[Article] PRODUCT LIFECYCLE DATA SHARING AND VISUALISATION: WEB-BASED APPROACHES

PRODUCT LIFECYCLE DATA SHARING AND VISUALISATION: WEB-BASED APPROACHES

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ABSTRACT

Both product design and manufacturing are intrinsically collaborative processes. From conception and design to project completion and ongoing maintenance, all points in the lifecycle of any product involve the work of fluctuating teams of designers, suppliers and customers. That is why companies are involved in the creation of a distributed design and a manufacturing environment which could provide an effective way to communicate and share information throughout the entire enterprise and the supply chain. At present, the technologies that support such a strategy are based on ***World Wide Web*** platforms and follow two different paths. The first one focus its attention on ***2D documentation improvement*** and introduces 3D interactive information in order to add knowledge to drawings. The second one works directly on 3D models and tries ***to extend the life of 3D data*** moving these design information downstream through the entire product lifecycle.

Unfortunately the actual lack of a unique **3D web-based standard** has stimulated the growing up of many different proprietary and open source standards and, as a consequence, a production of an incompatible information exchange over the WEB.

This paper proposes a structured analysis of web-based solutions, trying to identify the most critical aspects to promote a unique 3D digital standard model capable of sharing product and manufacturing data more effectively - regardless of geographic boundaries, data structures, processes or computing environment.

KEYWORDS

Collaborative design; Web3D, Virtual enterprise; Product lifecycle management

1 INTRODUCTION

Businesses today face three on-going challenges: improving customer intimacy, achieving operational excellence, and providing product leadership. Improving customer intimacy requires understanding and responding quickly to current and potential customers needs. Achieving operational excellence requires enterprises to focus on operating efficiently, effectively, and flexibly, working with their partners to reduce the cost and time necessary to deliver high-quality products that meet their customer's requirements in a timely manner. Providing product leadership means delivering leading- edge products and solutions tailored to customer needs. All of these challenges require getting the right products to the right market, at the right time, for the right cost. To meet these challenges, businesses must become more innovative. However, being an innovative business doesn't simply mean creating innovative products. It also means improving the processes a company uses to produce its products and the strategies it devices to support them throughout the entire product lifecycle [1]. Today, innovation is recognized as the critical aspect for a business to maintain its competitiveness advantage in the marketplace. Innovation must be achieved while reducing overall product-related costs across development, production, and service. A primary business driver is increasing product complexity and customization. As a consequence products are characterised by more and more intricate mechanical, electronics and software configurations with many possible alternatives. This increase in product complexity, coupled with the desire for personalized configurations, requires an enhanced ability to quickly define new product variations and options, and to manage the configurations being offered. Moreover, companies must manage the "entire" product or product family, integrating elements such as product recipes and packaging in order to meet regional requirements and regulations. This can best be accomplished through proper application of a **Product Lifecycle Management (PLM)** approach that addresses the needs of the extended enterprise [2,3]. PLM is a strategic business approach that applies a consistent set of business solutions to support the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise from concept to end of life, integrating people, processes and business systems. Moreover, while product life is rapidly decreasing and product structure is frequently changing and becoming more customer-oriented, manufacturing systems have become today complex and globalized. For this reason manufacturers have reduced the development and the manufacturing production time, and have adopted an outsourcing approach. In fact, product development and production do not occur within a single manufacturing plant, but have become a joint venture between suppliers, manufacturers, distributors, and customers [4,5]. So, it becomes very important to manage the workflow harmoniously and to share information efficiently among geographically dispersed users. Starting from these needs, the new concept of collaboration focuses its attention on tools for sharing information and knowledge in various divisions and for executing tasks cooperatively in order to improve product quality.

2 THE ROLE OF 3D VIRTUAL PRODUCT IN PRODUCT LIFECYCLE

Today, everything from toaster to automobiles to jet aircraft is designed on a CAD solution. This includes over all product design as well the development of individual parts. Typically the best design is reached through many iterations, without any guarantee that more iterations will get closer to an optimum. This means that the designer does not know if his design process is mathematically convergent. Nominally, the design process consists of the different steps: problem definition, basic requirements, design, analysis, testing, prototype testing, design modification and production testing (Fig. 1)

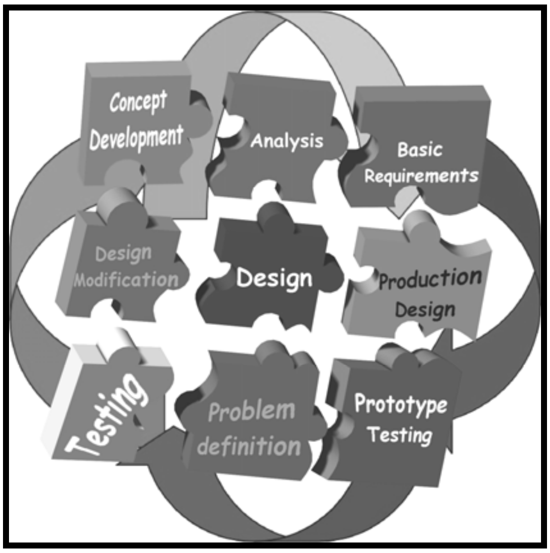

Fig. 1. The integrated phases of the mechanical design process

Every phase must be flexible, integrated and must be updated in real time. The long design and development process can be attributed to the need for many design iterations.

In this scenario, a surprising amount of different engineering drawings and 3D models is normally created. Designers often start thinking on 2D drawings (sketches), while expressing their thoughts regarding the model geometry. Then from these sketches, some detailed dimensioned drawings are created, and other engineers sometimes translate these drawings into 3D models. Moreover, the manufacturing department recreates other production drawings for NC machine tools while some other 3D models and drawings are produced for static and dynamics analysis needs[6,7].

If designers worked with a unique 3D digital model, from concept to manufacturing, a big part of the duplication work could be eliminated, thus minimizing the errors caused by design intent misinterpretation. The benefits of the 3D virtual product workflow are evident throughout the entire product development process. The use of parametric CAD and similar engineering tools encourages the interactive manipulation of complex 3D forms early in the design process. Photo realistic rendering allows an accurate visualization of design details even before the creation of any prototype. There are not only 2D drawings to interpret but the original design intent is accurately expressed with the help of 3D models and 3D animations, that demonstrate product functionalities and preview assembly methods.

Unfortunately CAD companies today do not support cooperative product design concurrently and interactively and tend to use proprietary formats. This situation has created a heavy constraint, especially for the integration with Product Lifecycle Management asset, since the different actors that are part of the same design team often employ different CAD solutions [8,9].

A first solution to this problem has been the use of CAD neutral formats (IGES, STEP, …) in order to allow the data exchange between the different designer teams. However, the presence during the product development of non technical users (sales operators, customers, …), (concurrent engineering), who need to access the product design data, has obliged the industrial information technology providers to move towards more efficient solutions [10,11]. Thanks to the significant improvements proposed by the computer graphic and the Internet context, the constraint cited above and concerning the employment of neutral files, has been skipped. In fact, web developers had the idea of creating objects and environments which could be viewed and manipulated via Web with the use of standard browsers, and without specific 3D CAD tools. As far as **Web3D is concerned,** the technical literature normally indicates those technologies for displaying and exploring interactively web three dimensional contents. This approach only asks a low hardware and software investment, and an easy and customizable system. It is precisely because of the low hardware requirements and the portable platform that the collaborative company asset could actually be operatively implemented by a wide number of societies [12,13].

3 Web3D: PRODUCT LIFECYCLE REPURPOSING 3D DATA STRATEGIES

Besides giving collaborative access to product data during its development, today these WEB tools, are promoting two new strategies. The first solution family works directly on 3D models and tries to extend the life of 3D data by moving these design information downstream through the entire product lifecycle. For every different phase of the product life, this standard allows a selective access to the virtual product information. The second solution family focuses its attention on 2D documentation and introduces 3D interactive information in order to add knowledge to drawings.

