Assessment of 3D Viewers for the Display of Interactive Documents in the Learning of Graphic Engineering

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ABSTRACT

The purpose of this study is to determine which 3D viewers should be used for the display of interactive graphic engineering documents, so that the visualization and manipulation of 3D models provide useful support to students of industrial engineering (mechanical, organizational, electronic engineering, etc). The technical features of 26 3D visualization software programmes (viewers, publishers, 3D output formats) are examined, to select the three visualization configurations that best meet our needs at the Graphic Expression Department of the University of Burgos (Solidworks plus Solidworks eDrawings; Catia plus Catia eDrawings and 3DXML; several Computer-Aided Design software programmes plus Adobe Acrobat Pro Extended). These are compared using the Quality Function Deployment tool known as House of Quality. The House of Quality has enabled us to identify and quantify the importance attached by engineering teachers to each of their requirements for 3D viewers, and to identify and quantify the technical importance of each of the measurable features of these viewers.

Keywords

Web3D, Virtual interactive learning, Viewer, 3D interactive documents

Introduction

Throughout their learning processes at our university, students of mechanical, organizational and electronic engineering use Computer-Aided Design (CAD) packages in various CAD/Computer-Aided Engineering (CAE)/Computer-Aided Manufacturing (CAM) studies. It is necessary to develop spatial visualization ability when the computer is used as a design tool, in order to be able to see and understand the operation of the complex mechanisms in the CAD package. This visualization ability must be developed during the initial stages of the engineering learning process. Spatial representation systems were the tools used to develop this ability until the introduction of CAD packages. Nowadays, the acquisition and development of spatial visualization ability requires autonomous learning, learning that uses educational platforms, and within graphic engineering, a common tool that is independent of any software (3D viewers) and which makes it possible to review the 3D models.

An early trend still in use today in the viewing of 3D models is to insert them directly into the website using a plug-in. Initially, the most commonly used standard format, VRML (Virtual Reality Modelling Language) was normally used, in web environments, in viewers such as Cosmo Player and Cortona. This VRML format has not been developed any further since 1997, but it has been used in various graphic engineering teaching applications, such as the visualization workshop at the University of Burgos (Ramos Barbero et al., 2003), in mental rotation exercises for the development of spatial abilities (Rafi, Anuar, Samad, Hayati, & Mahadzir, 2005), and in the ME-105 "Computer Aided Engineering Graphics" course at the Middle East Technical University of Turkey (http://www.me.metu.edu.tr/courses/me105/Outlineindex/outlineindex.htm). The "WEBD" project, designed under the Leonardo da Vinci International Programme, also used the VRML format initially, but in its new "3DWebEPL" version (http://www.gig.etsii.upm.es/moodle) it uses several viewers such as   3DVIA-Composer, Viewpoint Media Player and eDrawings (Ciobanu, Tornincasa, & Ciobanu, 2009).

A new ISO standard—eXtensible 3D (X3D) Graphics (*Web 3D Consortium*, 1999)—is the next generation VRML language. X3D constitutes an improvement over VRML and opens up a wide range of applications for web-based collaborative visualization in distributed product development. For example, Chih-Hsing Chu (Chu, Cheng, & Wu, 2006) has developed an application, in which it is possible to view various configurations of a 3D product using SpinFire (collaborative visualization utilities), an applications server, and a PDM system.

Choosing the most suitable viewer in a particular environment, with specific needs in mind, is not a simple. We have to bear in mind the following four points: the CAD package in use; whether a 3D publisher is integrated into the CAD software or whether an external one is used; whether a viewer or a plug-in is used; and its format type. In the engineering applications environment, Ron LanFon (LaFon, 2007) assesses the features of the following 3D publishers: SpinFire, Adobe Acrobat 3D, MYRIAD, XVL Studio Pro, QuadriSpace, Right Hemisphere and eDrawings, most of which have trial versions and free viewers.

In the teaching/learning of graphic engineering we can also use these viewers for the manipulation of parts and mechanisms in the initial learning of visualization skills and in the subsequent self-review of various exercises by the students themselves. The manipulation of 3D models using viewers is also useful to us in teaching, in understanding the operation of the devices and their assembly, if these have their simulations incorporated, but unfortunately, there is no standard viewer that covers all web-based 3D information sharing needs. An early study aimed at assessing the features of viewers with regard to their use in teaching was carried out by Tornincasa (Tornincasa & Chirone, 2002). This study compares the viewing tools of 3DAnywhere, cult3D and Viewpoint. A second large study comparing the various Web3D tools was carried out by Vezzetti (Vezzetti, 2009). This examines the features of the following tools: WEB3D-CDF, 3Dif-U3D, Actify-3D, SolidWorks-eDrawings, Cycore-C3D, Viewpoint-mTx, RealityWave-XGL, Lattice3D-XVL, UGS-JT, Cimmetry-CMF, and Tech Soft America-HSF.

The technologies of Web3D formats use CAD 3D models without the use of CAD software. This reduces the size of their files considerably and maintains many of the properties of the models in the CAD, to make it possible to measure distances, add information, manipulate the viewpoint and the zoom, hide/show components, view sections, create animations, etc. The integration of this information and knowledge in the Web3D models into any document is very useful in our students' learning processes, because studying the movements of the various components and devices helps the student to develop spatial visualization, and to understand functional analysis and the assembly of its various components. A third study compares the properties of seven Web3D tools for an e-learning training course in the field of mechanical engineering. This study was carried out by Violante (Violante, Vezzetti, Tornincasa, Bonisoli, & Moos, 2009) and compares the following Web3D tools: Adobe Acrobat 3D, Anark Core, 3DVIA composer, XVL Studio Pro, Cortona 3D, QuadriSpace document3D and Viewpoint Media Player. Violante uses the 3D models in the eDrawings format of the 3DVIA composer technology for his CAD e-learning course as a Web3D tool on the Moodle platform.

A second, current trend in Web3D is becoming increasingly popular and involves the use of electronic documents (for example *.pdf and *.doc formats) which have 3D models integrated into the images, and where it is possible to view and manipulate the 3D models within the electronic document, applying a different plug-in according to the CAD publishing/visualization software in use. The authors of this paper believe that interactive documents are one of the most important web-based resources for the learning of graphic engineering.

