Assessment of 3D Annotation Tools as a Substitute for 2D Traditional Engineering Drawings in Aerospace Product Development

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ABSTRACT

Reducing the costs of bringing a new product to market is an objective common to all industries. In aeronautics, one of the options being pursued to achieve this goal is to eliminate the use of traditional engineering drawings from the product development process– chiefly by integrating a portion of the information normally contained in these drawings into a 3D digital mockup (DMU). Before making this major change, several industrial practices must be revised and certain technological problems need to be resolved. One of the challenges is the transposition of the information found on traditional 2D engineering drawing, namely notes, dimensions and tolerances, to a 3D DMU. This article presents an evaluation of the feasibility of enriching 3D DMU with the aim of eliminating engineering drawings, based on the results of experiments in transposing samples of aerospace 2D engineering drawings to 3D environments using Catia V5 R17 SP6, a Computer-Aided Design software product. Experimental results show that placing annotations on the 3D DMU is feasible even for complex aerospace drawings. These results should help engineering design organizations decide if eliminating traditional engineering drawings is suitable for them.

Keywords: engineering drawing, digital mockup, annotations.
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1 INTRODUCTION

The industrial revolution created the conditions that allowed businesses to bring new products to market much faster. Taylor's concept of observing and breaking down work processes, put into direct practice by Ford in his assembly-line production, further increased the speed of this revolution [22]. In the 20th century, computerized automation and rapidly advancing technologies gave new impetus to industries – leading to higher production standards, improved quality and the ability to personalize products. These conditions, in turn, involved major evolutions in the definition of product conception and development processes by offering new tools to improve productivity [16]. Computer-assisted design (CAD) systems, computer-assisted manufacturing (CAM), computer-aided inspection (CAI), product lifecycle management (PLM) and material resource planning (MRP) are all examples of various business fields where these new tools and concepts have been deployed[3]. All of these systems rely on the digitization of information to facilitate and optimize management of the available product data – from conception and development to product retirement.

The realm of digitization has entered a new stage – the elimination of traditional (2D) engineering drawings (EDs) from product design and development processes. This can be achieved by improving the digital mockup (DMU) and can reduce the time and the costs of product development. This initiative has begun to take shape in the industry over the last few years. Companies such as Boeing [4] and EADS [27] in aeronautics, and Toyota F1 [11] and Honda [21] in the automotive sector, as well as Dassault Systems [8], which produces CAD and PLM systems, are all very active in implementing this approach. According to a recent study [26], businesses in the aeronautics sector foresee significant gains in terms of costs, of time-to-market and of quality. More precisely, they predict possible improvement in each of the following areas:

- the accuracy of the work with suppliers and industrial partners;
- the costs associated with drawings and their printing;
- the capacity to interrogate models more effectively;
- the quality of data from a single source; and
- the problem of associativity between 3D models and 2D drawings.

However, limited data is publicly available from such industrial efforts, a scientific research project was launched to provide a neutral perspective on the maturity of the required technologies and to provide the needed quantitative data to evaluate this new approach. This paper thus provides new information that may help engineering businesses make decisions about eliminating engineering drawings from their design processes. Two particular areas have to be taken into consideration when tackling the elimination of EDs: the technologies required and the processes required to put them to work. A research program covering two technological aspects and one process is being conducted in order to evaluate the feasibility of eliminating EDs from the product-definition (PD) process:

- the process of managing modifications in a digital environment;
- the technological aspect involved in long term storage of annotated DMUs (or Model-based definition, MBD);
- the technological aspect involved in the capture of notes, dimensions and tolerances in a DMU.

This article focuses on this latter challenge of capturing the notes, dimensions and tolerances within a DMU, this transposition being a partial solution to substitute the 3D DMU to traditional 2D engineering drawings. The objective is to assess the feasibility of eliminating traditional EDs from the development of aeronautic products through annotating DMUs with the annotations usually presented on EDs. Hence, in this paper, we adopt the definition of *annotation* proposed by the ASME: Y14.41-2003 "Digital product definition data practices" [1], which includes dimensions, tolerances, notes, texts or symbols. Considering the fact that 3D models do not generally offer the same information as EDs[16] and that the information presently supported by EDs is indispensible for PD, it is necessary to verify that the Computer-Aided Design (CAD) software allow the annotations to be transposed to the DMU while respecting the norms of EDs applicable to the DMU environment.

The overall objective of this effort is to determine the practical feasibility of adding annotations to DMUs, with the aim of eliminating the need for 2D EDs. Three specific objectives have been set in order to address this problem. The first consists of evaluating the capacity of Catia V5 R17 SP6 software to apply the traditional ED dimensioning and tolerancing standards (ASME Y14.5M-1994, "Dimensioning and tolerances" [2]) to the 3D environment, in accordance with the good practices defined by the standards on the presentation of annotations in 3D (ASME Y14.41-2003, "Digital product definition data practice"), so as to offer the same level of functional expression as with EDs. The second specific objective is to evaluate the correspondence between tolerancing norms and industrial practices. The third specific objective is to evaluate the capacity of Catia V5 R17 SP6 to enrich 3D DMUs with annotations to define a product in a way that offers the same level of functional expression as that of traditional 2D drawings used in the development of industrial products. Catia V5 was selected to conduct the experiment because it is the CAD application used by the industrial partner providing the

ED samples, as well as because it is widely used amongst the aerospace industry. By working with these objectives it is possible to determine how these three elements are integrated: engineering drawings, standards and software, and to then evaluate the feasibility of adding annotations to a 3D DMU so as to support industrial needs.