Web3D for extending life of 3D data

As far as product lifecycle management is concerned, the primary benefit of Web3D is that it allows CAD sourced 3D diagrams and animations to be shared, displayed and utilized outside of the proprietary CAD software products. This possibility of breaking the *"proprietary CAD barrier"* opens the door to the use of 3D graphics and animations in an host of areas later on in the typical product lifecycle. Within engineering and manufacturing, 3D will still be primarily used, shared and viewed within the proprietary CAD software tools (Fig.2). Once a product has been manufactured, the bias of 3D use switches to theWeb3D solution. At this point, 3D graphics can be employed within a host of areas and activities. For instance, Web3D will enable the use of 3D graphics and animation in product beta and test marketing, marketing collateral and design-to order sales processes (most likely online). Web3D will also allow the inclusion of 3D product and component renderings within maintenance, support manuals and documentation. Of course, the value of including 3D graphics in marketing, training and maintenance materials varies from product to product. 3D provides tremendous value for visualizing and comprehending complex products like airframes, engines, medical equipment and industrial machinery, but provides little additional value over 2D for simple products like food or apparel. Thus, the value of Web3D is directly proportional to the complexity of the product being marketed or maintained (Fig.3). Equally, the size of the potential audience for the 3D graphics has a direct bearing on the value of providing them. If there is only a small audience, then the value and return on providing 3D graphics outside of proprietary CAD environments is relatively small, even for some complex products. However, if the audience is large, then the value of 3D, and therefore of Web3D, increases exponentially.

While in some industries Web3D will have very little useful application, in others, like the automotive industry, Web3D has the potential to be a disruptive technology, providing early adopters with significant competitive advantages. In industries that manufacture, service or maintain complex products with a large enough market segment, the significant short- and long-term cost savings that can be realized from including 3D graphics within sales, training and maintenance literature, will make Web3D an essential technology. Some consumer product manufacturers are also likely to start adopting Web3D relatively rapidly. Manufacturers of products that require consumer assembly or configuration (e.g. computers, home entertainment equipment, flat-packed furniture, etc.) will gradually transit to 3D electronic-format assembly instructions.

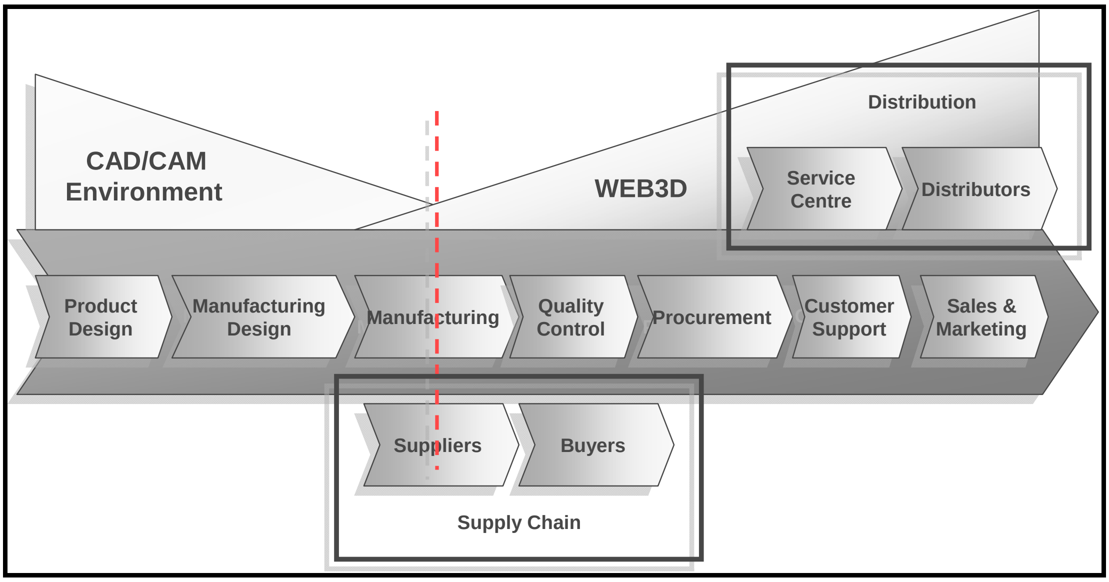

Fig. 2. Relative value and areas of use across the product lifecycle

This transition to 3D electronic-format assembly instruction will not only make life easier for the consumer, it will also reduce the manufacturer's support and return/replacement costs, providing a competitive advantage to early adopters (Fig.3).

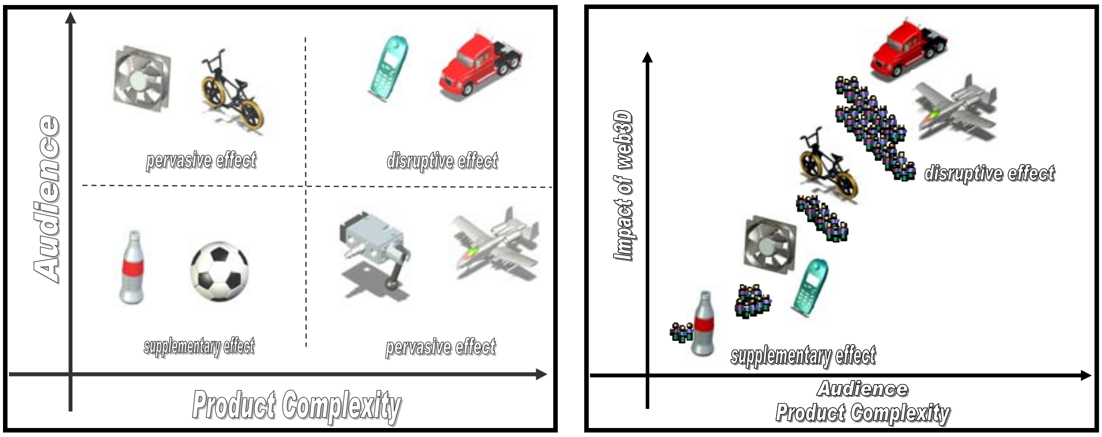

Fig. 3. Value of a Web3D approach proportional to audience size and product complexity

Eventually, Web3D will become pervasive in all industries that market either complex or consumer products. Even when a product is not that complex, and does not require any kind of assembly, the inclusion of 3D within sales documentation has the potential to increase sales[14]. Following this idea some 3D tools providers have proposed their own solutions: **WEB3D-CDF**, **3Dif-U3D**, **Actify-3D, Solidworks–eDrw, Cycore-C3D, Viewpoint-mTx, RealityWave-XGL, Lattice3D-XVL, UGS-JT, Cimmetry-CMF, Tech Soft America-HSF.**

Web3D for improving 2D technical documentation

An alternative method that has been gaining popularity in recent years between designers, is recreating the current paper process in an electronic form using formats such as TIFF, JPEG, PDF, ... The drawback is that these electronic paper formats cannot capture the knowledge located within a design. In order to solve this problem, some WEB3D tools providers have proposed a solution which combines the convenience of simple electronic papers (for instance *pdf* format) integrated with 3D rich data, together with viewing, tracking, querying, plotting, printing, workflow, and security capabilities as demanded by designers. The idea of this second Web3D family is to propose a medium for engineers to quickly capture and securely distribute rich design data anywhere needed-both within the design profession and beyond it.

They protect the integrity of the designs and allow a precise publishing, rendering and printing of even the most complex 3D designs and models [15]. Following this idea some providers have proposed their own solutions: **Right-hemisphere-U3D, AutoDesk-DWF**

4 SELECTING THE RIGHT Web3D COLLABORATION SOLUTION

In order to give a qualitative evaluation of the different web based visualization solutions existing in the PLM context, it is important to remember that product development organization is best served when it is supported by a visualization and collaboration system able to meet the viewing needs of as many stakeholders as possible. Generally, stakeholders that require access and provide input to such product intelligence, based on their function and role in the product life cycle, are dispersed geographically. These stakeholders, ranging from design to procurement and manufacturing to sales and marketing, also require product information to be accessible in different formats, at different stages of the product life cycle[16,17]:

Design and Manufacturing: During the early phases of product development, the number of ad-hoc iterations refining a concept can be high as engineers explore ideas. Change management procedures at this stage of the product development lifecycle must be flexible. They need to focus on identifying inconsistencies and errors introduced during rapid-paced creative design. When product specifications and drawings are ambiguous there is a strong chance that two or more designers, working at different locations, will interpret them differently. This can lead to one designer creating parts that may not fit with the other designer’s work, or parts that when combined do not work correctly as a system due to clashes or interference problems. For this reason, it is necessary to access quickly and simply the different parts designed, by combing them in order to identify, already in early stages, inconsistencies and errors introduced during rapid-paced creative design work. Unfortunately Multi-CAD design environments are becoming ever more prevalent. Parts and sub-assemblies that enter into a product are likely to have been created in several different MCAD applications. CAD systems often locate foreign data through translators and importers which can further complicate the development process. Not all systems have translators available for all formats. Moreover, comments and suggestions should be fed back with text and graphics overlaid on actual engineering data to minimize the likelihood of miscommunication and in a format that CAD systems can import directly, thereby reducing CAD editing time. All these steps should be carried out electronically, thus avoiding the need to print out and physically ship materials, with resultant savings in time and money. A quick access to design data is very important for tooling engineers, since it helps them to achieve an efficient tool design; besides, as far as process planner is concerned, an earlier access to the Bill Of Materials (BOM) can cause a significant reduction of production time and cost.

