WHAT IS THE CONTENT OF A DMU? ANALYSIS AND PROPOSAL OF IMPROVEMENTS

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Abstract:

A Digital Mock-Up contains a set of component. What are the possible treatments that can be derived from this model? An analysis of the DMU content is performed to answer this question and show the lack of consistency in a DMU explaining the difficulties in performing automated treatments to derive technological and functional information about components.

Then, a first set of proposals is described, aiming at improving the consistency of DMUs and making possible the automated treatments to derive functional information of components from conventional interfaces between components.

Mots clés: assembly, DMU, CAD

1 Introduction

Assembly models are widespread and key elements in Product Development Processes (PDPs) where they often form reference data for companies. Design reviews strongly rely on assembly models to assess design solutions and modifications. Such reviews use Digital Mock-Up (DMU) software tools, which are widespread in automotive, aerospace and naval industries. Current DMU tools are used to virtually examine assemblies: components layout examination, interference checking, space allocation/evaluation, assembly process design, maintenance task design, kinematics simulation, immersive simulations, and visualization of data attached to components such as finite-element analysis results. A DMU is often processed to prepare FEA calculations for the structural behavior simulation of a whole assembly, or to generate a fluid domain around a general wrapping / envelope for thermal convection or CFD in the context of aerodynamics and thermal comfort simulations. However, processing DMUs for the above purposes is very tedious.

A DMU very often reduces to a collection of 3D models which are spatially positioned to represent the product shape being developed. Very few technological information / functional data can be processed to automatically generate kinematics, assembly processes, rigid and flexible body dynamic simulation. Analyzing the geometric content of DMUs as encountered in industry is a starting point to structure assembly models so that they can incorporate technological / functional data that can be processed to support more efficiently design reviews as well as a PDP.

Form features and features have been set up extensively to structure component models and help processing them at various stages of a PDP [1]. Often, the user has to add external information to define features or form features, which is efficient but may increase the overall model processing time because feature parameters must be specified interactively. Generally speaking, adding technological data to components or assemblies is efficient [1, 2] if small amounts of input data are enough to significantly reduce the combinatorial complexity of assembly processing. Following this approach, a key issue appears that would be to identify the core data (technological, mechanical, etc.) from which feature parameters, attached to components or assemblies, can be derived using technological, mechanical, or other properties.

A design review stakeholder checking geometric interferences in a DMU is subjected to a large amount of false positive results because standard connections between components representations are often idealized, e.g. an idealized representation of threads can cause an interference between cylinders representing internal and external threads. Using a conventional representation for standard parts would enable DMU analysis tools to discard idealized screw assemblies from the whole set of interferences rather than false-positive clashes.

Enriching DMUs with relative mobility between components is needed to configure rapidly DMUs for immersive simulation operations with haptics [3-4]. Collision detections in pin-hole assembly configurations are among the cases where facetted models create undesired haptic behavior when pin and hole diameters are too close to each other, thus requiring assembly model transformations to obtain acceptable simulation results, which could be automated using relative mobility information.

Here, the paper addresses particularly the current content of DMUs and analyses various aspects with regard to their overall consistency and how their content is structured and can be used to infer automatically functional or technological data of assembly features. This analysis is at the origin of some proposals contributing to an improved consistency of a DMU: a first step toward a really consistent DMU model. The paper is organized as follows:

- Section 2 describes the content of a DMU, including industrial practices and facts observed for assembly representations. A strong emphasis is put on the coherence between DMU representations of given standard components and overall consistency of this DMU.
- Section 3 proposes improvements of the 3D models and spatial positioning to infer components functions, and component specifications.

2 Analysis of the DMU content

CAD modelers are used in industry to define the DMU using a set of entities:

- The component, representing the shape (geometry and topology) of an elementary part of the product,
- The location and orientation of components in the DMU reference frame,
- Attributes associated to each component like its name, color, etc.

A *component* can be either:

- An elementary component, considered as a non-decomposable one,
- A subassembly, i.e. a set of components grouped through a criterion.