In accordance with our research methodology, information from industrial partners was first gathered and analyzed in order to choose the ED samples to be evaluated. Our sample drawings correspond to different types of parts (investment casting, high precision machining, etc.) [19].Sample were sorted so as to define a complexity scale[23]. Next, tests were carried out to evaluate the capacity to exploit the ASME Y14.5M standard via the ASME Y14.41 standard in the 3D environment of Catia V5 (Catia V5 R17 SP6, functional tolerancing and annotation module, Dassault Systems). The procedure consisted of using the unit tests prescribed by the standards and transposing them into the CAD software in order to evaluate the degree of conformity. Following the transposition of unit cases, a verification of how well the industrial practice corresponds to standards measured the level of standardization in aeronautics industrial practices, based on ED samples. Finally, actual 2D ED samples were transposed to the 3D DMU in order to evaluate how well Catia V5 can satisfy industrial practices based on the same ED samples.

The objective of these evaluations is to connect the three elements of this study: standards, software and actual engineering drawings and to assess their level of integration so as to determine the feasibility of eliminating EDs by enriching 3D DMUs and thus eliminating the non-value adding duplication of information through EDs[6].

This article focuses on the results and analysis of the third specific objective – evaluation of the representation of EDs in a 3D environment, using Catia V5, to express the PD with the original level of functional expression. The results and analyses of the first objective are available in [23] and [25], and those of the second objective are found in [23]. A brief summary of these results is presented in the introduction section of this article. The next (second) section of this article presents the results and analysis of the transposition of actual industrial 2D drawings to a 3D DMU. The third section offers a discussion of the results of the whole project, and leads to the recommendations presented in the subsequent section, followed by a conclusion.

2 TRANSPOSITION OF ENGINEERING DRAWINGS TO 3D DIGITAL MOCKUPS

This section presents the results and analysis of an evaluation of the capacity of a software package to enrich a 3D DMU with annotations to define a product in a way that offers the same level of functional expression as traditional 2D EDs. This evaluation is conducted by transposing information from aerospace Ed's samples to 3D DMUs using Catia V5 R17 SP6 software. This step constitutes the third and final objective of the overall project. These results complete the feasibility study of eliminating EDs through the use of annotated 3D DMUs. There are three parts to this section: the methods and hypotheses used to carry out the transposition, the results, and an evaluation of the impact of these results in an industrial context.

2.1 Experimental Procedure

The goal of this experiment was to test the capacity of software to transpose typical industrial annotations and to manage a large amount of annotations and views in a single 3D DMU. All annotations found on six ED samples, provided by one of our two industrial partners, were transposed into 3D DMUs. Testing samples contained a great deal of annotations, some of them being specific to the industrial partner. The experiment allowed the identification of borderline cases at the levels of the software, of the material, of the 3D environment and of industrial practices.
Four primary rules and hypotheses were defined and used to carry out these transpositions. The four main rules are that:

1. all of the annotations on the ED sample should be transposed to the 3D DMU, unless otherwise indicated;

2. each view created on the ED is respected and represented in the 3D environment;
3. two views may be combined if the opportunity arises and if doing so does not change the understanding of the information in the ED; and
4. each reference is transposed only once, even if it appears multiple times on the ED, since the software, in accordance with the standards, does not allow repetitions.

The underlying hypotheses attached these rules is that each annotation placed on an ED is needed to fully define the product and convey the designer's intent, and therefore needs to be defined on the 3D DMU. All of the transpositions of 2D samples to 3D DMUs were done with Catia V5 R17 SP6 on a Dell Inspiron laptop (Pentium M 1.6 GHz, 1.0 GB, Radeon X300-64Mb). The transpositions of annotations to 3D DMU were performed using the FT&A module.

2.2 Results

The results obtained from transposing the six ED samples are presented in the following sections. Fig. 1 presents an overall view of the results of the transposition from the most complicated ED set to the 3D environment. This set of ED includes 30 pages and 1600 annotations.

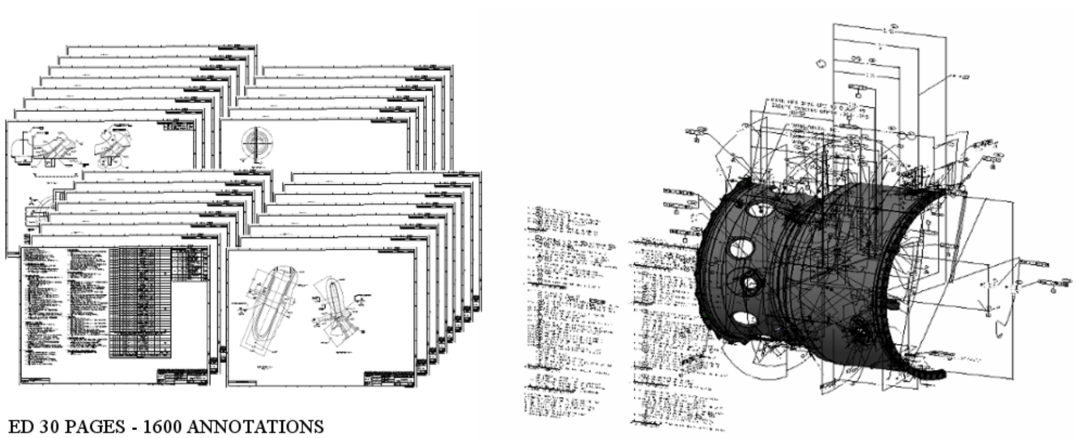

Fig. 1: Result from transposing a complex set of EDs to a 3D DMU.

