, M.: Advanced industrial archaeology: a new reverse-engineering process for contextualizing and digitizing ancient technical objects. Virtual and Physical Prototyping, Vol. 3, No. 2, pp. 105-122 (2008)
7. Reeb, G.: Sur les points singuliers d’une forme de Pfaff complètement intégrable ou d’une fonction numérique. Comptes Rendus de l'Académie des Sciences de Paris, Vol. 222, pp. 847-849 (1946)
8. Tangelder, J. W. H., Veltkamp, R. C.: A survey of content based 3D shape retrieval methods. Multimedia Tools and Applications, Vol. 39, No. 3, pp. 441-471 (2008)
9. Fenves, S.J., Foufou, S., Bock, C., Sriram, R.D.: CPM2: A core model for product data. Journal of Computing and Information Science in Engineering, Vol. 8, No. 1, 014501 (2008)
10. Sudarsan, F., Fenves, S.J., Sriram, R.D., Wang, F.: A product information modeling framework for product lifecycle management. Computer Aided Design, Vol. 37, pp. 1399-1411 (2005)