For all the above reasons, the subject of this study concerns the right choice of 3D viewers which, bearing in mind our particular requirements, will enable us to manipulate 3D models in documents, within the graphic engineering learning process.

Pedagogical rationale

The fundamental theory that motivates the educational use of EVEs (Educational Virtual Environments) is constructivism. As pointed out by Harper (Harper, Hedberg, & Wright, 2000), apart from reality, the most appropriate way to generate a context based on authentic learner activity may be through the use of EVEs. Following this theory, interaction with the world is relevant for the learning process. For this reason, Web3D technologies, which give great interaction, flexibility and portability are used in an educational context in various ways: formal education, informal education (for example, visits to virtual museums), distance or electronic learning and training. In general, EVEs can provide a wide range of experiences, some of which could never be observed in the real world, such as the internal operation of machines through virtual simulation, for which it is necessary to cut open machines or make certain pieces transparent. An important advantage concerns the use of three dimensional graphics, which allows for more realistic and detailed representations of topics, offering more viewpoints and more inspection possibilities than 2D representations. In many educational contexts (e.g., engineering), this can be crucial to our acquiring a better understanding of topics (e.g., the internal combustion engine).

A significant number of the students who enter our university have fairly undeveloped *spatial abilities*. This is mainly because technical drawing is only an optional subject in further education in Spain. According to Saorin (Saorín Pérez, Navarro Trujillo, Martín Dorta, Martín Gutiérrez, & Contero, 2009), spatial ability is the ability to manipulate objects and their parts mentally in space. Spatial ability is divided into two categories: *spatial relations,* in which the ability to rotate and compare models is developed; and *spatial vision,* in which the ability to manipulate complex visual information is developed (various stages being needed to obtain the solution), such as the recognition of an item by folding and unfolding its faces. Students who need to improve their spatial abilities can be helped by using test collections such as DAT-SR (Differential Aptitude Test in Spatial Relations), PSVT:R (Purdue Spatial Visualization Test: Rotations) and MRT (Mental Rotations test), by using interactive games or spatial visualization workshops, and by performing exercises with the real items in augmented reality or virtually on a computer. It is necessary to use a 3D viewer which meets the learning needs of our students, in order to be able to view and manipulate the 3D models virtually on the computer, which assists our students in the development of their spatial abilities. The 3D viewer that is chosen must therefore be a tool which makes it possible to view and manipulate 3D models, in order to further develop the spatial abilities of graphic engineering students.

Sorby (Sorby & Baartmans, 1996), in the conclusions to a course on 3D visualization abilities, concluded that performing exercises by computer (in his case with I-DEAS software) improved the learning processes of those students who had the greatest learning difficulties. Significantly, Rafi (Rafi et al., 2005) confirmed that the use of Web3D applications as a teaching tool with 3D models in the VRML format improved the development of spatial abilities. Other investigations, however, such as that of Koch (Koch, 2006), have shown that there are no significant differences between sketching and solid-modelling design methods used for technical problem solving.

ICT (Information and Communications Technology) is essential to enable innovation in the communication methods between students and teachers, and the use of learning-based teaching techniques for our students, within the EHEA (European Higher Education Area) (Barajas & Owen, 2000). Investigation into educational techniques and systems associated with the use of Web3D is very limited, and there is great potential for a large number of educational applications that require visual understanding (Strong & Smith, 2001), (*Web 3D Consortium*, 1999). It should be noted that more emphasis has been given to the visualization of 3D objects, because 3D immediately enhances the learning process (Liarokapis et al., 2004). Students can explore a 3D visualization of the teaching material, thus enabling them to understand more effectively through interactivity with Web3d content. It is believed that the experimental scenarios presented can provide a rewarding learning experience that would otherwise be difficult to achieve.

Nevertheless, as Chittaro (Chittaro & Ranon, 2007) affirmed, we must not forget some of the limitations of Web3D technologies in the use of EVEs. These include the teachers' lack of experience or interest in using them, and the fact that their browsers are not always intuitive or easy to use. Furthermore, these Web3D technologies are not cheap and there is no standard method of assessing them (which means that some of their features may be of little relevance). It should also be remembered that using these technologies may have a demotivating effect on certain students.

Definition of the most important requirements in 3D viewers

The Quality Function Deployment (QFD) method is used here, in order to determine the most important items required of 3D viewers for the constructivist learning process in graphic engineering and to see how well these needs are met by the 3D viewers that are currently available on the market. This method is based on identifying the needs of the customers and, in our case, the needs which the viewers are required to meet for the purposes of teaching and learning.

There are studies which identify these needs from perspectives other than our own. For example:
- Tornincasa (Tornincasa, Vezzetti, Calignano, & Moos, 2008), having interviewed workers using CAD/CAM/CAE tools in engineering and manufacturing companies, found that the 4 most important requirements are views, sections, dimensions, and dimensional and geometric tolerances.
- Ortega (Ortega Izquierdo, 2002) used the QFD method to assess digital mock-up systems—Enovia DMU and VisMockup—in three departments of a multinational company in the car industry. It was found that the digital mock-up systems had to meet the following requirements: easy installation, multiplatform modes, precise

visualization, user-friendly operation, with functions for measurement, and analysis (interferences, distances, geometry comparison, etc.), simple simulation, sections, mechanisms and assembly, file printing and export.

The most important items required of 3D viewers with regard to the learning of Graphic Engineering have been defined by the authors of this paper as a team and are given in Table 1. They take into account the above-mentioned studies and the needs of the teachers at our university. The 30 most important needs are divided into 6 sections: visualization, manipulation, document and web integration, format exchange and file properties, performance of software and mechanisms and assemblies.