Procurement: In a just-in-time, on demand world, ensuring that sufficient capacity is available whenever it is needed, means understanding how the product design impacts on manufacturing processes, equipment, and materials requirements. Whether production is handled in-house or contracted out, it is prudent to involve Manufacturing Engineering and outside contractors in product development activities as early as possible. As for design organizations, the challenge clearly involves communicating product data, so that quotes for production or outside design work are accurate. This challenge is typically faced by delivering product data as engineering drawings or as 3D models. Of course, the manufacturer must be able to accept product data in its delivered form and this has often meant deploying the same design software used by the Design and Engineering organization, regardless of its suitability for Manufacturing’s own purposes. This issue is compounded for those contractors who work with multiple customers, who often use a variety of different design applications. A visualization application with on-line, real-time collaboration features would make it easier for these sort of contractors to bring stakeholders together and to carry out several other important tasks, such us responding to questions, reviewing design proposals, and refining design elements.

Sales: Sales presentations and bid packages are more persuasive when they are augmented with the use of compelling visuals generated directly from engineering data. When a visualization application is embedded in the electronic presentation or bid package itself, it allows the prospect to experience the product, instead of just being told about it. Additionally, real-time product configuration, with the help of a visualization application, can be a uniquely powerful sales tool for vendors of highly configurable or made-to-order products.

Marketing: Within the product development cycle, marketing documents participate in design reviews to ensure that customer requirements are being met. As a consequence, visualization tools can be used to generate illustrations for collateral materials directly from the engineering data.

Support and Training: Depending on the type of product or contractual arrangements, maintenance and repair activities may take place at the manufacturer's facilities, a sub-contractor's facilities, or the customer's site, but in all cases they will require maintenance and repair documentation. This information can be delivered in the form of on-line manuals containing embedded engineering drawings and models of the product or installation. Maintenance and repair technicians then have access to very high quality product information that they can not only consult, but also manipulate and query. The mark-up features of the visualization application can be used to update the data in engineering drawings or models with as-built and as maintained information as part of the service record, and report it back to engineering electronically.

To sum up, these considerations render it possible to understand that an efficacy visualization and collaboration tool has to struggle with several barriers in order to attempt to provide an effective visualization of product data to all stakeholders involved in an organization or project [18,19]:

- Product data is everywhere and used by many people
- Product data comes in varying formats
- It must be comprehensible to users of differing backgrounds, technical levels, and needs
- Data must be secure, yet readily accessible and reliable

In order to understand if the collaborative solution meets the stakeholders' needs, it is necessary to analyse a series of parameters in order to characterise the different web – based solutions [20,21,22]. The five parameters chosen (Visualization, Net Performances, Security, Customization, User Interaction) contain and describe the technical features implemented by the different solutions to cover every aspect of the product life cycle management (Fig.4, Tab.1):

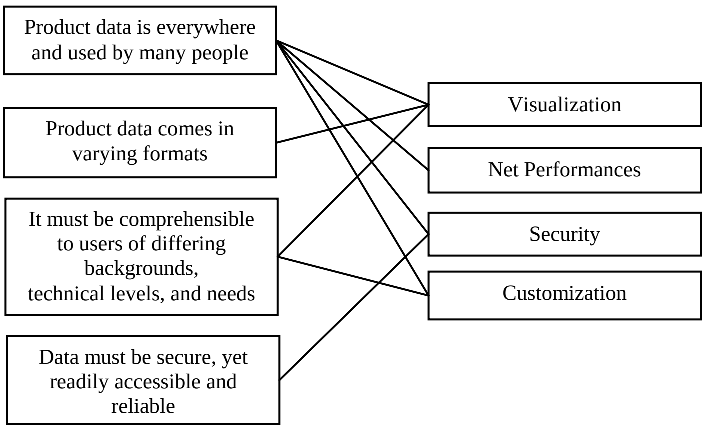

Figure 4. Web 3D characterizing parameters

Visualization: Solid modelling applications generate, part and assembly models in their own proprietary formats ***(B-rep, NURBS)***. These models, combined with drawings and other data, become the master definition of the product. They contain the primary visual manifestation of the product's design. Most of them also generate **a tessellated (faceted)** form that is faster to render and display than the more **complex solid model**. Besides, tessellated data is usually a smaller file than the native CAD data. Some visualization solutions cannot access the **native CAD data** and rely only on the **faceted data** when displaying a file. Often, the visualization tools apply various algorithms and filters to this faceted data to render it as smooth and accurate as possible **(rendering, texture)**. However, while the viewable information may look very much like the product design, the underlying tessellated information may not be accurate enough to support analyses or calculations, such as precise measurement, interference detection, and mass properties. Imprecise data can lead to incorrect product design decisions and costly mistakes. Furthermore, the number of formats of information used during the product lifecycle does not only contain ***geometrical data,*** but also ***data attributes***. These are used to support decision-making throughout the product definition lifecycle and throughout the extended enterprise and its supply chain. To effectively support the needs of the extended enterprise, visualization systems must support a broad range of formats of different types. A complete visualization solution must handle both 3D models and product attributes (2D drawings, raster, scanned data, hybrid documents, office, and graphics formats) from within a single interface. ***(Bill of Material (BOM), …)***

User Interaction: Collaboration on product data consists, at its core, of two basic concepts: accessing product data in a comprehensible format, and providing feedback on what is accessed. **Measurements, animation, workflow features, mark-up** and **annotation** are used to access product data and then to provide feedback elements. When a designer, engineer, reviewer, customer, or supplier needs to provide commentary on a piece of product data, it is usually easier to do it directly on the document, drawing, or model itself. In order to implement this feature without altering the original file, visualization solutions provide mark-up and annotation tools. An efficient way to communicate design changes is to create a mark-up file describing the alterations, and attaching or referencing the necessary documentation. The tools used to create a mark-up file should be complete and flexible. A comprehensive annotation facility not only supports basic mark-ups such as text, lines, and shapes, but also provides advanced tools, allows users to import symbols from their own libraries, and provides the flexibility to add or remove specialized tools from the interface.

Customisation: to provide maximum benefits in the product life cycle management, the visualisation solution must be integrated within the environment. This integration could be implemented with the use of the Application Programming Interface (API). The integration can be obtained merging the printing functions of the two applications and allowing users to automatically import document details into headers, footers, watermarks, and stamps.

Security: Considering the importance of most of the product data, security over the Internet is an essential consideration. Many companies which involve connections trough the Internet have, as a component of their security configuration, a firewall and proxy server between their intranet and the Internet. An effective Web-based visualization system must be able to work with firewalls and proxy servers. One of the best ways to protect an original document is to never transmit it at all. If the original native format never leaves the server, there is no chance it will be intercepted during transmission. Visualization systems typically transmit only the viewable data to the client machines. Today, the most common form of security in use on the Internet is that of **encryption** via *Secure Socket Layer (SSL).* The information transmitted by the visualization system can be encrypted with HTTPS. Besides, it is important that the Web-based visualization system complies with the security protocols of the host system with which it is integrated. Thus the security procedures of the PLM system carry over and offer added security to the visualization system.

Net Performances: The file sizes output by design applications can be quite large, causing problems about the time consumed accessing a file. So, the data is not transmitted to the client machine all at once, but it is rather **streamed** over the network over time. The client software immediately displays the incomplete file, which gradually becomes more detailed as more information arrives. Otherwise the file is rendered into a lighter, viewable version on the server which is transmitted, instead of the native data. The user can still query the native data file on the server for tasks such as measurement; thus he maintains access to native data, but only the visual rendering of the data is transmitted to him. The optimal resolution to this issue is a combination of server-side rendering and data streaming. A lighter visual form of the file is rendered on the server and streamed down to the client machine. This combination of solutions has two additional benefits: first, it adds security, and second, the user can see the file before it has fully arrived, so that, if he has requested an incorrect one, he can cancel the transmission before it is complete. Some other solutions increase the visualization performances by using **compression techniques**, in order to reduce the original dimension of the CAD file, and by providing **continuous level of detail**. This last feature allows a low vertex count version of the triangle mesh which can be displayed before the entire file has been processed. Continuous level of details dynamically adjusts the number of vertices in the mesh used for visualization. This is very useful when working with large, complex models over relatively slow networks or on relatively less capable graphical display clients.