Table 1 shows the results of each ED transposition, according to three different categories of annotations. The elements in category 1 represent the annotations transposed by the 3D annotation tools and whose 3D representation is therefore identical to that of the 2D environment. Category 2 shows the annotations that cannot be identically transposed with the 3D annotation tools, but which are identically transposable by using additional operations such as the creation of geometrical elements or sketches. The elements in category 3 represent those ED annotations that cannot be identically transposed with 3D annotation tools or by using additional operations. Specific examples are provided below.

Drawing	Annotation total number	Category-1		Category-2		Category-3	
Detail - 1	141	137	97%	4	3%	0	0%
Detail - 2	261	246	94%	15	6%	0	0%
Detail - 3	462	408	88%	51	11%	3	1%
Assy. - 1	159	151	95%	5	3%	3	2%
Assy. - 2	215	183	85%	32	15%	0	0%
Assy. - 3	1598	1545	97%	51	3%	2	0%
Total	2836	2670	94,1%	158	5,6%	8	0,3%

Tab. 1: Results from transposing ED annotations

Out of a total of 2,836 annotations, only 8 fell into category 3 and were considered non-transposable to a 3D environment, a figure which represents only 0.3% of the total annotations. This extremely low value indicates that good results can be expected in transposing 2D annotations in a 3D DMU. Besides these 8 category-3 annotations, it is also important to evaluate the impact of the 158 (5.6%) annotations that fell within category 2. These required additional interventions in order to be transposed into the 3D environment. The sum of all of the category 2 and 3 annotations represents fewer than 6% of the annotations processed in the transposition from EDs to 3D DMUs. 94% of the annotations could be transposed in an identical fashion with no difficulty. Experimental details can be found in [23] and [25]. The following sections present an analysis of categories 2 and 3 so as to better define the problems and limitations, and to determine if solutions are possible.

2.3 Category 3 Annotations

Category 3 annotations are not transposable to a 3D DMU, either because they reflect an industrial practice in 2D that does not have a relevant significance in 3D, or because the annotations tools do not allow this annotation to be created. In the first case, the problem is linked primarily to the annotation itself, while in the second case the problem is a limitation of the software. Examination of real cases from the transposed samples helps clarify these two types of problems.

2.3.1 Non-transposable (Cat. 3) Industrial Annotations

Figure 2 shows an example of annotations which could not be transposed into 3D by the tested software. Observe that in this figure it is possible to see an image corresponding to an assembly of two views placed at 90 degrees to each other. This practice, used on samples, allows the total number of views on a design to be reduced. However, in these circumstances it is necessary to specify the 90 degree angle between the views. In this example, the repeated view R-R is used to annotate two view planes of the same element. These view planes correspond to an R-R view and a view 90 degree perpendicular to R-R. Transposition of this annotation has no significance in 3D since this angle represents the angle between the two annotation planes. This incapacity is due to an industrial practice and the problem is avoided if each view is created independently. The angle annotation could still be obtained, if necessary, in a perpendicular annotation plane.

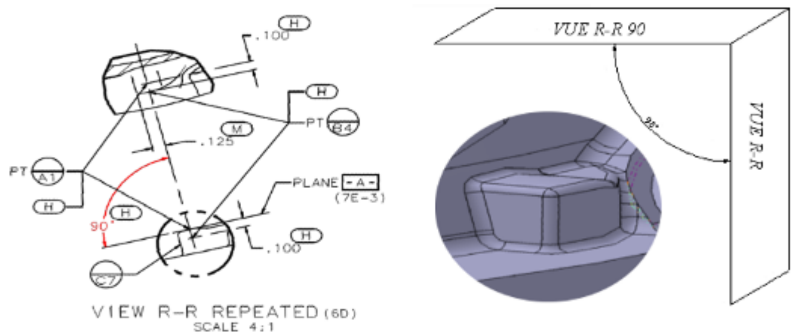

Fig. 2: Industrial annotation non-transposable to 3D.

2.3.2 Non-transposable Annotations (Cat. 3) due to Software Limitation

Figure 3 shows an annotation that was not transposable to a 3D environment because of a software limitation. This annotation defines the maximum allowed dimension between two edges, but it was not transposable. Annotations A, B and C show the possible cases in a 3D environment. The software does not offer the possibility to place annotation A parallel to annotations B and C.

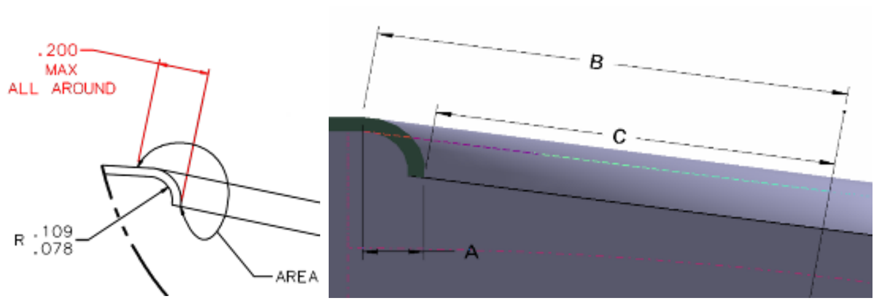

Fig. 3: First case of non-transposable annotation due to software limitation.