Table 1. Survey on the features required of 3D viewers

Features required of 3D viewers for the teaching of Engineering
Please indicate with an X the option (A, B, or C) which you consider appropriate for each of the features required of a 3D viewer for a teaching platform .
Where: **A= Essential, B=Necessary, C=Desirable.**

Nº	Requirements	A	B	C
	VISUALIZATION			
1	Rendering and rendering control	☐	☐	☐
2	Visualization (slides, scenes, edges, etc.).	☐	☐	☐
3	Predefined and standard views.	☐	☐	☐
4	Control of vizualisation of drawings	☐	☐	☐
5	Vizualisation of annotations and dimensions	☐	☐	☐
	MANIPULATION			
6	Zoom, movement and rotation (free or on the axis line)	☐	☐	☐
7	Cuts and dynamic sections.	☐	☐	☐
8	Measurement.	☐	☐	☐
9	Creation of annotations and dimensions	☐	☐	☐
10	Precision (measurement)	☐	☐	☐
	DOCUMENT/WEB INTEGRATION			
11	Educational platforms (Moodle, etc.)	☐	☐	☐
12	In the Web, multi-browser	☐	☐	☐
13	In office, pdf, open office, etc.	☐	☐	☐
	EXCHANGE OF FORMATS AND FILE PROPERTIES			
14	Small file size.	☐	☐	☐
15	Importing and exporting (variety of formats).	☐	☐	☐
16	Printing.	☐	☐	☐
17	Security of intellectual property (watermark, signature).	☐	☐	☐
18	Opening without downloading, multiple in the case of simultaneity.	☐	☐	☐
19	Less loss of information (surfaces, centres, precision).	☐	☐	☐
	PERFORMANCE OF SOFTWARE			
20	Low response time.	☐	☐	☐
21	Speed of opening of files.	☐	☐	☐
22	Minimum hardware requirements.	☐	☐	☐
23	Simple intuitive handling.	☐	☐	☐
24	Low price (freeware if possible).	☐	☐	☐
25	Simple installation.	☐	☐	☐
	MECHANISMS AND ASSEMBLIES			
26	Manipulation of components.	☐	☐	☐
27	Decomposition and contraction of the mechanism.	☐	☐	☐
28	Animations.	☐	☐	☐
29	Hiding of components.	☐	☐	☐
30	Distinguishing between components in cuts and sections.	☐	☐	☐
	THANK YOU FOR YOUR COOPERATION.			

Table2. The features required of 3D viewers – The Results

		A (%)	B (%)	C (%)	Mean
	VISUALIZATION				
1	Rendering and rendering control.	30,2	32,1	37,7	2,85
2	Control of visualization (slides, scenes, edges, etc).	35,8	47,2	17,0	3,38
3	Predefined and standard views.	66,0	22,6	11,3	4,09
4	Control of visualization of drawings.	54,7	28,3	17,0	3,75
5	Visualization of annotations and dimensions.	45,3	32,1	22,6	3,45
	Visualization mean (average score)				**3.50**
	MANIPULATION				
6	Zoom, movement and rotation (free or on the axis line).	81,1	15,1	3,8	4,55
7	Cuts and dynamic sections.	45,3	41,5	13,2	3,64
8	Measurement	41,5	32,1	26,4	3,30
9	Creation of annotations and dimensions.	22,6	41,5	35,8	2,74
10	Precision (measurement).	18,9	50,9	30,2	2,77
	Manipulation mean (average score)				**3.40**
	DOCUMENT AND WEB INTEGRATION				
11	Educational platforms (Moodle, etc).	17,0	47,2	35,8	2,62
12	In the web, multibrowser.	34,0	37,7	28,3	3,11
13	En office, pdf, open office, etc.	18,9	35,8	45,3	2,47
	Document and web integration mean (average score)				**2.73**
	EXCHANGE OF FORMATS AND FILE PROPERTIES				
14	Small file size.	49,1	37,7	13,2	2,89
15	Importing and exporting (variety of formats).	39,6	37,7	22,6	3,72
16	Printing.	7,5	32,1	60,4	3,34
17	Security of intellectual property (watermark, signature).	9,4	41,5	49,1	1,94
18	Opening without downloading, multiple in the case of simultaneity.	28,3	49,1	22,6	2,21
19	Less loss of information (surfaces, centres, precision).	49,1	37,7	13,2	3,11
	Exchange of formats and file properties mean (average score)				**2.87**
	PERFORMANCE OF SOFTWARE				
20	Low response time.	47,2	35,8	17,0	3,60
21	Speed of opening of files.	47,2	32,1	20,8	3,53
22	Minimum hardware requirements.	26,4	50,9	22,6	3,08
23	Simple intuitive handling.	64,2	28,3	7,5	4,13
24	Low price (freeware if possible).	49,1	37,7	13,2	3,72
25	Simple installation	45,3	41,5	13,2	3,64
	Performance of software mean (average score)				**3.62**
	MECHANISMS AND ASSEMBLIES				
26	Manipulation of components.	49,1	39,6	11,3	3,75
27	Decomposition and contraction of the mechanism.	39,6	49,1	11,3	3,57
28	Animations.	32,1	43,4	24,5	3,15
29	Hiding of components	50,9	43,4	5,7	3,91
30	Distinguishing between components in cuts and sections.	43,4	47,2	9,4	3,68
	Mechanisms and assemblies mean (average score)				**3.61**

To ascertain the importance of the items required in these 3D viewers, the survey shown on Table 1 was sent by e-mail to 82 teachers at 40 Spanish universities who work in the field of graphic engineering and who were selected, in view of their bibliographies, teaching, and research work in areas that involve the use of 3D CAD and 3D viewers. 54 teachers from 29 universities provided responses to the survey.

The results of the survey on 3D viewers are shown on Table 2 in which 5 points are given to Option A (essential), 3 points to Option B (necessary), and 1 point to Option C (desirable). This table shows that the three most important requirements were considered to be: zoom, movement and rotation (free or on the axis line) with 4.55 points; simple, intuitive handling (4.13 points); and, predefined and standard views (4.09 points). The maximum possible would, of course, have been 5 points.

Selection of the 3D visualization configurations to be analysed

First of all the technical features of 26 softwares for 3D visualization were studied (viewers, publishers and 3D output formats): Adobe Acrobat Pro Extended, RxView, SpinFire Professional, MYRIAD, XVL Studio Pro, Publisher3D Professional and Pages3D Professional, Deep Exploration CAD Edition, eDrawings Professional, 3DVIA Composer, Anark Core Workstation, Cortona 3D viewer (Parallelgraphics), Viewpoint Media Player, Kaon Web3D, Hoops Stream Toolkit, 3D XML player, AutoVue (Oracle), Meshlab, OneSpace Designer – 3D Access, 3D-Tool, Alteros 3D, Cult3D (Cycore Systems), Delcam Exchange, 3DVIA-printscreen, Autodesk ® Design Review, COLLADA, Interactive Product Animator (IPA).