		CDF	eDrw	C3D	U3D	.3D	JT	mtx	XGL	XVL	CMF	HSF	DWF
Visualization	**Facets**	o	o	o	o	o	o	o	o	o	o	o	o
	Texture	o		o	o	o	o	o		o			
	Rendering	o	o	o	o	o	o	o	o	o	o	o	o
	Animation		o	o	o	o	o	o	o		o		
	Product structure	o	o		o		o	o	o	o	o	o	o
	Precise geometry	o					o			o			
User Interaction	**Measurement**		o			o	o		o	o	o	o	o
	Mark-up		o			o	o		o	o	o	o	o
	Workflow features						o				o		o
Security	**Encryption**	o			o		o			o	o		o
Customisation	**API Libraries**	o		o	o	o	o	o		o	o	o	o
Net Performances	**Progressive streaming**	o			o		o	o	o		o	o	
	Continuous level of details				o			o		o		o	
	Compression	o	o	o	o	o	o	o	o	o	o	o	o

Table 1: Web3D Solutions characterisation

Starting from the parameters explained above, a graphical representation has been designed in order to give a qualitative comparison of the solutions actually proposed in the PLM context [23]. This representation consists of a pentagon connecting the main phases of the product life cycle. A parameter has been located in the middle of every pentagon side, and a qualitative scale has been employed to show how much a solution satisfies a specific requirement, in relation to the number of technical features which the solution owns. Each parameter is characterised by a different scale subdivision. For instance, the criteria "Visualisation" has 6 possible locations on the scale line, since it shows six technical features in the previous table (Tab.1) (facets, texture, rendering, animation, product structure and precise geometry). Likewise, "Security" will be 0 (close to the pentagon centre) if the feature is not available, or 1 (close to the pentagon external side) if the feature is available. In this way it is possible to have a simple but consistent evaluation of the different technologies by using the same objective methodology for evaluating every solution. The use of the technical features in order to evaluate the different WEB3D solutions is justified by the necessity to succeed in satisfying as many product lifecycle users as possible, as written in the first line of this paragraph.
The evaluation proposed above, covers the whole product life cycle, since, as it has been previously stated, all product lifecycle phases take an average advantage from web – based collaboration features. For this reason, it has been impossible to give a separate evaluation on the incisiveness of the different solution selectively on the different product lifecycle phases. So for every parameter evaluation the same weight has been chosen, considering that all of them participate globally to an efficient implementation of a collaborative solution along the product lifecycle[24]:
Moving from the centre to the side of the pentagon figure, the criteria expresses a proportionally higher satisfaction given by an higher number of technical features owned by the solution analysed along the parameter. The choice of this sail diagram has the only purpose to point out, in terms of area within the lines connecting the different levels parameters reached, the solution efficiency. So, the best solution will show a bigger covered area within the pentagon figure (Fig.5).

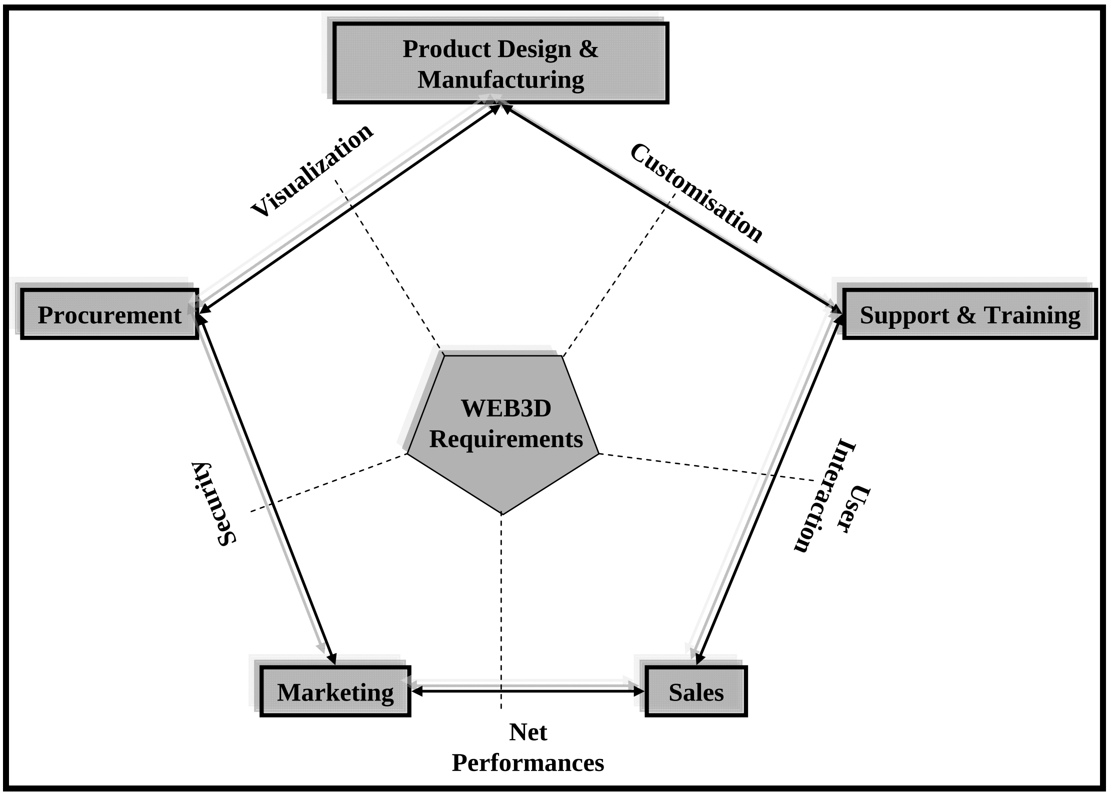

Figure 5. Web3D selecting criteria role in the product lifecycle

Every solution has been described through a short text underlying the most peculiar aspects proposed, a synthetic table to underline some technical peculiarities and a sail graphic to evidence its efficacy.

4.1 Viewpoint-mTx
Viewpoint Experience Technology (VET) is Viewpoint Corporation technology that streams 3D and rich media content (media atoms) on the Internet. A Media atoms is any form of media which can be used in a VET scene. VET uses XML (Extended Mark-up Language) to create an .mtx file, which is the command centre of a Viewpoint scene. By Using the XML commands of this guide, developers can manipulate and animate elements of a VET scene. Viewpoint Media Files can be exported directly from many 3D modelling applications or published from the Viewpoint Scene Builder, a utility designed to assemble and edit the content of a Viewpoint scene. One significant aspect of the Viewpoint solution is that, without requiring any unique server software, it permits the immediate streaming display of content. [25](Fig.6)(Tab.2)

Visualization formats	Mark-up functions	Analysis and Measuring functions	Animation functions	Security functions
3dstudiomax, Maya, Solidworks	No.	No	Scene animation	No

Table 2: Viewpoint solution main features

4.2 Solidworks–eDrw
eDrawings Professional allows the creation of highly compressed 2D and 3D eDrawings files, which are viewable with a free Viewer. eDrawings files are substantially smaller in size than the original ones. This feature makes them easy to send via email, even over slow connections. Besides, this solution allows the user to examine internal details of parts and assemblies with dynamic cross sectioning, manage, and track and merge comments from different team members. Moreover, the presence of intelligent measurement tools render it possible to obtain a critical measurement of parts, assemblies and drawing geometries. Lastly, another important feature that characterises eDrawings is the animation, which automatically demonstrates how drawing views are related to each other (Fig.7)[26] (Tab.3).