Figure 4 shows another non-transposable annotation due to a limitation of the software. In the 2D view, one can see an annotation between two geometric elements that belong to two different parts of an assembly. In a 3D environment, the problem is that the two elements are not parallel – the tube is not perpendicular to the annotation plane and there is no real edge on the tube intersecting the annotation plane. These problems prevent the software from creating the minimum distance annotation between these two geometric elements. This type of problematic annotation can be created differently, while respecting the designer's intentions, by using a note indicating the minimal distance between these two elements. However, this practice should be validated by practitioners in industrial settings.

Each of the eight cases of category 3 annotations not transposed by the current CATIA V5 R17 SP6 tools fall within one of the three types of problems discussed here (the first type of problem occurred three times). It is clear that these cases are marginal and that their representation in an identical manner is not feasible, but that a representation of the designer's intention remains possible by using other annotations, and that this practice merits the attention of industrial practitioners.

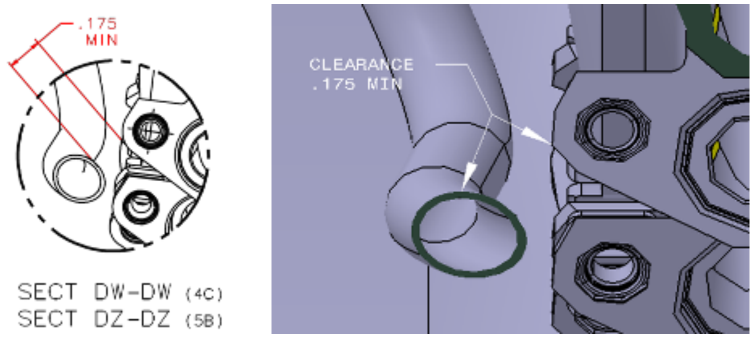

Fig. 4: Second case of non-transposable information due to software limitation.

2.4 Problems Specific to the 3D Environment

Beyond the cases of category 3 non-transposable annotations, other types of annotation problems were observed. The problematic cases are either those classified in category 2, or others that create particular problems when they are transposed. The latter are most often associated with 2D practices that are not transposable or that have no significance in a 3D environment. To distinguish among these different cases, they can be classified into three categories of problems: those associated with the change of environment, those associated with a CAD software limitation, and those linked to industrial practices.

2.4.1 Example of a Problem due to the Change of Environment (2D to 3D)

The 3D environment allows the complete geometry of a product to be visualized, whereas in 2D only a limited section can be viewed at one time. At the same time, certain annotations that are practical and necessary in 2D are not relevant in the 3D environment, either because they are based on secondary elements that do not exist on a 3D DMU or because they refer to concepts that have no meaning in 3D and thus their representation becomes completely unnecessary. The three following figures show cases where annotations support elements that only have a meaning in 2D or that require supplemental elements to be able to represent them as they exist in 2D EDs.

2.4.1.1 Cutting Plane Line

Elements such as cutting plane line and hatching are used regularly in 2D representations. However, these elements lose their significance or their usefulness in a 3D environment. A cutting plane line is generally used to define where the view or section is located, and in this sense is not applicable in 3D (see Fig. 5). This line, a geometric element linked to the 2D representation, becomes a cutting plane in 3D.

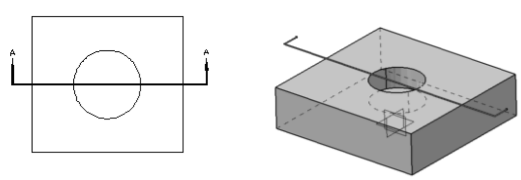

Fig. 5: Non-significance of a cutting plane line in 3D.

2.4.1.2 Hatching

In a cut or a section, the cut portions are usually represented by hatching. The hatching serves to identify and differentiate the main materials [10] or the different components that are found in an assembly. In a 3D environment these hatchings are no longer necessary since this information is directly available from an object's visible characteristics or in an assembly's tree structure.

2.4.1.3 Half-sections and Other Sections Types

Half-sections and others sections types are methods by which a detail or a hidden portion of a part can be shown without having to make a complete section. Fig. 6 shows an example of a local section taken from an industrial sample. This practice is most often used on drawings that have little need for annotations [10]. These sections become difficult to envision in 3D because the tool used to create a section in 3D is a plane; just as in geometry a plane is, by definition, infinite, it is necessary to limit it to a specified zone – which adds a great deal of complexity to the application of this method in 3D. Meanwhile, the annotations found on a local section can be represented in 3D by using another view with a complete section.

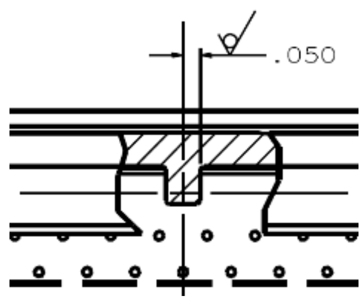

Fig. 6: An example of a local section.

2.4.1.4 Geometric Element Derived from a Section

In order to make annotations of certain geometric elements of a part in a 3D DMU, it is often necessary to use a section (Fig.7). In the 2D environment, representation of a section is made by edges that represent the intersection of the part and the plane of the section. In a 3D environment, the plane section tool allows solid elements to be hidden and the silhouette of the part to be visible in its place, but the solid model does not show these edges because these geometric elements do not have a concrete existence in the solid. These non-selectable edges make the creation of certain annotations difficult or impossible. Still, sometimes these cuts can be integrated into a 3D model with the help of an intersection tool, but these new edges add an additional level of geometric elements to the model. This new level of geometric elements is difficult to manage and leads to clutter in the 3D DMU.