As a consequence of this initial study, we realized that in the process of selecting 3D viewers for teaching purposes it is necessary to take into account not only the specific visualization softwares but also all the items that are involved in the process, namely the CAD package (SolidWorks, Catia, Solid Edge, Inventor, Pro/Engineer, NX, etc.), the publisher, the output format (3D XML, VRML, COLLADA, etc.), the viewer/plug-in (eDrawings, MYRIAD 3D Reader, etc.), and the format of the document. Bearing in mind these items, we have considered two alternatives (Figure 1): the first is generated from the CAD model which is exported to a visualization format and, by means of the appropriate viewer or plug-in, is integrated into the document; and, in the second, a publisher which accepts the CAD format and exports it to a format which is compatible with the model or type of document is also needed.
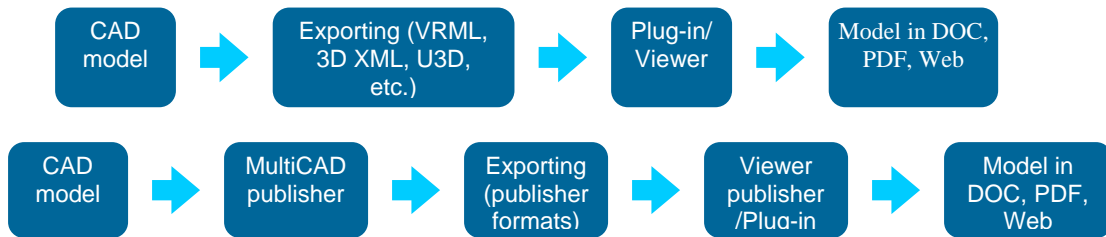
Figure1. Viewers: the two alternatives.

Following an initial study of the technical features of the 26 softwares, and taking into account the above two alternatives, the CAD packages available, and the possibility of having documents with interactive 3D models, we selected three cases of 3D viewer configurations for the learning of graphic engineering. These are:

- *Configuration A* (Figure 2). Exporting the models in eDrawings format from SolidWorks. The files obtained keep the animations and review tools of the CAD models (Figure 3 and Annex 1) and it is possible to manipulate the models with the eDrawings freeware viewer which can be downloaded from http://www.edrawingsviewer.com/pages/programs /download/.
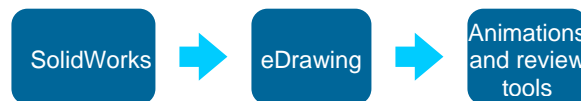
Figure 2. Configuration A

The strongest points of configuration A are as follows: easy insertion of 3D models in Office and Internet, freeware viewer, and importing of animations generated in SolidWorks.
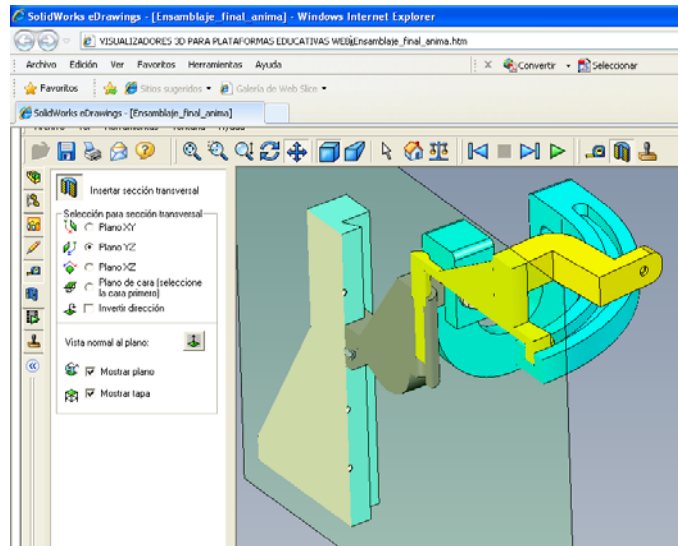
Figure 3. Example of cutting tool with eDrawings (Annex 1).

- *Configuration B* (Figure 4). First of all, the models are exported from Catia to 3DXML format, and by means of the 3D XML Player freeware viewer (which can be downloaded at http://www.3ds.com/es/products/3dvia/3d-xml/1/), the models can be manipulated and the Catia generated animations (Figure 5 and Annex 2) are kept, with easy integration into Office documents and into the web, but without review tools. 3DXML is a proprietary 3D file format developed by Dassault Systèmes under its 3D Via Brand; it uses an XML container whose specifications were published but it should not be confused with X3D, which is the ISO standard XML-based file format for representing 3D.
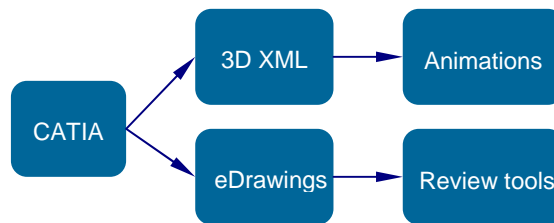
Figure 4. Configuration B
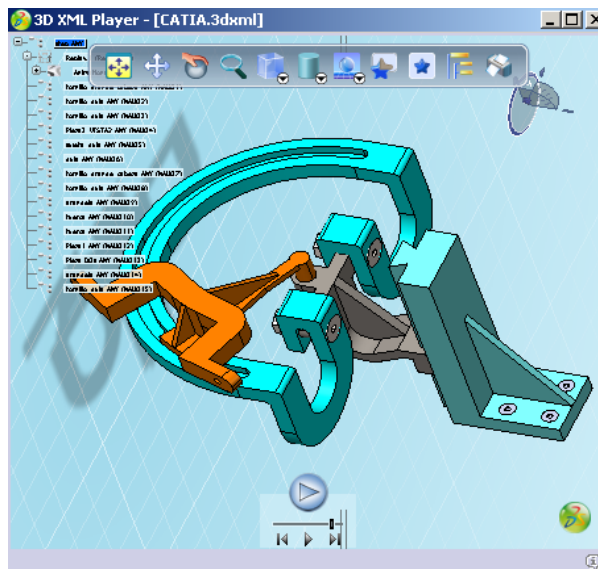
Figure 5. Example of animation in 3D XML Player (Annex 2)

The strong points of the 3DXML output formats are: easy insertion of 3D models into Office and Internet, the viewer is freeware, and the importing of animations generated in CATIA. But the package does not, however, have basic model review tools such as measuring or making cuts and, furthermore, only SolidWorks and CATIA export in 3D XML.