2.1 Components' geometric representation

Considered components are volumes defined as B-Rep models, composed of faces, edges, and vertices. The geometry of faces is based on canonical surfaces (plane, cone, torus, cylinder, sphere) and NURBS for free-form surfaces. The geometry of edges is based on canonical curves (circle, line, ellipse), and NURBS for free-form curves.

In industrial DMUs, standard parts such as seals, gears, and bearings, are often imported from their manufacturers' catalogs available through online libraries or DVDs. These catalogs provide components in native CAD formats as well as standard exchange format. However, the catalogs analyzed provide native CAD formats without any design features or history tree of the part, when the part is imported as a single B-Rep to form one component of a DMU and then, saved in the native CAD format.

Traceparts.com, a component library, [5] is commonly used in small and medium industries who are not constrained to specific technology requirements for their products compared the automotive and aeronautic industries where standard components are driven by their specific needs. By analyzing the content of standard parts libraries, it can be determined whether CAD models designed by manufacturers feature some uniform representation rules for threads, bolts, nuts, rivets, etc.

Firstly, we found that all parts manufacturers use the same simplified representation for screw threads, i.e. a cylinder whose diameter is equal to the nominal screw diameter d (see Figure 1) while they represent screw heads with detailed shapes characterizing the screwdriver (Slot, Square, Hex, Cross, etc.), chamfers, with true dimensions (see Figure 1). This convention, though simple, leads to a representation identical to any cylinder bearing surface of shafts.

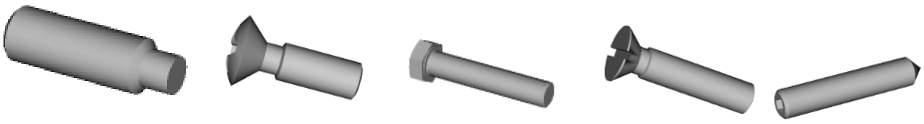
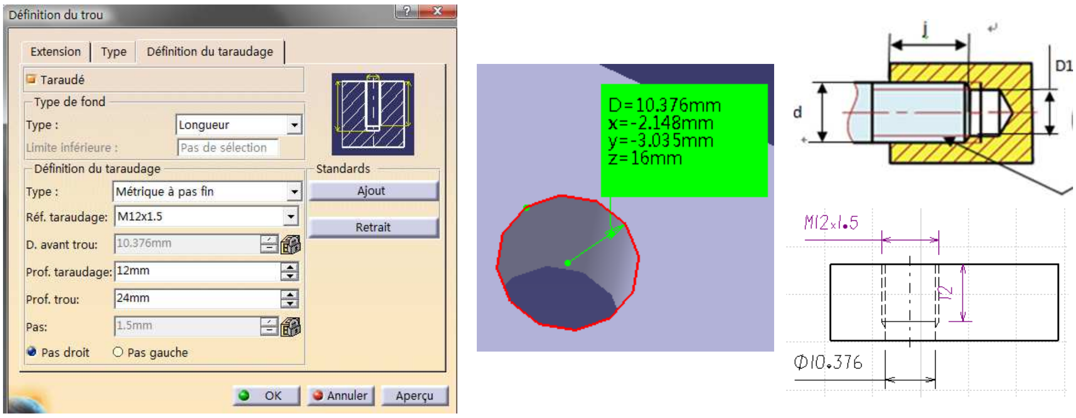


Figure 1 CAD parts of screws provided by manufacturers on online part library Traceparts.com

Secondly, we observed that most CAD modelers propose hole generation assistants to produce threaded holes (see Figure 2). All CAD modelers simply represent threaded holes by a cylinder, whose diameter is either the drill diameter D_2 or the minor diameter of the threaded hole D_1 (in the ISO standard NF E 03.001 / ISO68, $D_1 = d - 1.0825\,p$ and $D_2 = d - p$ where d is the screw nominal diameter, p the pitch size). Thus, the 3D representation of a given threaded hole can differ according to the CAD modeler used to represent the DMU, leading to the first lack of uniformity. It is worth noting that CAD modelers do not necessarily represent graphically thread features with a specific texture or shape.