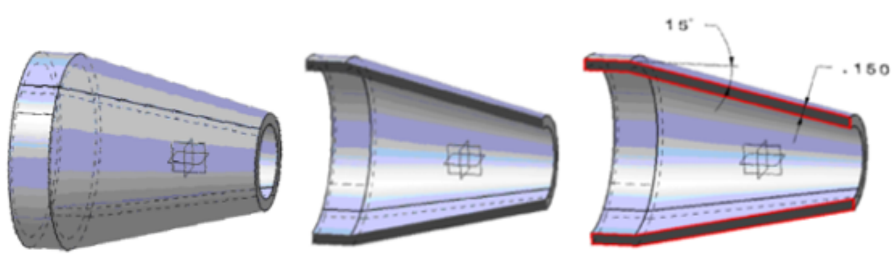

Fig. 7: Example of annotation problems in a section.

2.4.2 Difficulties due to Software Limitations

The CAD software Catia V5 R17 SP6 presents certain limitations in the transposing of annotations to a 3D environment. The following problems could be part of an upgrade request, on the part of industry, to the software editor.

2.4.2.1 Managing Supplemental Elements in 3D

In certain cases, the need to add supplemental elements to the 3D geometry is necessary to express particular information that is typically supported by 2D representations on EDs. The tested software does allow creation of an axis, of a diametrical circle for groups of holes, etc. by means of a construction element in the annotation module. This software also allows the creation of sketches, lines, curves, or of planes outside of the annotation module. However, it does not allow these supplemental elements to be linked to the annotation captures, so their display cannot be managed by filters. This problem creates difficulties in interpretation, because all of the additional elements are either permanently displayed on the 3D model (creating useless clutter as shown in Fig. 8), or they are all hidden, which results in annotations that point to non-displayed elements. Fig. 9 shows an annotation with and without its relevant geometric element.

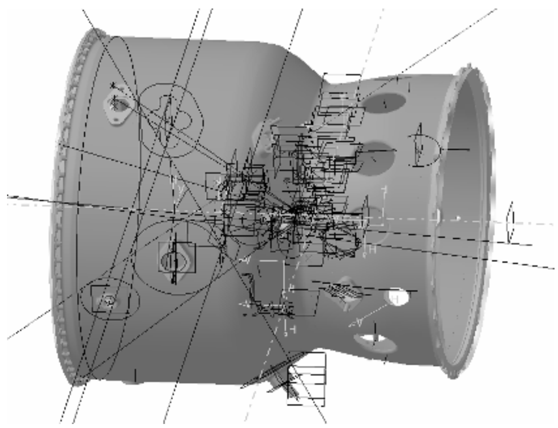

Fig. 8: Example of clutter due to additional elements on an annotated 3D model.

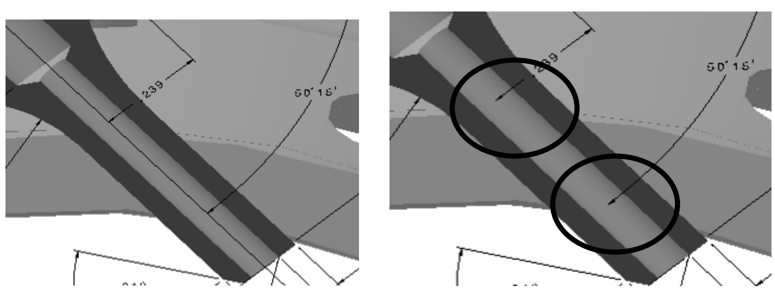

Fig. 9: 3D annotations with and without an additional element.

To transpose all the annotations from industrial ED samples to a 3D environment, several additional elements were required. However, a majority of these elements are planes that are necessary to support a 3D annotation plane and which are equivalent to the section lines that have to be created in a 2D ED. Thus, one could conclude that the impact of these elements on the definition time will be negligible. The salient point here is that the CAD software publishers must solve the problem of the display link between these additional elements and the capture in which they are used, since, by their sheer number, these elements have a negative impact on understanding the annotated 3D DMU.

2.4.3 Problems Arising from Industrial Practices

Finally, some of the annotations observed in industrial practice are themselves problematic and require the creation of additional elements. Also, some industrial practices present difficulties because they refer to elements that do not correspond to the 3D geometric model. In both of these groups, internal symbols and annotations, typical elements, and the definition of views for manufacturing or inspection processes are observed/presented.

2.4.3.1 Internal Symbols and Annotations

There are certain symbols and annotations that do not exist in the software, but which are used in industrial practice. These include internal annotations that have already been discussed [25]. The symbols are often created in libraries that are available in the 2D environment. It is important to verify that the symbol library is transferred so that the 3D annotation tools can have access to all of the symbols. Fig. 10 shows a group an example of such a symbol.

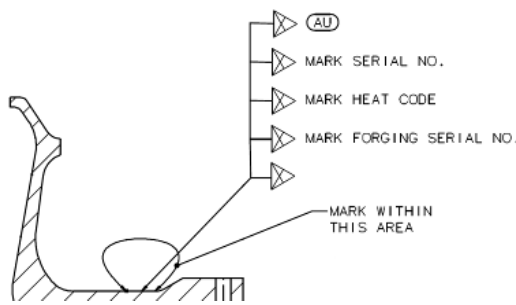

Fig. 10: Industrial symbol indications which are not transposable by the software.