Visualization formats	Mark-up functions	Analysis and Measuring functions	Animation functions	Security functions
Inventor, Pro/ENGINEER, CATIA UGS, CoCreate's OneSpace Designer	the mark-up capabilities work on parts and assemblies.	eDrawings allows to view design analysis results created from COSMOS Works or COSMOS Xpress software	Automatic animation between views	No

Table 3: eDrawing solution main features

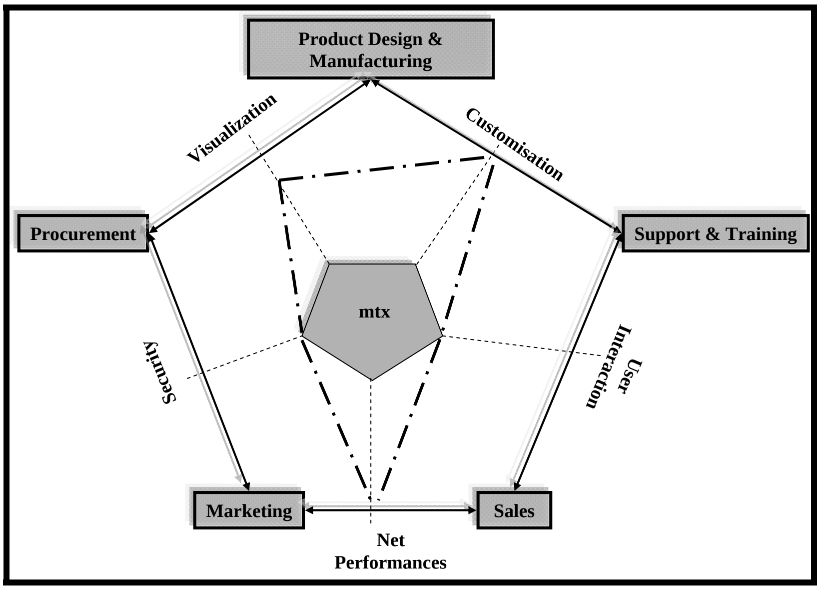

Figure 6: mtx solution

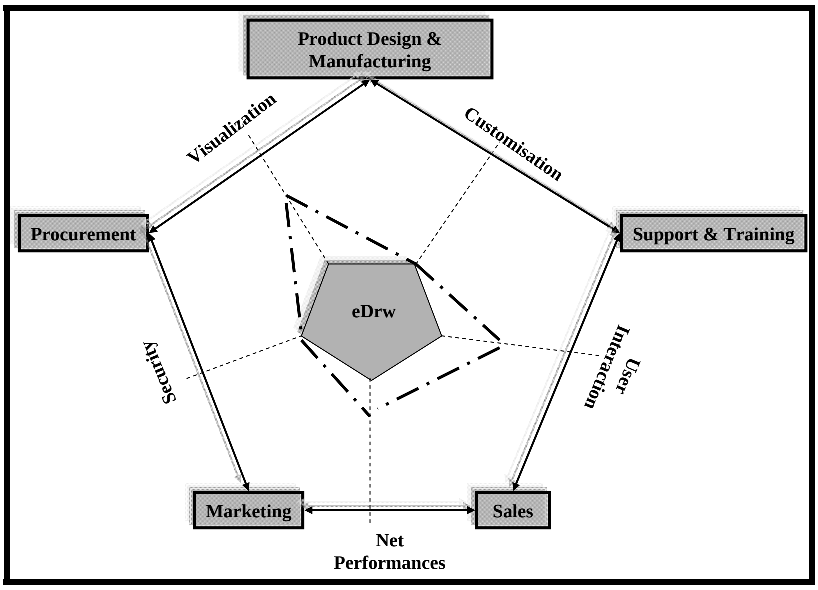

Figure 7: eDrw solution

4.3 Actify-.3D

Another solution is the SpinFire solution, which uses .3D standard, Software Development Kit (SDK), and COM (Component Object Model). This solution allows customers to integrate .3D publishing features into a back-end publishing system. The three main features of SpiFire are rotate, pan, and zoom functions. This last feature allows the user to quickly locate and visualize design features. In terms of interaction, this solution renders it possible to measure and mark-up 3D design data for analysis and collaboration purposes. Besides, it allows real-time cross-sectioning, which reveals critical design details normally hidden from view. Lastly, a good level of compression, 10% of original CAD file sizes, grants an efficient use of the net bandwidth (Fig.8) [27] (Tab.4).

Visualization formats	Mark-up functions	Analysis and Measuring functions	Animation functions	Security functions
Inventor; Mechanical Desktop; CATIA V4, V5; SolidWorks; I-DEAS I-DEAS WEB; Parasolid; Pro/E Wildfire; Solid Edge; UGS NX; CADDS; Discreet 3D Studio; CGM; ACIS SAT; DWF; DWG; DXF; Direct Model (.JT); HPGL; IGES 3D; 2D; ISO GCode; PRC; STEP; STL; VRML; VDA-FS; XVL; MICRO CADAM; TIFF	HTML, Javascript, and XML: include designs inside web pages with OBJECT or EMBED tags	Measuring both on 2D and 3D models	parts easily positioned in space and provide replayable animated transitions between saved scenes.	No

Table 4: SpinFire solution main features

4.4 Cycore-C3D

Cult3D, the solution proposed by Cycore, is based on 3D models imported from mainstream content creation tools, and it may embed advanced interaction and behaviour implemented in Java. Cult3D objects are embedded in html pages and are compressed in file size in order to suit all modem connections. Software-based rendering works on all major platforms with a high speed and visually realistic rendering. Cult objects have full transparency, reflectivity, particle systems, bump mapping, phong shading, movement and sound, thus they are able to show the object as it really is, even in the smallest details. (Fig.9) [28] (Tab.5).

Visualization formats	Mark-up functions	Analysis and Measuring functions	Animation functions	Security functions
Maya 3DStudio MAX	No	No	Vertex and Physic Animation	No