In the second stage, the eDrawings Publisher integrated into Catia (Figure 4) allows the CAD model to be exported in the eDrawings format, and review tools (sections, measurements, annotations, etc) are now incorporated in the eDrawings freeware viewer. The file can be integrated into Office or web documents. We now need two files, however, to do the same thing. The Catia and SolidWorks eDrawings files are almost identical, except that former do not convert the animations or the disassembly.

If the documents are needed in *.pdf format, it is more appropriate to use Configuration C (below) than to convert the Configuration A and B Office documents to *.pdf format because in the conversion we lose all the options of interaction with the 3D model in the *.pdf document.

- *Configuration C* (Figure 6). In this configuration, we start from a model generated with the available CAD 3D software. The model is kept in the predefined format of that particular CAD 3D software, to be imported later on into the Adobe Acrobat Pro Extended publisher (http://www.adobe.com/products/acrobatproextended/) (Figure 7). If it is necessary to include animations, these are generated with Adobe 3D Reviewer (Figure 8 and Annex 3) and may be exported in *.pdf format with option U3D ECMA 1 activated.
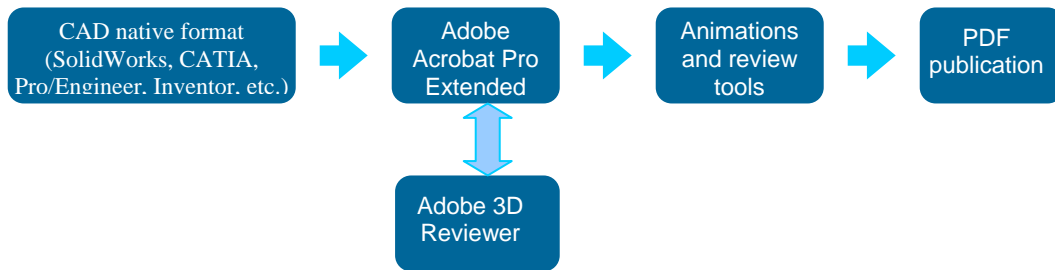
Figure 6. Configuration C
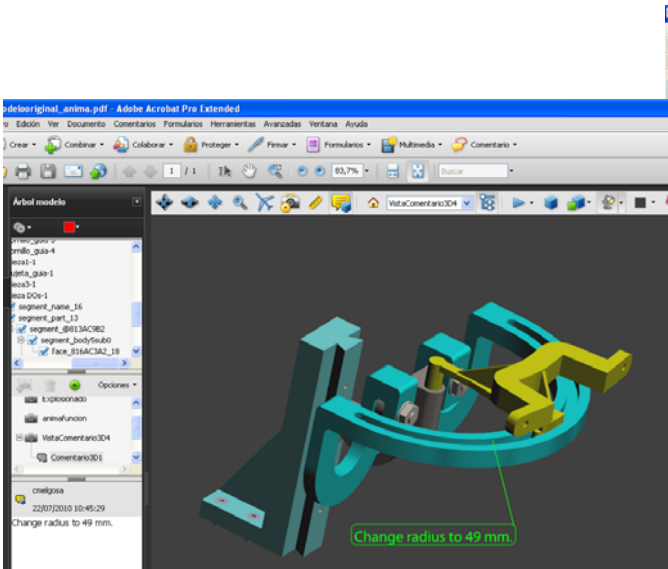
Figure 7. Example of annotation in Adobe Acrobat Pro Extended
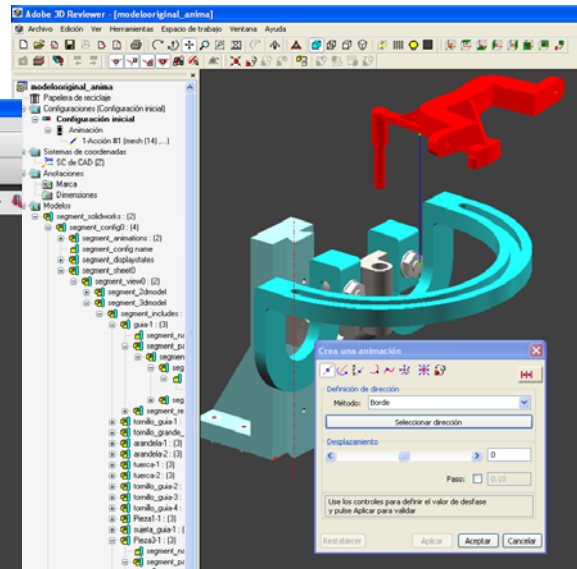
Figure 8. Example of animation in Adobe 3D Reviewer (Annex 3).

The most popular CAD and neutral formats can be imported directly into Adobe Acrobat Pro Extended, but if any type of file is not imported, the 3D files can be converted to the neutral U3D format from the CAD package, it is

imported in Adobe Acrobat Pro Extended and stored in the pdf file. Universal 3D (U3D) is a compressed file format standard for 3D computer graphics data. The format was later standardized by the Ecma International Technical Committee 43 (TC43) as ECMA-363 (ECMA, 2007). In 2007, TC43 added support for Uniform and Non-Uniform, Rational and Non-Rational Free-Form Curves and Surfaces. It does however have important limitations such as the fact that the meshes must always be triangles. The U3D format can be edited in Adobe 3D Reviewer.

The strong points of Configuration C are as follows: It accepts most CAD formats. It works with the U3D format and generates a very good rendering appearance. However, it does not import the animations created in the CAD packages and it is necessary to create them with Adobe 3D Reviewer.

When the eDrawings files are exported to html format, eDrawings review tools may be used, but if they are inserted into an Office document, it only allows the use of basic visualization and manipulation tools, not the review tools. When the Office documents are converted to *.pdf they lose the 3D options. However, the installation of Adobe Acrobat Pro Extended adds an Adobe toolbar to Office, which enables us to embed 3D models from the native CAD packages in Office, maintaining the visualization and manipulation options of the 3D models. Only Office users who have installed the Adobe Acrobat Pro Extended package can manipulate these 3D models correctly.