2.4.3.2 Aspects/views of Typical Elements

In order accelerate the work of industrial draftmen, some elements that are well-defined within a company and that are common to several parts are encapsulated in typical views collected in a library. This library makes these views reusable on different EDs. Fig. 11 shows an example of a typical view, representing a radius groove. The problem with these typical views does not lie with the annotations they contain, but with the support for those annotations that are not an extraction of the 3D model. The support comes from additional wire elements created in the 2D environment. These elements are not available in the 3D environment – they must be created by adding sketches, lines, curves, etc., and these additions lead inevitably to the same problems that were presented in 2.4.2. Should CAD software editors solve the problems linked to the display and management of additional elements, it will be possible to use these typical views, but they will have to be restricted to a dedicated annotation plane.

2.4.3.3 Views that are Defined for Manufacturing

This last category of problems arises from the need to define the manufacturing options of a part on an ED. Also, industrial practice sometimes makes it necessary to indicate how a part will appear if it is made according to the maximum possible tolerances, and to be able to compare this to a part made to the normal tolerances. Fig. 12 shows an example of the options for the production of a hole. The R view in the upper part of the figure corresponds to a geometric model of the 3D DMU, while the R view at the bottom corresponds to a modified model that shows the possibility of making the hole by a drilling process followed by a welding.

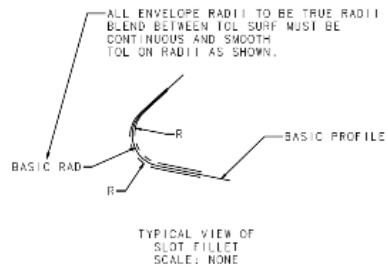

Fig. 11: Example of a typical 2D ED view.

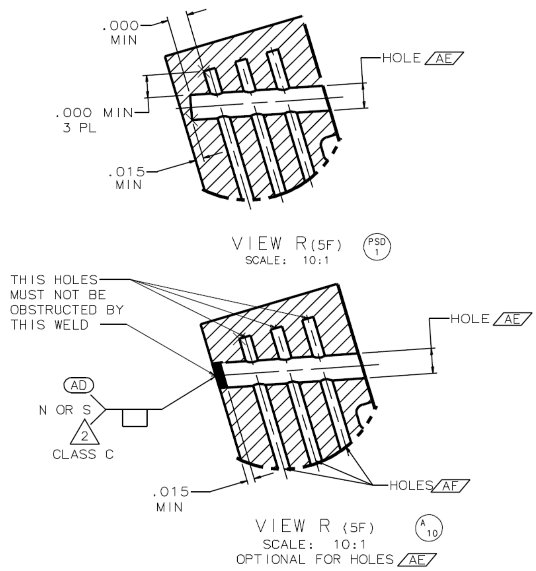

Fig. 12: Example of a manufacturing view that differs from 3D geometry.

As with the usual views, these views use geometric elements that have to be added to the 3D DMU and should be confined to a distinct annotation plane.

2.5 Industrial Impact

The cases that fall into categories 3 and 2 represent 6% of the industrial annotations that were to be transposed into a 3D environment in the experiment. Before planning the transposition of 2D information from EDs to a 3D environment in an industrial setting, these cases should be evaluated and solutions devised to replace them in a way that preserves their meaning and does not create representation problems in the 3D DMU.

For industry, the overall results of this evaluation are positive. Keeping in mind that only 0.3% of the annotations are in category 3 (8 out of 2,836), and that the sum-total of the annotations in categories 2 and 3 is 6% (166 out of 2,836), it is clear that it is feasible to eliminate EDs by transposition to 3D DMUs, and that to reach a 100% transposition level will not require an enormous effort. Even though they are very encouraging, these results still give an incomplete view of the results that could be obtained by using a 3D environment for PD. The following section presents a new approach that allows the best results for the transposition to the 3D environment.

3 DISCUSSION

From the experiments and the analyses presented in this project, some conclusions can be drawn regarding the possibility of transposing notes, dimensions, and dimensional and geometrical tolerances to a 3D environment using the standards of 2D engineering drawings (EDs) (ASME, 1994; ASME, 2003). This section presents a synthesis of the observations and the conclusions arising from the results and the analyses realized in this study. Comparisons between the results of transposition from 2D to 3D and observations on creation time, semantic annotations, interpreting information in a 3D environment, and storing and managing 3D information are covered here.

3.1 Standards, Software and Engineering Drawings

In this project, the results from the transposition of information from 2D EDs to annotated 3D DMUs have showed that this will likely become a very real possibility in industrial practices in the near future. A summary of these results is presented next.

In the first section of this study [25], the evaluation of the feasibility and efficacy of using the CAD program Catia V5 R17 SP6 to transpose annotations into a 3D environment while respecting the ASME standards Y14.5-1994 and Y14.41-2003 gave positive results for more than 97% of the standard case transferred. The standard non-transposable cases are minimal, and are chiefly due to problems with graphic representation. These cases should not prove an obstacle to using a 3D DMU to support product development. Also an evaluation of the agreement between tolerancing standards and industrial specifications found a concurrence of 81% (2301/2836) [23]. The industrial specification are "drafting room manual" based on tolerancing standard. At the same time, the evaluation of the agreement between tolerancing standards and industrial specifications has highlighted the advantage of adopting tolerancing standards in industrial practice. Finally, evaluation of the transposition of the ED samples supplied by our industrial partners shows the practical feasibility of this transposition, since 99.7% (2828/2836) of the annotations were transferred with no problems. The Venn diagram in Fig. 14 shows the grouping of the results.