Table 5: Cult3D solution main features

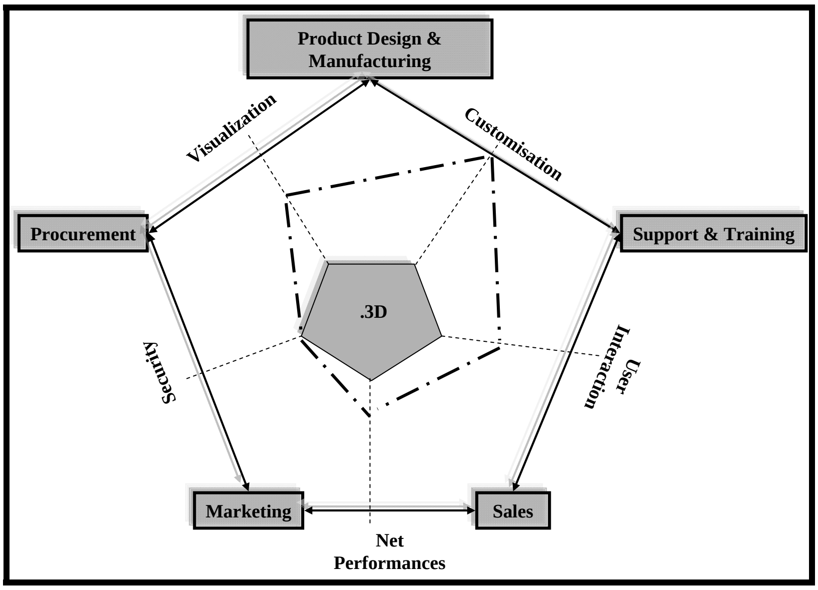

Figure 8: .3D solution

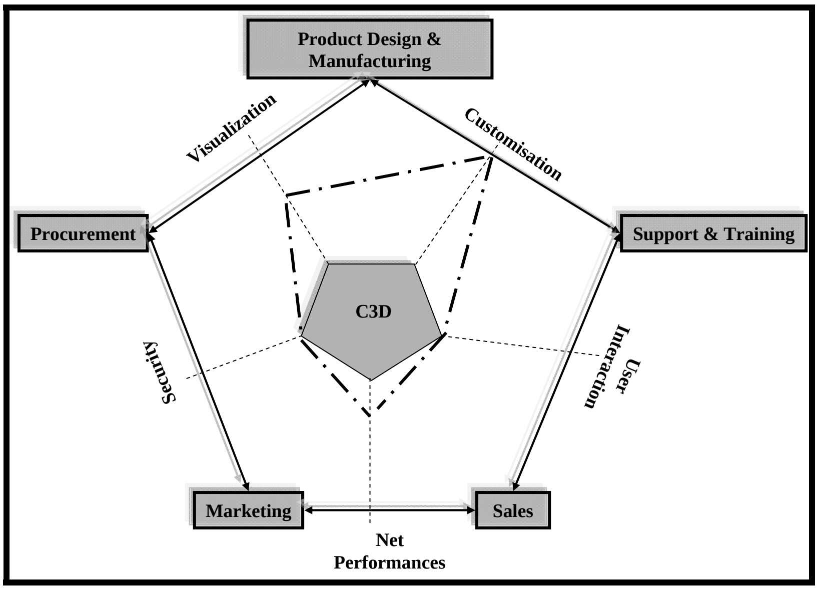

Figure 9: C3D solution

4.5 3Dif-U3D

The 3Dif Consortium Universal 3D file format (U3D) is the triangle mesh open-source standard. This format supports optional inclusions of multiple texture coordinate layers, vertex colours and explicit vertex normals. There are two methods for storing the triangle mesh geometry information. The first method is raw and uncompressed, whereas the second method is progressive and compressed. The compression performance is competitive with existing geometry compression techniques. This second method enables U3D's continuous-level-of-detail (C-LOD) feature. With the C-LOD technology, a low vertex count version of the triangle mesh can be displayed before the entire file has been processed. C-LOD dynamically adjusts the number of vertex in the mesh used for visualization. Besides, U3D takes advantage of runtime libraries for implementation of compression, streaming, rigid body and skeleton based animation, file format and run-time extensibility. Extensibility will be a key feature, allowing the addition of new modifiers that can change a 3D model. The use of the standard Common Intermediate Language (CLR) together with the associated Common Intermediate Language (CIL) for plug-ins – and the inclusion of their required interfaces in the standard – will facilitate cross-platform availability (Fig.9). Recently, Adobe has introduced the U3D standard into Acrobat 7, thus allowing 3D objects, including CAD data, to be embedded in .pdf files. For its viewing technology, Adobe uses one of the Right Hemisphere softwares. Acrobat Reader is free. CAD data can be embedded by converting them to U3D by using Right Hemisphere tools. Adobe cannot see users having the ability to manufacture using .pdf, but see it more for documentation, maintenance documents, and for review and commentary. Moreover, Immersive Design (ID), has jumped on the Acrobat 3D viewing bandwagon [29,30,31] (Tab.6).

Visualization formats	Mark-up functions	Analysis and Measuring functions	Animation functions	Security functions
More than 128: CATIA, MicroStation, Pro/E, Pro/DESKTOP, Solid Edge, SolidWorks, UGS NX; AutoCAD, ACIS, STEP, CoreCAD, CADKEY, gPlug Module, Granite, IGES, IronCAD, JT Open, Neutral Part File, Parasolid, others; plus 3D & 2D files, raster, vector, audio, motion picture formats	No	No	Editing and translation, scale, and rotation animation capabilities	extensive security and permissions features

Table 6: U3D 3Dif solution main features

4.6 Web3D-CDF

The open-source X3D standard, proposed by the WEB3D consortium, is mainly characterised by the use of both triangles and B-Rep to describe 3D models. This solution is completed by SDK, which contains XML data definitions and libraries. In terms of accuracy, this solution contains a programmable shader enabling cinematic rendering effects; advanced texturing support, including 3D textures and cubic environment textures for hyper-realistic environments, improved Level Of Detail (LOD) support for optimized performance on a broad range of machines and improved text support. X3D's language-neutral Scene Authoring Interface enables real time 3D content and controls to be easily integrated into a broad range of web and non-web applications. The CDF standard distils down high complexity data to low complexity one. This solution is open-source and, at the moment, it does not contain animation functions (Fig.11) [32] (Tab.7).

Visualization formats	Mark-up functions	Analysis and Measuring functions	Animation functions	Security functions
Supports all major CAD systems	No	No	No	Encryption

Table 7 CDF solution main features

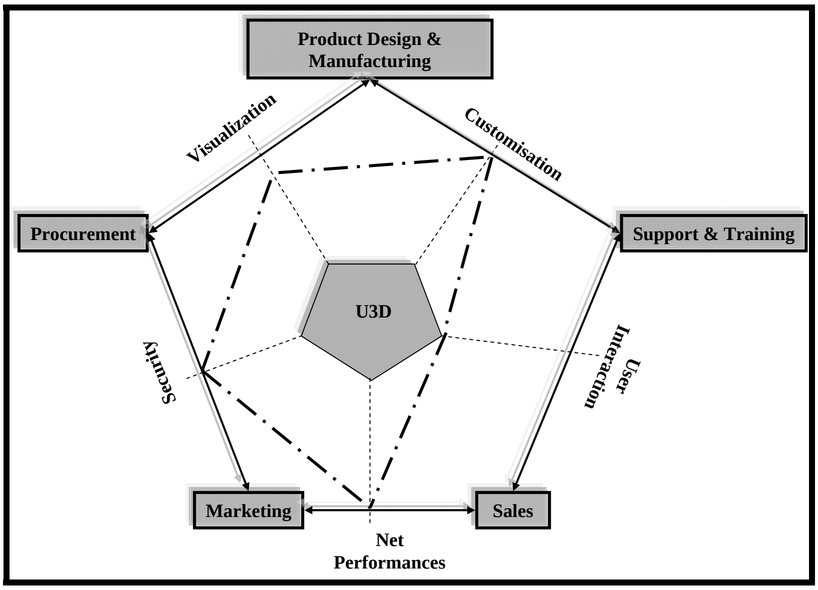

Figure 10: U3D solution

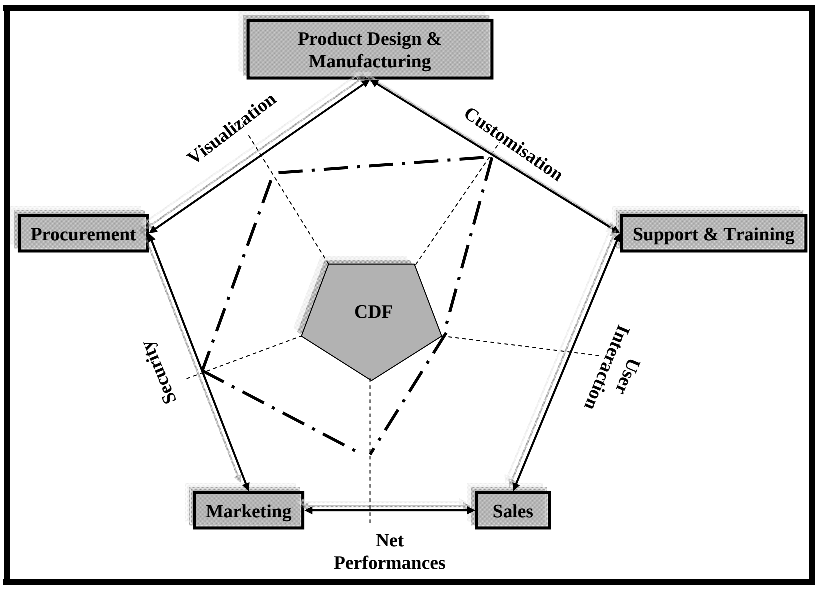

Figure 11: CDF solution

4.7 Lattice3D-XVL

XVL™, developed by LATTICE Inc., is a universal, highly compressing 3D-format which derives from the experience of the VRML standard. Unlike the polygon-based (tessellated) motifs used by every other format, Lattice 3D's XVL resurfaces the whole model inside and out to create a NURBS-based model. This last model is a math model which tessellates during viewing, and which avoids the problems of visualizing curves in polygon-based models when you zoom in close. Besides, NURBS-based models are more compressed than polygon-based visualizations. Thus, if a user wants to increase resolution, he can re-tessellate as part of the viewing process, without having to go back to the CAD model to create a new visualization. The size of the file does not change when the user regenerates and the model is 98% compressed. Most animations are based on video, and consist of very large files showing a set of different frames as photographed. Therefore it is not possible to change the viewpoint from which they are viewed without doing a new video. XVL, on the other hand, saves the data regarding which part moves, and where it moves in a very small file. Thus, during the animation, users can move each part around during animation, so that they are able to see anything from any and all viewpoints (Fig.12) [33] (Tab.8).