Définition du trou

☑ Taraudé

Type de fond
Type : Longueur
Limite inférieure : Pas de sélection

Définition du taraudage
Type : Métrique à pas fin
Réf. taraudage: M12x1.5
D. avant trou: 10.376mm
Prof. taraudage: 12mm
Prof. trou: 24mm
Pas: 1.5mm
● Pas droit ○ Pas gauche

D=10.376mm
x=-2.148mm
y=-3.035mm
z=16mm

Figure 2. Representation of a threaded hole in CATIA V5.

All manufacturers represent threaded holes of nuts by simple cylinders (see Figure 3), but their diameter also vary from the drill diameter D_2 to the minor threaded hole diameter D_1. This shows that parts manufacturers don't follow specific rules to represent components in 3D.

Figure 3. Representation of nuts found in Traceparts.com

The representations of deformable components, like grower washers or tooth lock washers, are even more problematic, since manufacturers represent them either in their released state, or in a deformed state, which simplifies their shape down to canonical functional surfaces (see Figure 4).

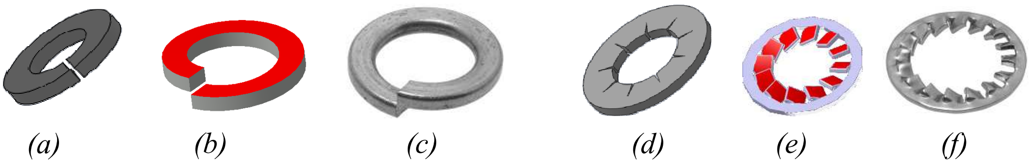


Figure 4. Representations of a grower washer in (a) constrained planar state (b) released state (c) photography of the released state; Representations of a tooth lock washer in (d) constrained planar state (e) released state (f) photography of a released state

When focusing on other components like rivets, seals reinforce the above observations.

2.2 Definition of the location and orientation of components

In a DMU modeling process, the location of each component can be specified by a set of geometric constraints between user selected surfaces of different components lying in the same subassembly. Most of the time, canonical surfaces are used to set up geometric locating constraints, because these basic surfaces are characterized by their axis (cone, cylinder, torus), center points (sphere, cone), dimensions and directions (plane) that enable the definition of coaxiality, coradiality, perpendicularity, parallelism, coplanarity, coincidence, etc. It is much more difficult to set up geometric positioning constraints between free-form NURBS surfaces that only enable coincidence and tangency at pre-defined points.

To set up geometric locating constraints, users can select surfaces as well as axes, and points defined on canonical surfaces or construction entities. Often, the user selected surfaces are functional surfaces but this is up to the user and may differ from one component to another in the same assembly model.

It must be noticed also that maintaining geometric constraints can become very difficult to handle when assembly modifications are performed. Effectively, when a component modification takes place, several geometric constraints may become invalid. Thus, it can be tedious, time consuming and difficult for a user to set up an updated set of constraints when an assembly has several hundreds of components and even more geometric constraints. In a DMU, constraints are often reduced to a translation and a rotation of each component's local frame in the reference frame of some subassembly or of the assembly. In this case, component positions are defined with respect to the reference frame hence, they are independent of each other and there is no geometric constraint between the components. This latest solution is commonly used in aeronautics and in the automotive industry to represent large and complex products without facing the difficulty of identifying all the constraint involved in a modification. Because there is no geometric constraint, relative position of components may be subjected to errors, which can be hardly detected.

Nevertheless, none of the two possible methods rely exclusively on the areas of contact between two components, while this information represents intrinsically the mechanical linkage between the functional surfaces of two components.

The relative position between components has no unique solution, for example a tooth lock washer can be positioned with teeth in contact with the screw and the plate (see Figure 5(b)) or an interference between screw and plate (see Figure 5 (c)). The tooth lock washer can even be represented in a flattened configuration, which produces a position similar to Figure 5b with a contact rather interfering with screw and plate. Observations of component libraries show that a key issue is the ease of insertion of a component in a DMU, i.e. to position it correctly with respect to its neighboring components using easily specified geometric constraints.