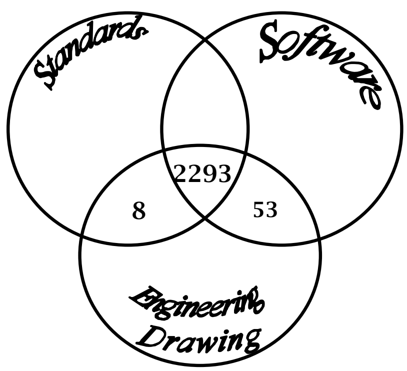

Fig. 13: Venn-diagram distribution of all of the transposition results.

This intersection of the information allows the display and interpretation of the 2836 ED annotations in the following way, from the perspective of the ED:

- 2293 annotations found on ED samples (80.8%) comply with the standards and are transposable into 3D;
- 535 annotations (18.9%) do not respect the standards but are transposable;
- 2828 (99.7%) of the annotations were transposable;
- and only 8 annotations (0.3%) were not transposable into a 3D environment.

This part of the evaluation allowed observation of the industrial practices used for product definition (PD). On the basis of these observations, a revision of these practices by adopting the principle of minimal dimensioning in order to reduce the quantity of information to transpose to 3D DMUs is being considered [19]. In sum, the results presented here confirm that the transposition from 2D EDs to 3D DMUs is feasible, but product designers will have to adjust their practices and software editors will have to address the limitations of their product so that the full potential of the 3D numerical environment can be achieved.

3.2 Creation Time

This study confirms that the process of product definition in a 3D environment is essentially the same as that used currently in a 2D environment. Comparison of the software functions and the creation processes have clearly shown that the creation and manipulation time of annotations is very much the same for the two environments [25]. Table 2 shows the experimental creation times in 3D environment for the group of defined ED samples.

Drawing	Complexity	Experimental Time	Industrial Time
Detail	Low	5,2 h	7 h
	Medium	10,7 h	10 h
	High	20,8 h	25 h

Tab. 2: ED creation times based on the average experimental times.

By comparing the times obtained experimentally to the corresponding average times supplied by an industrial partner, one can see that for the same level of complexity creation times are similar, and that in industry, the gains in creation time and the associated costs will be minimally affected by doing PD in a 3D environment. This observation is one of the reasons why the principle of minimal dimensioning [23], [20] is considered in order to achieve significant time savings in the PD process.

3.3 Storage and Information Management

The gains in storage and information management were also made evident in this study. Table 3 displays a summary of the file sizes required for PD, from industrial examples: 3D model, engineering drawing and 3D DMU/annotated 3D model. The first column shows the size of the initial 3D model (without 3D annotations), followed by the traditional engineering drawings samples. The third column shows to the size of the first two, which make up a complete PD. The next column, 3D_FT&A, shows the size of the initial 3D model, enriched by the annotations from the Catia V5 R17 SP6 FT&A module.

A comparison between the initial 3D DMU and the annotated 3D models is shown in the column “3D FT&A vs 3D”. These results from the six ED show that the size of the models increases by an average of 9%. Despite this increase in size, when comparing the size of a 3D model-ED pair to the corresponding annotated 3D model, there is an average decrease of 27% in the size of a complete PD. In an extreme case, where the ED takes up 30 pages, the storage space can be halved (49%).

Finally, even more than reducing the disc space required for the PD, the total number of files can be reduced through the use of an annotated model. In the case of a complex assembly, the number of file goes down from three (a 3D model and 2 EDs) to one. This small decrease, multiplied many times, will result in simplified file management – which could be significant in an industry that generates millions of designs and models.

		Files size (ko)				Margin	
Drawings	Complexity	3D	ED	3D+ED	3D FT&A	3D FT&A vs 3D	3D FT&A vs 3D+ED
Detail	Low	1053	1410	2463	2269	115%	-8%
	Medium	11689	5038	16727	13341	14%	-20%
	High	68119	18104	86223	71301	5%	-17%
Assembly	Low	68832	10717	79549	69149	0%	-13%
	Medium	1530	11202	12732	3160	107%	-75%
	High	26542	41047	67589	34442	30%	-49%
Total		177665	87518	265283	193662	9%	-27%

Tab. 3: File sizes of industrial engineering drawings (2D and 3D).

3.4 Further Observations

Other observations have been made over the course of this transposition of 2D EDs to annotated 3D DMUs. These observations are presented in the following subsections.

3.4.1 Creation by Semantic Annotations

At the level of annotation creation, several creation errors to be avoided through the use of a tool such as the annotation semantic function. This function makes it possible to perform a first check of the representation of the information that defines the product. Thus, the revision time and the associated costs are reduced. However, the results of the unit tests based on the ASME Y14.5 and ASME Y 14.41 standards [25] have shown that the semantic annotation tools are not able to completely present the annotations necessary for the PD because 14% of the tests could not be transposed by the semantic annotation tool. Therefore the conventional annotation tools are still required at this time for these particular cases.

3.4.2 Associativity

Another advantage of using annotated 3D models has to do with the associativity between the annotations and the 3D DMU. By associating the references and the tolerances to the model, it is then easier to make use of this information for the subsequent steps in the product development process. One example is the capacity to produce manufacturing or inspection codes directly from the 3D annotations [14]. Proceeding in this way offers the advantage of reducing the risk of error arising from the transfer of information from 2D to CAM and CAI systems, and it allows the quality and integrity of the inspection process to be raised [17].