Visualization formats	Mark-up functions	Analysis and Measuring functions	Animation functions	Security functions
Supports all major CAD systems	in XVL Studio, Embed, Composer, Publisher enable extensive markup, editing and publishing.	in XVL Player Pro, Studio, Embed, Composer	No	in XVL Signer

Table 8: Lattice3Dsolution main features

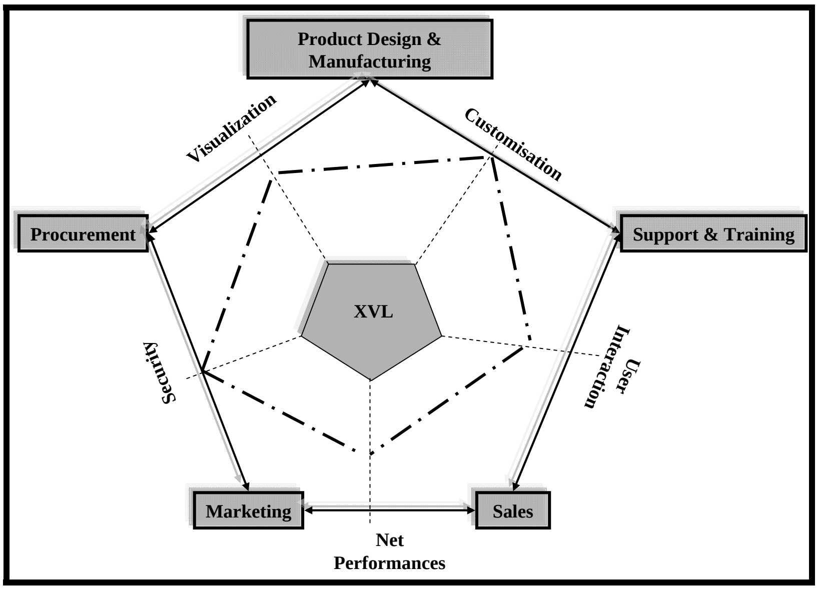

Figure 12: XVL solution

4.8 UGS – JT

UGS JT is a highly flexible format. It can either be extremely lightweight, holding little more than facet data, or be richer and hold precise model geometry, product structures, attributes, and product manufacturing information (PMI), including GD&T and annotations. JT supports textures, lighting models, and motion, as well as multiple tessellations for level of detail (LOD) generation. Besides, JT offers a highly accurate B-rep version of the geometry primarily for engineering purposes. It also contains the Parasolid modelling kernel, so that users of NX, Solid Edge, and other Parasolid-based MCAD programs can be certain of the absence of any kind of deviation from the actual geometry. Moreover, since this format can also stream data, users can start using visualization and manipulating the view while still downloading (Fig.13)[34] (Tab.9).

Visualization formats	Mark-up functions	Analysis and Measuring functions	Animation functions	Security functions
Supports all major CAD systems via the neutral JT	GD&T markup tool for annotating drawings with proper tolerance information	Digital mock-up Digital prototyping Product Manufacturing Information (PMI)	Ability to review multi-media Visualization Publish deliverables	extensive security and permissions features

Table 9: UGS solution main features

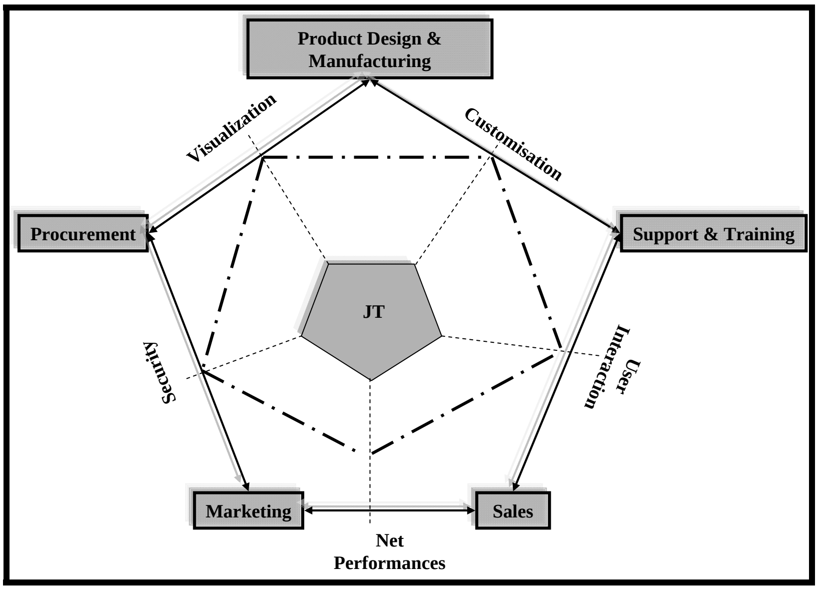

Figure 13: JT solution

4.9 Cimmetry-CMF

AutoVue is one of the most original multi-format viewers. It provides a large number of printing and plotting features, including batch and bulk printing, headers, footers, stamps, watermarks, force to black, and layering of mark-ups. Its Multi-MCAD digital mock-up (DMU) functionality enables users to create virtual prototypes using parts and sub-assemblies designed. Besides, thanks to the Open APIs system, AutoVue is able to interface with PLM, EDM, ERP, and other enterprise applications to provide viewing, mark-up and metadata querying capabilities, and to facilitate conformance with regulatory and quality requirements. (Fig.14) [35] (Tab.10)

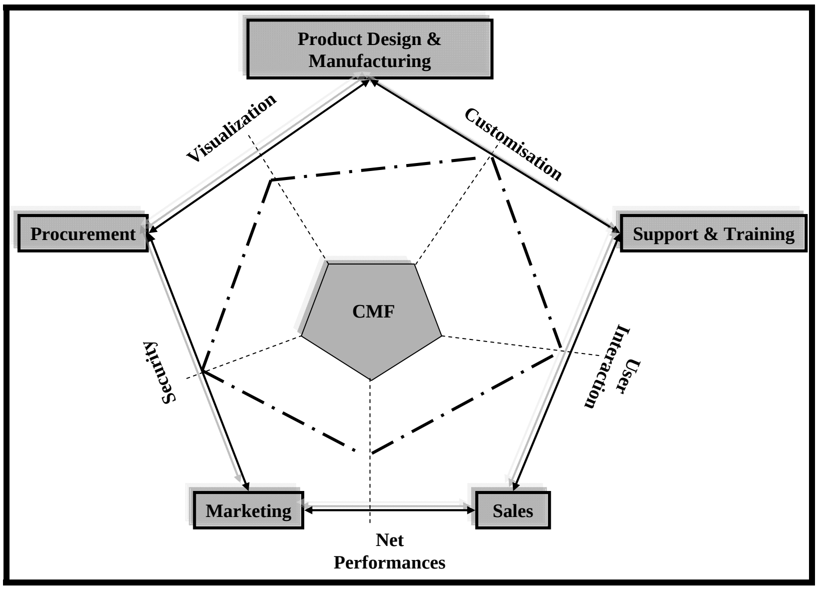

Figure 14: CMF solution

Visualization formats	Mark-up functions	Analysis and Measuring functions	Animation functions	Security functions
Inventor, Mechanical Desktop, CATIA V5, V4 AutoCAD, HPGL, IGES, MicroStation, Pro/E Wildfire, Solid Edge, SolidWorks, UGS NX, 2D CAD, EDA, Office, PDF, raster, graphics.	AutoVue does provide markup functionality but does not edit parts and assemblies. Markups are performed on a separate layer and are saved as a different file, leaving your original document intact	Measuring both on 2D and 3D models	Editing and translation, scale, and rotation animation capabilities	extensive security and permissions features

Table 10: Cimmetry solution main features

4.10 AutoDesk –DWF

AutoDesk DWF is an extensible print-ready format which supports multiple pages and object properties. The high compression allowed by this format grants complex and huge models of management and sharing, together with the use of Autodesk DWF viewer. Beyond graphics, DWF files contain rich information from the original CAD model, including drawing and viewport scales, precise design coordinates, assorted views, hyperlinks, sheet details, and XML based object properties. (Fig.15) [36] (Tab.11)

Visualization formats	Mark-up functions	Analysis and Measuring functions	Animation functions	Security functions
3D DWF files published out of any of the Autodesk design applications:	Immediate capture of design-related content for mark-up Draw or comment using freehand tool Snap to geometry Publish DWF files from DWG files Resave DWF files with mark-ups, redlines, and annotations Add stamps and custom symbols Create subsets of drawings Add, delete, reorder, and rename sheets	Access intelligent design data (object and sheet properties) Measure to scale	No	Yes; when the DWF files are published from Autodesk software products, password protection and encryption are added. DWF Viewer supports the same password protection used to open the file before viewing, printing, etc. DWF Composer does not have capabilities to add password protection before sending the marked up file out