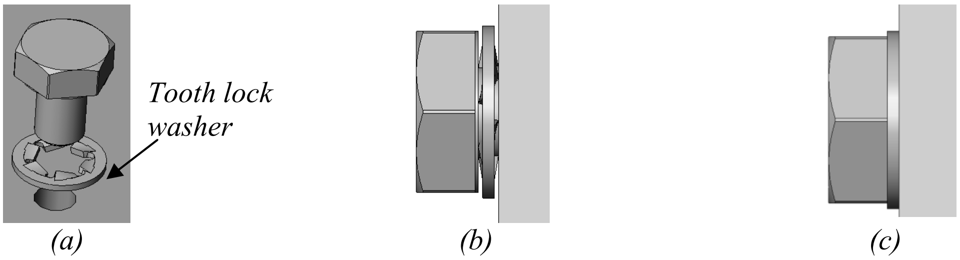


Figure 5. Different positioning constraints between a hexagonal screw, a tooth lock washer, and a hole (a) exploded view (b) screw and plate contact against the extremity vertices of the teeth (c) screw and plate interferences with the tooth lock washer.

Rivets are joint components submitted to plastic strains, which can adapt to two thin shells having non-planar surfaces as contact areas. In reality, the rivet shape deforms following the contact surface of the shells, while its CAD representation in the DMU can be in a deformed state (see Figure 6) or an undeformed one. In the case illustrated in Figure 6, the rivet has been positioned by (a) creating a plane tangent to the cylindrical shell adjacent to the rivet head (b) inserting a coplanar constraint between the rivet head and the plane. Choosing deformed or undeformed component state is strongly user-dependent and there is no strong criterion appearing to select either of these states. Consequently, a DMU can rely on a collection, not necessarily consistent, of criteria and component states differing from one component to the other.

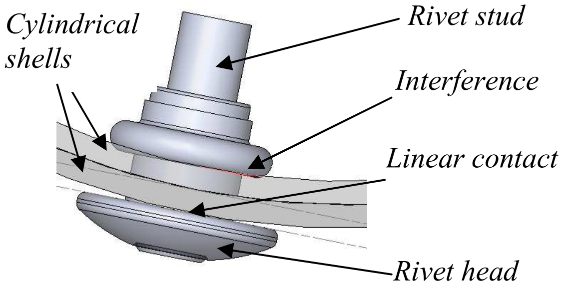


Figure 6. Rivet represented in a deformed state, having an interference stud-shell and a linear contact head-shell.

2.3 DMU structuring: subassemblies defined as components lists

The structure of a DMU is obtained by grouping components with a given criterion. This criterion is defined by the designer or prescribed by company methodologies. It is implicit because it is not available as an attribute of a sub-assembly. As an example, components can be grouped together so that they can be handled simultaneously and turned upside down without separating: this criterion is based on kinematic properties of the component set. In addition, it should be mentioned that implicit criteria may lead to non uniform assembly configurations, i.e. in the same assembly, the criterion used for a subassembly may differ from the one assigned to another subassembly.

The set of components is represented as a tree structure where leaves belong to elementary components, and nodes are subassemblies, and the root is the whole product. In the current CAD software, this tree is unique for a given product in a given product file, even though this product structure may need to be reorganized to meet the requirements of different PDP stages [6]. This highlights the fact that the tree structure needs not be unique and multiple criteria take place for an assembly. PDM systems offer possibilities to derive several tree structures for a given product, which requires specific software development for setting up the data structures and the procedures to store and process these tree structures.

Even though tree structures are the only category of data structure available to describe an assembly, it does not mean that users can correctly describe an assembly structure under any type of criterion, e.g. if the decomposition criterion is a kinematic criterion and the assembly is a mechanism, the product structure is a loop, which cannot be described with a tree structure.

2.4 E-BOM, designation of components

Here, the term « semantic information » designates technological information, kinetic properties, and functions of components. Indeed, it is used here as a generic designation for non geometric information.