3.4.3 Comprehension of the Information

A 3D annotated model brings a higher level of clarity and readability than that of traditional EDS, which is beneficial to the interpretation and to the global comprehension of the dimensioning [9]. If a picture is worth a thousand words, then a 3D model is worth a thousand drawings [18]. Also, a user without a solid background in using EDs will find it much easier to visualize a 3D model than to mentally reconstruct a model from the views found on an ED [5]. In addition, 3D annotation offers the advantage of using a system of association between the annotations and the model which allows “questions and answers”. This system can help in the understanding of information in several ways, for example, when an annotation refers to several elements, or when it offers the possibility to present the face linked to a reference. The 3D environment also offers the possibility of filtering them, making it possible to present only the information relevant to a particular user. This feature can be particularly useful when a client wants to see, all at once, only those aspects of the model that are necessary to prepare for its manufacturing. Finally, the annotated DMU offers users the ability to visualize the model from an unlimited number of views, contrarily to what is possible with 2D EDs.

4 RECOMMENDATIONS AND FUTURE WORK

This research is a step towards product definition in a digital 3D environment. Despite the encouraging results obtained thus far, there still are questions that remain to be addressed to fully solve the problem of the capture of notes, dimensions, dimensional and geometric tolerances within the 3D DMU in order to eventually eliminate EDs. To follow up on the work accomplished in this research, the main recommendations and future work can be grouped in three themes: industrial practice, software, and PD in a 3D environment.

4.1 Industrial Practice

The following recommendations mainly deal with the eventual avenues of research and solutions that the industry should consider for a transition towards PD in 3D.

- Application of the principle of minimal dimensioning [20] to improve the results of transposing PD to a digital 3D environment. The industry can achieve savings in time and costs by using this approach for PD.

- Development of a standardized format to simplify complicated definitions will respond to a clearly defined need. Definition of a complex part requires the creation of multiple views and annotations. In this study, the description of the most complex part contained close to 120 views. This information should be structured in a way which makes it easier to organize and understand. One of the problems in industry concerning the 3D environment is the absence of partition zones (A, B, C and 1, 2, 3) [26]. This elimination of zones in 3D forces the industry practitioners to develop new work methods. Some possible solutions are tools such as annotation filters and the associativity of 3DLive (Dassault Systems) [7], which allows visualisation to be shared on more than one computer and makes simultaneous communication possible via the Internet (WCE, 2006).

4.2 Software

The following recommendations present both the software upgrade requests aimed at the publishers, and the orientation of future work needed to evaluate other aspects of software required for PD in 3D:

- Engineering drawings are subject to multiple modifications during the life cycle of the product that they define. Management of these changes could be simplified if the use of semantic annotations allowed the automatic propagation of the changes from the 3D DMU towards the 3D annotations. This is one of the recurring problems in linking 2D EDs with 3D DMUs[13]. The use of the 3D environment for product definition could eliminate this problem.

- One of the problematic aspects of PD in a 3D annotated environment has to do with the incorporation of supplemental geometric elements. The impossibility of connecting these elements to the captures of annotation views makes managing the display, and thus comprehension, much more difficult. This situation must be addressed by the software publishers/developers.

4.3 Product Definition in the 3D Environment

The realisation of PD in a 3D environment is one of the way through which the elimination 2D EDs in industrial practice can be considered. However, some problems remain to be resolved.

- The archiving and the legal status of 3D documents raise questions. Various international efforts are addressing this issue [15].

- An important technological aspect to PD in the 3D environment is to offer an access to information that is comparable to that presently offered in 2D [12]. The PD should be available to several clients, for manufacturing, for inspection, etc., and so it is essential to offer these clients access to information without requiring them to use CAD software such as Catia, NX or Pro-E. Several tools are now commercially available [24], but their capacity to transmit information and to be used in various locations where the information is remains to be evaluated.

- The engineering drawing is at the center of several communication processes in the development of a product. It allows the transfer of information between multiple clients of a PD, such as the design, manufacturing and inspection, departments. It also supports several processes such as validation and the management of modifications. Elimination of the 2D ED requires the definition of new processes, which will have to be evaluated in order to determine how other tools and other work methodologies can replace the 2D support currently in place. A project on managing changes in a 3D environment is underway.

5 CONCLUSION

The results presented here show that the day when the contents of 2D drawings will be completely transposed into a 3D model, to create an annotated model, is almost at hand, since 99.7% of annotations found on our engineering drawing samples were successfully transposed on the 3D DMU. Thispaper confirms that the 3D DMU is a suitable substitute to this specific traditional, partial, role of ED.The savings in drawing creation time itself anticipated from the elimination of 2D support will not be significant if only the change of support is considered. However, defining a product in a 3D environment makes it possible to expect benefits in the level of understanding and in the ease of communicating information, because of the stronger link between the 3D DMU and the annotations. Gains in terms of management and storage of information can also be anticipated by the use of a single electronic file. Using an exclusively 3D environment to express product definition also opens up promising areas such as the use of 3D annotations to directly generate inspection codes, or making good use of the smart functions of semantic annotations.However, some technical issues raised by eliminating ED, such as long-term archiving of PD, and new processes by which PD will be conveyed and exploited downstream (shop floor, maintenance, etc.), where the 2D support may still have some advantages, need further investigation. Finally, even if technically feasible, eliminating 2D drawings may raise cultural issues in most organizations.

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