Table 11: AutoDesk solution main features

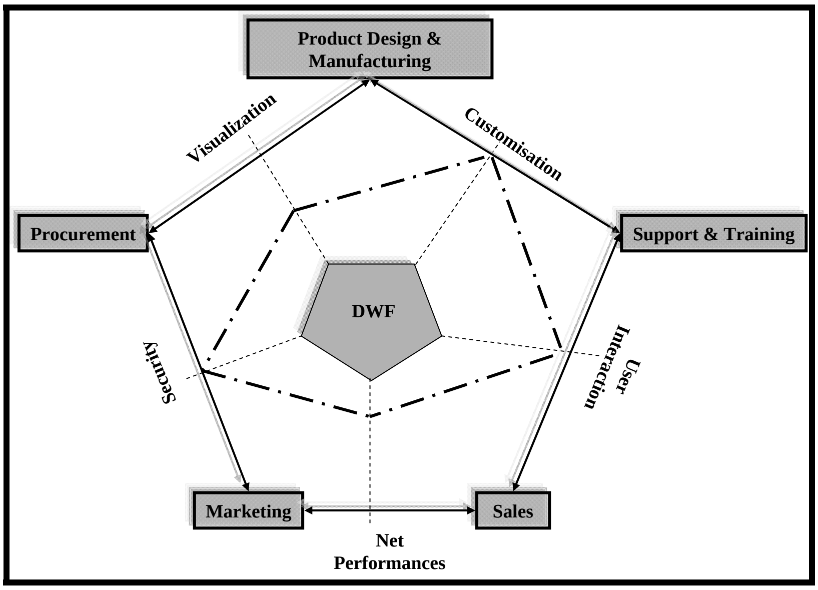

Figure 15: DWF solution

4.11 RealityWave-XGL

The RealityWave XGL solution is a collaborative environment tool for 3D viewing and mark-up. The 3D collaborative viewer includes rotate, pan, zoom, section-view, dynamic clip-plane, isolate-part features, and much more. Its integration with solution components allows viewing and mark-up also on 2D drawings. Besides, It is possible to enhance mark-up with features such as measurement, wire-frame, snap-to-edge, bleed-through, transparency, and an associated comment log. Thus, this solution is able to dynamically optimize and 'segment' the streaming data requested, based on bandwidth, latency, and PC power. The client determines what the user can view, measures the visibility of items in the viewing space, and, through the use of a communication link, is able to request the data in an order which is specific to the user's viewpoint. The data to be streamed is indexed for random access, thus enabling the viewing application to access information without limits on its size or complexity. (Fig.16) [37] (Tab.12).

Visualization formats	Mark-up functions	Analysis and Measuring functions	Animation functions	Security functions
Autodesk Inventor SolidWorks Solid Edge 3ds Max Cosmos Microstation SDRC MechanicalDeskTop CADKey Pro/E UG AutoCAD CATIA	Yes	Yes	Pan, zoom, rotation, configurations	No

Table 12: Reality Wave solution main features

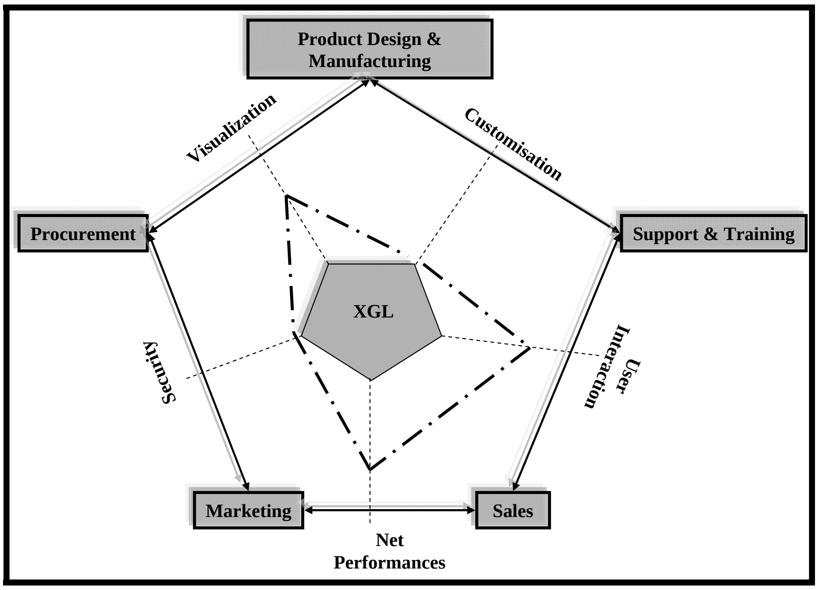

Figure 16: XGL solution

4.12 Tech Soft America-HSF

HOOPS 3D Product Suite consists of three distinct products that may be used independently or as a tightly integrated bundle. These three products are: **HOOPS 3D Application Framework, Hoops stream toolkit** and **Hoops net serve modules. HOOPS 3D Application Framework** is an extensible graphics API, which performs rendering and interaction with high level of details. This suite is, in turn, subdivided in several different sub-components; among them there are **HOOPS/3dGS, which** is a graphics system providing the algorithms and data-structures necessary to incorporate 2D and 3D, vector and raster graphics into graphics applications, and **HOOPS/MVO** is a set of platform-independent C++ objects that implement much of the common functionalities found in 3D applications, such as model manipulation and animation. **Hoops stream toolkit** and **Hoops net serve modules are products which enable**, developers to customise streaming, client-server or real time collaborative applications. Thanks to the use of Java bindings, this solution also allows the use of java environments, while the **3dGS** provides extensive texture mapping capabilities. Recently the Hoops suite has developed a specific Direct3D driver for its suite **D3D.** It is a low-level, immediate-mode drawing interface designed to facilitate the hardware acceleration of 2D and 3D graphics display, similar to OpenGL. The D3D API is a Windows-specific graphics “platform” that applications and higher level subsystems can leverage to gain superior graphics quality and rendering speeds (Fig.17)[38] (Tab.13).

Visualization formats	Mark-up functions	Analysis and Measuring functions	Animation functions	Security functions
Supports all major CAD systems via Parasolid XT	Yes	Yes	No	No

Table 13: Hoops solution main features

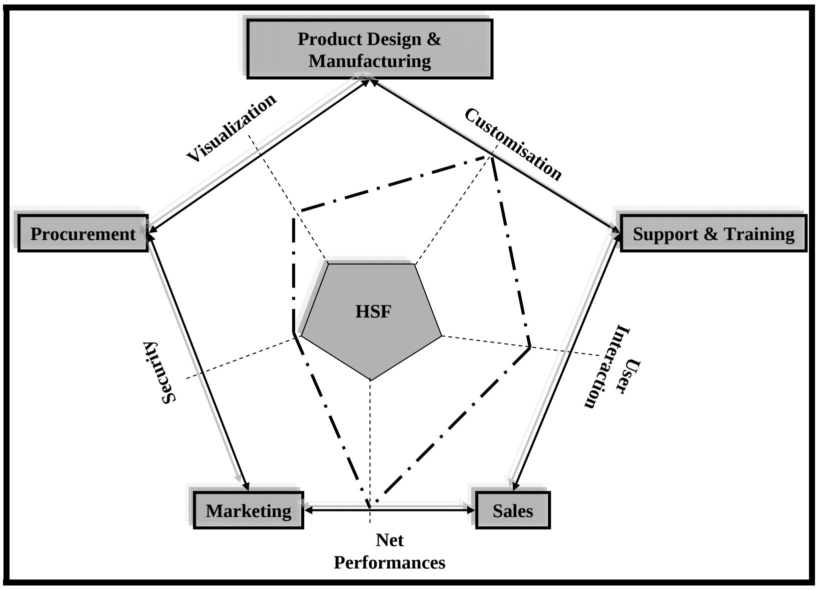

Figure 17: HSF solution

5 CONCLUSIONS

Introducing an effective Web3D visualization and collaboration solution into an organization's work flows can deliver tangible gains. These are typically realized very rapidly, especially when the solution is introduced as a part of a broad PLM initiative. A wide deployment of the right visualization and collaboration technologies can benefit those organizations that are wrestling with issues of file format incompatibilities, in particular, they will prove themselves very useful in the following situations: when product data and available software do not match; when the volume and variety of product data to be handled during the product lifecycle is rising; when there are virtual teams, whose members belong to different organizations and are in geographically dispersed locations; when there are multidisciplinary and cross-functional teams, whose members have different expertises. In all these cases, these technologies will ensure the efficiency and effectiveness of communications not only within the enterprise, but also with suppliers, partners and customers. Thus, they will improve the quality and timeliness of decision making, while providing simple support material to maintenance and improving product customization tools for marketing personnel.

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