Such semantic information is necessary throughout the Product Lifecycle Management (PLM) phases, thus, different CAD systems allow for keeping a track of those pieces of information to facilitate the design, manufacture, and maintenance of a product. Moreover, standard data exchange formats, such as STEP AP214 [10] and STEP AP203e2, permit the existence of different semantic information alongside the geometrical representation of the product. However, those standards do not define any norms about how such semantic information should be represented. Efforts have been paid to unify such representation by recommending best practices to facilitate the communication between different software modules [6, 8, 9]. Nevertheless, those recommendations are still based on plain character strings representation of properties, leading to ambiguous interpretations in most of the cases. In AP214e3 [10], basic features are available such as ‘BOSS’, ‘POCKET’, ‘JOGGLE’, etc. All these feature instances are part of some component geometric model and hence, contribute to the definition of its boundary at some step of its modeling process. Therefore, the geometric entities (key lines, e.g. circles) and parameters, e.g. height, have all been processed through the geometric modeler to ensure their geometric consistency with respect to this component boundary since relationships can be set up between them and several surface patches forming a subset of this component boundary.

A ‘THREAD’ [10] feature is also proposed that contains, among other parameters, ‘thread side', 'major diameter', 'minor diameter', 'pitch diameter', 'number of threads', 'hand' parameters. Compared to the above features, these parameters are not all connected to the component geometric model. Consequently, their geometric impact has not been validated at any point of the product modeling process. These parameters act more as annotations independent of the geometric model of the component rather than real parameters of a geometric model.

Furthermore, and when analyzing CAD systems’ behavior, we observed that most of the non-geometric data are casted off when exporting the model to or importing it from a standard exchange format, making no use of the recommendations and best practices. This leads to a loss of information even when importing then exporting to the same software, not to mention the incompatibility across different CAD systems.

E-BOM (Engineering Bill-Of-Materials) reflects the product as designed by engineers, with the list of components and their part number, material, and designation. However, E-BOM data provides little semantic information on components. Furthermore, and as demonstrated above, its access and format are not standardized. There is no guarantee of consistency in the component designations because it reduces to a user-defined character string. Hence, functionally identical components, though slightly differing in shape, can be assigned different designations, which shows how the consistency of an assembly with respect to a criterion uniquely relies on the designer's analysis. Similarly, components having the same shape can contribute to different functions, whether their designations are similar or not.

2.5 Synthesis. Conclusion

As a synthesis of the above analysis, assembly models currently described in a CAD context essentially rely on user-based consistency checking, i.e.:

- if the user upload components from a standard component library, it is up to him/her to make sure that interferences, contact areas resulting from the product assembly configuration are meaningful and acceptable,

- if one or several users, because of the collaborative work involved in the generation of a DMU, unintentionally insert components using different principles (see Figure 5), this DMU may contain inconsistencies that can be hard to detect. Because there is no DMU consistency check when generating an assembly configuration, it is up to the user to make sure that the choice of relaxed/deformed component models together with their assigned locations, result in a consistent DMU where interferences and contacts are not reflecting any functional problem,

- if centre distances locating holes in two different components are not equal, tools like commonly available interference detection algorithms may not be useful to detect such configurations since interferences generated by screws may exist whether centre distances are identical, i.e. the DMU is valid, or not, i.e. interferences due to threaded areas are not tubular-shaped. Consequently, it is only through visual and dimensional inspections, locally performed by the user, that he/she can detect inconsistencies/validate the DMU,

- etc.

The tree structure of a DMU entirely relies on designers' criteria, which may not be consistent among themselves and across the subassemblies and components forming the DMU, e.g. functional or kinematic decompositions. Similarly, E-BOM and feature-based information, like the 'THREAD' analyzed at section 2.4, that are attached to DMU components do not enforce the consistency of the DMU since this information is input by designers but never processed for consistency with DMU functions and 3D component and DMU models, respectively.

As highlighted by the previous subsections and the above synthesis, a DMU may suffer from possible inconsistencies regarding the functional description of assemblies resulting from the abovementioned geometric inconsistencies. It is therefore difficult to develop algorithms that could efficiently process assemblies for inserting functional, technological, mechanical information to process these models.