Moreover, we can convert the Office file to a *.pdf file. These models can be viewed and manipulated with Adobe reader Version 7 and above, without the Adobe Acrobat Pro Extended package.

However, if the CAD 3D models are embedded directly in Adobe Acrobat Pro Extended the review options are lost. The visualization and manipulation options are maintained although it is necessary to do the animations with the Adobe 3D Reviewer module. These 3D models in Adobe can also be viewed with Adobe Reader versions above 7 and the review options are lost (measurement, sections and 3D commentaries).

Method of assessment of the 3D viewers

To compare the features of the three viewer configurations selected, we used "House of Quality," which is part of Quality Function Deployment (QFD). House of Quality (HQ) is a diagram, resembling a house, used for defining the relationship between customer desires and the capabilities of the firm/product. It utilizes a planning matrix to relate what the customer desires to how a firm (which produces the products) is going to meet those desires. It is reported to increase cross-functional integration within organizations using it, especially with marketing. It therefore enables us to make a competitive comparison of the configurations of the viewers that are on the market.

Table 3. House of Quality
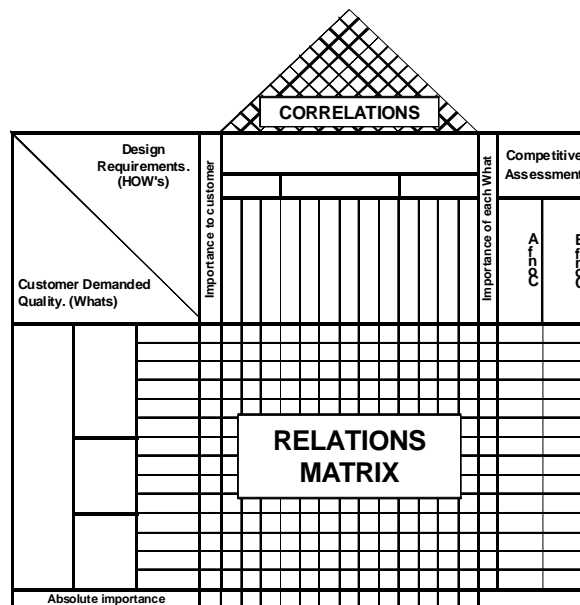
The basic structure of HQ is a table with "whats" as the labels on the left and "hows" across the top (Table 3). The roof is a diagonal matrix of "hows vs. hows" and the body of the house is a matrix of "whats vs. hows." We used a simplified house of quality, without correlations, as we did not use the house of quality as a tool for designing a new product but to compare existing software packages.

To begin the construction of the HQ, we identified and listed the customers' requirements (the "whats"). In our case, the customers were teachers who were experts in 3D CAD in the Graphic Expression areas of various Spanish universities. We also had to bear in mind the fact that the viewers under assessment were to be used for virtual learning. Based on our knowledge of customer needs, we will determine their demands and requirements vis-à-vis the products under assessment; in short, their expectations. The results of the survey, shown on Table 2, reveal the relative importance of the "whats" demanded by the customers.

The "hows" are expressed perpendicularly to the "whats", and each "how" is a measurable feature of a "what". For each "what" at least one measurable "how" should be identified (Table 4 or Annex 4). These "hows" were also identified by the authors in a group discussion in which they considered the earlier study by Ortega (Ortega Izquierdo, 2002).

The relationships between the above mentioned "whats" and "hows" are shown on the relations matrix using

numerical symbols, which indicate the strength of the relationship ($\triangle$ 1=weak, $\bigcirc$ 3 =medium, $\bullet$ 9 = strong).

The absolute importance of each "what" is obtained by adding up the values 1, 3 and 9 on each of the squares in the "what" row, and the result obtained is multiplied by the importance score of the "what" that was obtained in the customer survey. Calculated this way, the absolute importance of each "what" provides a vision of the overall importance of each customer requirement. It tells us how important each of the characteristics required of the viewers is, considering the importance attached by the customers to each "what" and the added importance of the "how" relationships.

The absolute importance of each "how" is obtained by multiplying the values (1, 3 and 9) of each square in the column by the result of each of the values of the "whats" obtained in the survey, and adding up all the values (Cuatrecasas Arbós, 1999). Calculated this way, this importance of the "hows" tells us how important each product feature is; in our case the features of the viewers.

Finally, we add the columns to the HQ of the three viewer configurations under assessment, attributing values of 0 to 10 to each of the "whats" that are assessed in each configuration. These columns, which are also known as competitive assessment columns, tell us the strong points and weak points of each of the configurations.

The final value of each configuration is determined by the weighted average of the absolute importance of each "what" and the assessments made of each requirement (what).

Results of the assessment of the 3D viewers

The results of the assessment of the viewers are shown in the HQ table (Table 4 or Annex 4) in which the values of the matrix of the relationships (weak, medium and strong) between the "whats" and the "hows", and the assessments of each of the "whats" of each of the three configurations have been obtained separately by each of the three authors. A discussion then took place in which each teacher explained his/her assessments and an overall score was allocated to each.

The scores from 0 to 10 points in the "whats" or requirements for the three configurations, A, B and C, were allocated as follows:
- 0 points, if a configuration totally fails to meet the requirement.
- 3 points, if it does not completely meet the requirement and requires the installation of accessories.
- 5 points, if it meets the requirement but it requires accessories or if it only half meets the requirements. And, so on, up to 10 points.

- 10 points, if it fully meets the requirement.

To assess the configurations we used the same 3D models on the different CAD softwares.