We've seen so far that designers of DMUs tend to simplify the representation of the product in certain situations such as highly detailed zones like threaded parts of a component, or deformable object such as elastic/plastic parts. Those idealizations compromise the accuracy of the geometric model for the sake of simplicity of representation. However, the loss of accuracy doesn't necessarily imply a loss of information, as those idealizations are applied to standard components where missing parameters can be inferred from the idealized representation itself, that is:

- either through the interfaces resulting from the idealized representations and the relative position of their neighboring components,

- or from associated annotations to the component when they have been subjected to consistency rules with the 3D model of these components and, possibly, their neighboring components.

Unfortunately, manufacturers and part designers so far use different approaches of representing idealized parts and transferring technical or functional information about different components. This lack of uniformity leads to ambiguous interpretations when trying to analyze a DMU to figure out certain properties of a component or an assembly.

Our DMU analysis and propositions aim at a adding more consistency between functional, technological, mechanical information and geometric properties of DMUs so that properties and algorithms will emerge to contribute to an improved and more automated consistency of DMUs. Our purpose is to stay close to current industrial practices, study the level of consistency reached to help designers adapt while taking advantage of more consistent DMUs. The long-term goal of our project is to ease the automation of functional analysis through inference mechanisms deriving component functions.

3 Proposals for DMU modeling improvements

For sake of space, this section is a short outline of the proposals with a restricted set of arguments to keep up with the paper length requirements.

3.1 Conventional idealizations of components' representation

Idealizations of representations characterize shape simplifications: assembly features composed of a large number of small faces and edges are replaced by idealized representations composed of a small number of faces and edges (see Figure 7). Moreover, free-form complex surfaces are replaced by canonical surfaces, i.e. planes, cylinders, etc. Here, the thread idealization matches the one commonly encountered in current DMUs, i.e. it is common industrial practice. Idealizations are said conventional because there is currently no standard referring to the 3D digital model of standard components.

Idealized representations ease the DMU modeling process at different levels:

- Canonical surfaces ease the set up of relative positioning constraints between components (see section 2.2). Indeed, relative position and orientation between two components can be defined more easily by geometric constraints between canonical surfaces: coaxiality, coplanarity, distance between parallel surfaces, orthogonality,
- Representations of component connections should not be over-detailed in order to enable interactive visualization, immersive simulations on large assemblies featuring thousands of connections. As an example, the idealized representation in Figure 7(b) is simpler and more adapted to process for immersive simulations and visualization.

Figure 7. Two representations of a screw and a nut (a) detailed model, (b) idealized model.

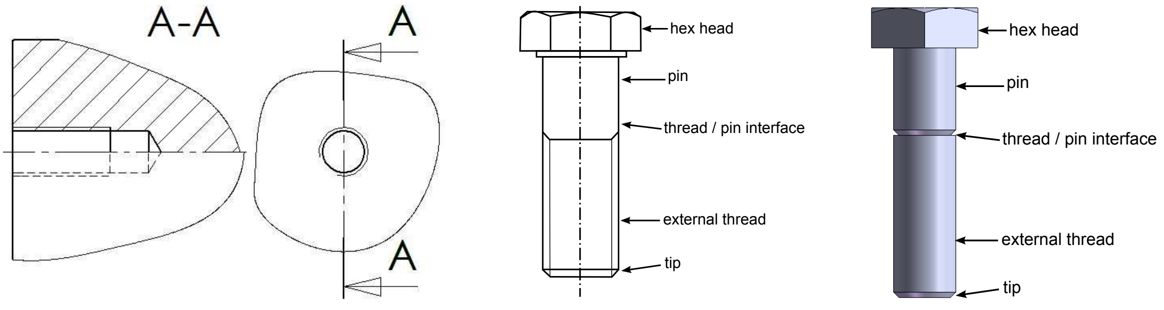
3.1.1 Improving coherence of components' representation with idealization conventions

In a DMU, the idealized representation of 3D components should follow idealization conventions, like it is the case in technical drawings. No uniform 3D simplified representation exist to represent major and minor diameter of threads, whereas technical drawing standards specify bold and thin lines representation of these features. In 2D drawings, the following conventional representations are set up:

- the major diameter of *external threads* uses bold lines, the minor diameter is then shown in thin lines. The interface between the thread and its adjacent smooth cylinder is defined by a bold line,

- the major diameter of *internal threads* is represented by a thin line, and the minor diameter is then shown with bold lines. The interface between the thread and the smooth cylinder of the hole is indicated by a bold line.

Conventional idealization rules would improve the coherence of components' representation in 3D by representing all internal and external threads with rules that would be coherent with regard to their nominal diameter and their pitch. Figure 8(c) shows an example of idealization rules applied to a screw thread: this area of the screw is represented as a cylinder whose diameter equals the nominal diameter of the thread, d, the end of the thread connects to the screw pin via an interface denoting the minor diameter, D_2, of the external thread. This idealized version enriches that of Figure 7 with the thread/pin interface. This interface is a means to embed the thread length into the 3D model of the screw, ensuring that any STEP, IGES input/output interface currently preserves this information across any CAD software. In addition, the thread/pin interface can feature the minor diameter D_2 using the conical surface. This surface enforces the validity of the relative values of the major and minor diameters (d and D_2). Hence, it is more robust and efficient than the 'THREAD' feature of STEP AP214 where these values are attached to one or more 3D faces, F_i, of the component but they are not engraved in the 3D model in the sense that there is no guarantee that edges or faces (F_i or boundaries of F_i) whose geometric parameters (face of type cylinder, edge of type circle, radius of cylinder or circle) equal some of the diameters of the 'THREAD' feature, e.g. d or D_2.



(a) (b) (c)

Figure 8. (a) and (b) 2D drawing idealized representation of internal and screw external thread (c) 3D idealized representation of a screw found on traceparts.com (courtesy Norelem).

3.2 Relative positioning of components, definition of conventional interfaces

The coherence of a DMU requires representing in 3D functional contacts between components' functional surfaces. Considering real components, their position must be defined by contact constraints between functional surfaces to respect the product coherence because no component can penetrate another one. In the context of a digital representation, the contact areas generalize to interfaces among which interferences can appear depending on conventional idealization of components.

Unless being surrounded by a fluid, any component has a restricted mobility, and it must share at least one contact area with other components. Because there is contact between real components, these ones generate reciprocal forces that drive their mobility: cylindrical fit mobility can be inferred from a coaxial contact between two cylindrical areas of components, a planar contact area denotes a planar connection that restricts the relative mobility to sliding components in their common plane. These informations can be used to contribute to functional identification of components.

Contacts between functional surfaces of components can be determined with an algorithm extracting the subset of surfaces whose distance to neighboring components fit within a tolerance interval. This tolerance is mandatory since the relative position of the components is performed, most of the time, through their algorithmic displacements.

Frequently, when the representations of peg and hole components use their nominal dimensions, the distance between surfaces is null. Consequently, clearances between functional surfaces are not represented explicitly in the DMU, they are also idealized in this case. This highlight the need for further studies and proposals about configurations characterizing these idealized representations.

3.2.1 Positioning components subjected to idealized representations

Idealized representation for threads, rivets, and tooth lock washers lead to interferences that exist in a DMU only. Using conventional positions of threaded components, a thread connection has the following properties: the cylinder with diameter d representing the external thread is coaxial with the cylinder with diameter D_2 representing the internal thread (see Figure 2). The thread conventional representation and the position of screw and piled-up parts lead to an interference having a tubular shape, which introduces the concept of conventional interface (see Figure 9).

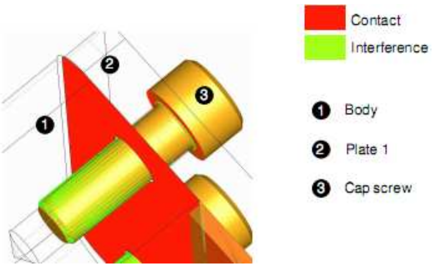


Figure 9. Conventional representation of a cap screw.