During the experiment, the following noteworthy points emerged:
- *Configuration A*. The eDrawings files obtained from SolidWorks do not have render control; it allows adequate visualization, manipulation and review of pieces and assembly; the eDrawings can be integrated into a Microsoft Office document (but not in the Power Point presentation) losing model review options and animations (Open file: "Annex 5 example configuration_A.doc"); drawings can be included. But if this document is exported to *pdf, all the information is lost.
- *Configuration B*. It is necessary to install the Catia eDrawings software in Catia to obtain the models in eDrawings format; the animations created are lost on exporting to eDrawings; from Catia it is possible to export in 3DXML format to obtain the simulations and with a plug-in it is possible to manipulate the model with fewer options in the viewer; the 3DXML files in the Microsoft Office documents can be used to see the animations (Open file: "Annex 6 example configuration_B.doc"); and Configuration B behaves in the same way as Configuration A with regard to the loss of interactivity on exporting the Microsoft Office document to *.pdf format.
- *Configuration C.* Adobe Acrobat Pro Extended accepts most CAD software formats; it does not directly insert the CAD software animations although they can be generated with the 3D Reviewer module in Adobe Acrobat Pro Extended; the visualization tools are more numerous in the *.pdf document than in the Microsoft Office document; and for the users of these 3D models in *.pdf, we only need Adobe reader Version 7 and above, and these are freeware (Open file: "Annex 7 example configuration_C.pdf").

The HQ not only enables us to make a diagnosis of the design of a product, it also enables us to make a quantitative comparison of products on the market, in our case 3D viewers for use in the learning of graphic engineering. By using the HQ (Table 4 or Annex 4), we identified the most important "whats" and "hows" to be taken into account when selecting viewers. These are shown below.

The most important technical features that the viewers should possess are as follows:
- Ease of handling.
- Integration into documents and web (Microsoft Office, Adobe Acrobat, educational platforms and various browsers).
- Variety of visualization modes (visible edges, hidden edges, etc.)
- Speed of manipulation.
- Ability to view dimensions and annotations.

A study of the averages of the requirements of the customers shows that the following are essential:
- Predefined and standard views.
- Control over the visualization of drawings.
- Zoom, movement and rotation (free or on the axis line)
- Importing and exporting (variety of formats).
- Simple, intuitive handling.
- Price (freeware if possible).
- Manipulation of components.
- Hiding of components.
- Distinguishing between components in cuts and sections.

The most important requirements of the customers, based on the survey of teachers and the matrix of relationships with the "hows," are shown in the "absolute importance of the "whats" column. These are markedly different from the survey values and are as follows:
- Exchange of formats: importing and exporting (variety of formats).
- Manipulation by means of: zoom, movement and rotation (free or on the axis line), cuts and dynamic sections.
- Simple, intuitive handling of the viewer and rapid response time.
- Control of visualization (transparencies, scenes, modes), and predefined and standard views within the visualization.

Table 4. House of quality: assessment of viewers

MEASUREMENTS OF THE PRODUCT (HOWS) — REQUIREMENTS (WHATS)

Column N° (HOWS)	Row N°	Results of the survey: mean	Token importance
VISUALISATION			
Rendering and rendering control	1	2,9	B
Control of visualization (slides, scenes, models)	2	3,4	B
Predefined and standard views	3	4,1	A
Control of visualization of drawings	4	3,8	A
Visualization of annotations and dimensions	5	3,5	B
MANIPULATION			
Zoom, movement and rotation (free or on the axis line)	6	4,6	A
Cuts and dynamic sections	7	3,6	B
Measurement	8	3,3	B
Creation of annotations and dimensions	9	2,7	B
Precision (measurement)	10	2,8	B
DOCUMENT AND WEB INTEGRATION			
Educational platforms (Moodle etc)	11	2,6	B
In the Web, multibrowser	12	3,1	B
In office, PDF, open office, etc	13	2,6	B
EXCHANGE OF FORMATS AND FILE PROPERTIES			
Weight	14	2,9	B
Importing and exporting (variety of formats)	15	3,7	A
Printing	16	3,3	B
Security of intellectual property (watermark, signature)	17	1,9	C
Opening without downloading; multiple in the case of simultaneity	18	2,2	C
Less loss of information (surfaces, centres, precision)	19	3,1	B
PERFORMANCE OF THE SOFTWARE			
Response time	20	3,6	B
Speed of downloading	21	3,5	B
Hardware requirement	22	3,1	B
Simple, intuitive handling	23	4,1	A
Price (freeware if possible)	24	3,7	A
Simple installation	25	3,6	B
MECHANISMS AND ASSEMBLIES			
Manipulation of components	26	3,8	B
Decomposition and contraction	27	3,6	B
Imported animations	28	3,2	B
Hiding of components	29	3,3	B
Distinguishing between components in cuts and sections	30	3,7	A

ABSOLUTE IMPORTANCE OF THE "HOWS"

REQUIREMENTS (WHATS) — Absolute importance of the "WHATS"

WHAT	Col N°	Abs. importance
VISUALISATION		
Personalized creation of renderings	1	100
Predetermined renderings	2	85
Edition of colours	3	103
Generation of slide	4	150
Application of illumination	5	118
Sold shading in the cuts	6	117
Variety in modes of visualization (visible edges, hidden edges, etc.)	7	230
Absence of polygonization	8	177
Capability of visualization of dimensions and annotations	9	206
Keeping views.	10	142
MANIPULATION (Ease of handling of mouse)		
Shift	11	167
Rotation	12	166
Zoom	13	167
Ease of locating icons.	14	120
Movement vis-a-vis a specific axis	15	118
Speed in manipulation	16	219
Ease of positioning of the section plane	17	102
Ease and capability of measurement of elements	18	195
Creation of dimensions (measurements)	19	152
DOCUMENT AND WEB INTEGRATION (Microsoft Office integration)		
Word	20	226
PowerPoint	21	226
Excel	22	226
Integration into Open Office	23	226
Integration into Adobe Acrobat	24	226
Integration into web pages	25	262
Integration into educational platforms UBU Campus, UBU Virtual (Moodle)	26	271
Microsoft Internet Explorer	27	224
Firefox	28	224
Chrome, Safari.	29	224
EXCHANGE OF FILE PROPERTIES AND FORMATS		
CATIA import	30	150
SolidWorks import	31	150
Solid Edge import	32	150
Inventor import	33	150
Pro/Engineer import	34	150
NX import	35	150
Auto CAD import	36	150
Importing of neutral formats (IGS, STEP, DXF...)	37	150
File size	38	196
Keeping original surfaces	39	148
Saving reference elements (axes, planes, points, etc.)	40	177
Protection of confidential data	41	65
Simultaneous use of a file by several users	42	71
SOFTWARE PERFORMANCE		
Easy understanding of interface (icons, menus, etc)	43	121
Possibility of choosing visible icons.	44	84
Immediate running of operations.	45	179
Compatibility with basic hardware	46	186
Compatibility with various operating systems.	47	53
Ease of installation	48	45
Availability of free plug-ins, at no cost	49	155
Ease of handling	50	248
Ease and effectiveness of use of help.	51	110
Ease of printing, graphic area	52	165
MECHANISMS AND ASSEMBLIES		
Keeping animations.	53	129
Keeping created views.	54	177
Keeping cuts	55	174
Keeping the entities of one piece together.	56	161
Keeping joints (cinematic splices).	57	117
Ease of selection of components.	58	174
Keeping the mechanism component tree	59	141