3.2.2 Conventional interfaces

Definition: An *interface* between two components is the set of intrinsic properties of two interacting components including:

- the *interaction type* between two geometric representations of localized components, i.e. clearance, interference, or contact,
- the *localization of the interacting surfaces* on each component, described by an exact B-Rep model based on canonical surfaces (planes, cylinders, spheres, cones), and canonical curves (straight lines, circles, ellipses), when possible.

Definition: A set of interfaces defines a *conventional interface* when its geometry and components adjacency verify properties that characterize a component and its function, resulting from conventional component representations and their conventional position in the assembly.

As an example of conventional interfaces and of the influence of their spatial layout, the function of a screw can be:

- A cap screw (see Figure 10): in this case, the conventional interface features (1) an annular contact area between the head screw and the mated component, (2) a tubular interference at the thread connection, and (3) a set of contacts between the piled-up components between the screw head and the threaded hole,
- A set screw (see Figure 10): in this case, the conventional interface features (1) a contact (point, line or surface) or an interference of the screw tip to bear on the mating part, (2) a tubular interference at the thread connection,

- And similar statements for locknut&screw, stopper screw, calibration screw, etc.

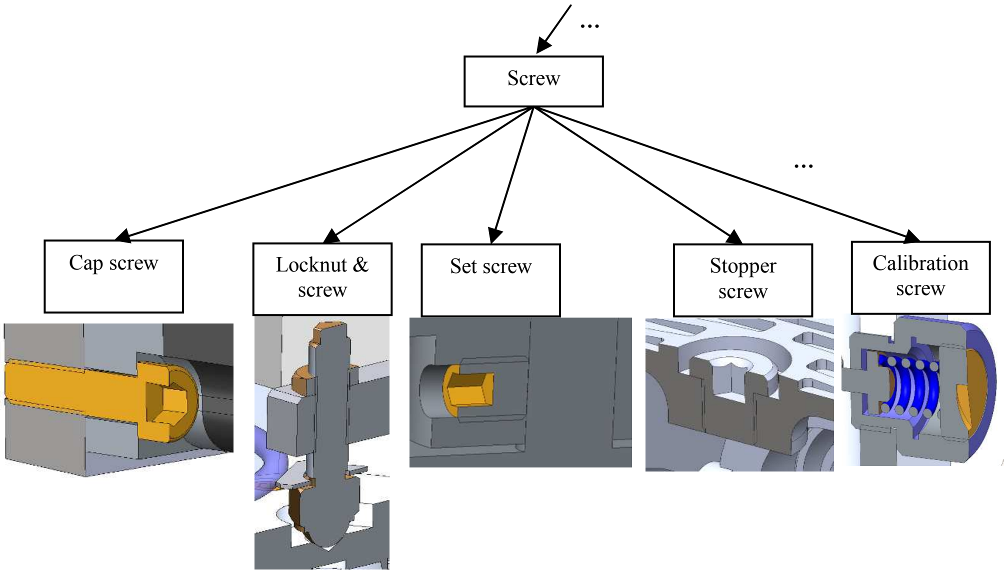


Figure 10. Interfaces of a screw with other components define its function.

4 Conclusion

In this paper we have shown the indispensable importance of DMUs in today's different stages of a PDP. Analyzing those models, we found that they mainly consist of the geometrical representation of the product, leaving only a small room for functional, technological or other useful information to be present. Moreover, it has been observed that components (like threaded connections for instance) are represented in an idealized manner for the sake of simplification. However, this idealization does not follow any standard conventions, leading to different representations in different models of the same component. This often leads to ambiguous or inconsistent configurations when trying to figure out the functional or technological attributes by running a geometrical analysis against the model in question.

We tackled this problem of inconsistency in representations by proposing idealization standards to simplify the product's shape when represented in a DMU. Those standards do not only allow for a uniform manner of representing idealized parts of a component, additionally they permit a consistent, unambiguous analysis of the model in order to infer valid conclusions about functional properties of a component or an assembly.

We also analyzed how semantic information, i.e. non-geometric data, including functional and technological information, can be presented alongside the geometrical information to allow for easier and more accurate analysis of a component, addressing as well some limitations of this approach. This analysis has focused on standard data exchange formats like STEP AP214.

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