ASSESSMENT

Configuration	Final assessment
CONF. A: SolidWorks + eDrawings	7,5
CONF. B: CATIA + 3D XML / eDrawings	6,7
CONF. C: SolidWorks / CATIA / Pro + Adobe Acrobat P.E.	7,1

Final assessment: 7,5 / 6,7 / 7,1

Relations between WHATS and HOWS:
WEAK (△) — MEDIUM (◐) — STRONG (●)

Token importance: A — ESSENTIAL; B — NECESSARY; C — DESIRABLE

The overall competitive assessment of the three configurations -A=7.5 points, B=6.7 points and C=7.1 points- is obtained as a weighted average of the "whats," evaluated for each configuration in accordance with the absolute importance of each "what" (Table 4 or Annex 4). This score is high in Configurations A and C, without any significant difference between these. The score given to Configuration B is acceptable. As the differences in the scores are not great, the choice of configuration would generally be more a question of the CAD software used and the type of interactive document into which one wished to introduce the 3D model.

It is necessary to bear in mind, in order to understand the results shown in table 4, that:
- The column "results of the survey: mean" is obtained from the last column in table 2.
- The column "token importance" is a conversion of the earlier column into: A(essential), B(necessary) and C(desirable).
- The relations between the "whats" and the "hows" (Central matrix of the table) are valued as: 1 point for weak relations ($\triangle$), 3 points for average relations ($\bigcirc$) and 9 points for strong relations ($\bullet$).
- The column absolute importance of the "whats" is obtained by adding the relations of the "whats" and the "hows" of each row of the relations matrix, and its result is multiplied by its corresponding one in the column "results of the survey:mean".
- The row of the absolute importance of the "hows" is obtained from the addition of the products of the elements in the column "results of the survey: mean" by the corresponding elements in the column of the relations matrix.
- The points given for the evaluation of the "whats" in the three configurations range from 0 to 10 points. The final score of each configuration is obtained as a weighted measure of the value assigned to each "what" in that configuration, the weights being the elements of the column "absolute importance of the whats."

Conclusions

The survey completed by 54 teachers with knowledge of CAD has shown the importance of the 30 requirements, which we had initially selected for use in the learning of graphic engineering, classed as: essential, necessary and desirable (Table 2). From the survey of teachers (Table 2) the following "whats" are considered essential: predefined and standard views; control of visualization of drawings; zoom, movement and rotation (free or on the axis line); importing and exporting (variety of formats); simple, intuitive handling; price (freeware if possible); manipulation of components; hiding of components; the distinction between components in cuts and sections.

The House of Quality is a tool which has enabled us to identify and quantify the absolute importance attached by the customers to each requirement (what), and to identify and quantify the technical importance of each of the features (how) (Table 4). It confirmed that the "whats" of greatest absolute importance in decreasing order are: -exchange of formats: importing and exporting (variety of formats); -manipulation by means of: zoom, movement and rotation (free or on the axis line), cuts and dynamic sections; -simple, intuitive handling of the viewer and rapid response time; -control of visualization (transparencies, scenes, modes), and predefined and standard views within the visualization. And the "hows" of greatest absolute importance in decreasing order are: ease of handling; integration into documents and web (Microsoft Office, Adobe Acrobat, educational platforms and various browsers); variety of visualization modes (visible edges, hidden edges, etc.); speed of manipulation; ability to view dimensions and annotations.

After assessing the technical features of 26 3D visualization software (viewers, publishers and 3D output formats), the following 3 configurations were selected and compared using the house of quality: A) SolidWorks plus SolidWorks eDrawings, B) Catia plus Catia eDrawings and 3DXML, and C) various CAD softwares plus Adobe Acrobat Pro Extended. The three viewer configurations are suitable for our purposes. Although we first intended to compare 3D viewers we discovered in the course of the exercise that the use of one or another viewer is affected by the CAD software, the publisher, the formats, the viewer and the type of document. It is for this reason that we advise:
- The use of configuration A for html files or files for independent visualization.
- The use of configuration B for files in Office format, where it is necessary to combine two files: an *.edrawing file and another *.3dxml file.
- The use of configuration C for files in pdf format.

- To bear in mind when selecting the visualizer the two alternatives for the implementation of the visualizers (Figure 1): compatibility with the export formats of the CAD packets in use (3D, XML, U3D), and compatibility with the multicad publisher in use and its export format.

Overall, similar scores were allocated to the three configurations but from our experiments we can say that the following differences exist between them:

- The eDrawings viewer has a greater number of design review tools from the engineering point of view. It is possible to export to eDrawings format from most CAD softwares. The animations created in SolidWorks are kept in the eDrawings format, but not those created in Catia.
- The 3DXML format is a format of Dassault Systèmes (owner of SolidWorks and Catia) which keeps the animations of the models but does not have a model review tool (such as, for example, measure).
- The *.pdf files obtained with Adobe Acrobat Pro Extended accept most CAD formats, though the Adobe package does not convert the animations from the CAD models and has a greater number of visualization and manipulation tools, but from the perspective of a general purpose CAD software.

Finally, we may say:

- that the visualization of the 3D models, in these three visualization configurations, by students, does not need the original CAD software, and the students need do no more than download a plugin for configurations A and B, which is without charge.
- that the user interfaces of these visualizers are intuitive and easy to use by people that are not experts in the matter, thereby eliminating some of the limitations advanced by Chittaro (Chittaro & Ranon, 2007).
- that the animations in the 3D visualizer takes up values of at least 1/100 with respect to the same animation in a video file with a 800x600 pixel resolution. Hence, online Internet visualization of animations with the 3D visualizers is immediate.

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