Transdisciplinary Lifecycle Analysis of Systems
R. Curran et al. (Eds.)

doi:10.3233/978-1-61499-544-9-575

Leveraging 3D CAD Data in Product Life Cycle: Exchange – Visualization – Collaboration

Alain PFOUGA and Josip STJEPANDIĆ
PROSTEP AG, Darmstadt, Germany

Abstract. With their practical introduction by the 1970's, virtual product data have emerged to a major technical source of intelligence in manufacturing. Modern organization have since then developed and continuously improved strategies, methods and tools to feed the individual needs of business domains, multidisciplinary teams and supply chain to master the growing complexity of virtual product data and manufacturing processes. Three principal activities are associated to the repurposing of virtual product data. These are Exchange, Visualization and Communication of the manufacturing intelligence from its virtual product representation perspective. One development approach alongside PLM, which declares the 3D CAD model as the record of authority and the source for which all other documentation flows is Model-Based-Design (MBD). By emphasizing digital CAD file use for collaboration at the beginning of development, it is the ground for a fully integrated and collaborative environment founded on a 3D model based definition detailed, documented and shared across the enterprise to enable rapid, seamless, and affordable deployment of products from concept to disposal. Since the practical introduction of virtual product data by the 1970's, several CAD interoperability and visualization formats have indeed been developed to support the aforementioned strategies. Most of them, however, have not yet provided the expected outcome mainly due to their lack of versatility and primary focus on only selected business need. This paper analyses methods and tools used in virtual product development to leverage 3D CAD data across the entire life cycle. It presents a set of versatile concepts for mastering exchange, aware and unaware visualization and collaboration from single technical packages fit purposely for different domains and disciplines.

Keywords: 3D, Visualization, Collaboration, Data Exchange, CAD, PDM/PLM.

Introduction

The introduction of virtual product data and predominantly the usage of Computer Aided (CAx) Systems have fundamentally transformed product development. Particularly applying 3D CAD and PLM strategies has led to higher productivity, better quality and a simultaneous reduction of overall development time and costs.

The fundamental advantages provided with the introduction of aforementioned methods and tools have likewise contributed to growing complexity. Combined with various domain- and organization-specific software applications available with new product development trends, the pace of changes, the volume of data and the amount of knowledge embedded in virtual product data are reaching exponential grow.

New product development methods such as Concurrent Design (CD) and Simultaneous Engineering (SE) have been widely adopted. They declare design and manufacturing engineering tasks as integrated functional units, which can be performed concurrently in the extended enterprise. In this context, it is fundamental to reach great accuracy at providing the right data, within the right application context to the right party. Modern organizations achieve this successfully, if core product development activities are contextually linked together. These main activities consist of the exchange and re-use of product relevant data across different applications, domains and disciplines. The visualization of virtual product models with purposely disclosure of the authors intents and the communication are other 2 main product development activities. The latest implies richer collaboration experience throughout engineering and is integrated across the entire supply chain.

Mastering quality, product design and configurations, bill of materials, changes and releases requires an overall product and process integration, which takes care of differences in coordination workflows, engineering domains, methods and tools of the parties involved in the development process.

1. The challenge with 3D enabled CAD interoperability formats

Several interoperability data formats have emerged in the past. At this, there are basically two primary types of formats: Proprietary and Open formats.

Proprietary formats are vendor-specific. They are used to describe product data in the majority of authoring tools in the marketplace. Descriptions of these formats are generally regarded as intellectual property by the software vendors and are protected appropriately. Due to their lack of openness they are essentially less suitable for collaboration in the extended enterprise and in the context of this paper. Thus, they will no longer be taken into account.

Open formats, on the other hand, are often developed to enable interoperability between applications. They provide definitions which are openly specified and accessible to third-parties (application vendors and customers), who wish to make data available from and to their own applications. Open formats and particularly international standards by their nature are stable and may slowly evolve. However, they protect the investment in tools, methods and processes by ensuring that the data they encapsulate is always capable of being leveraged downstream and recoverable from an archive repository [5].

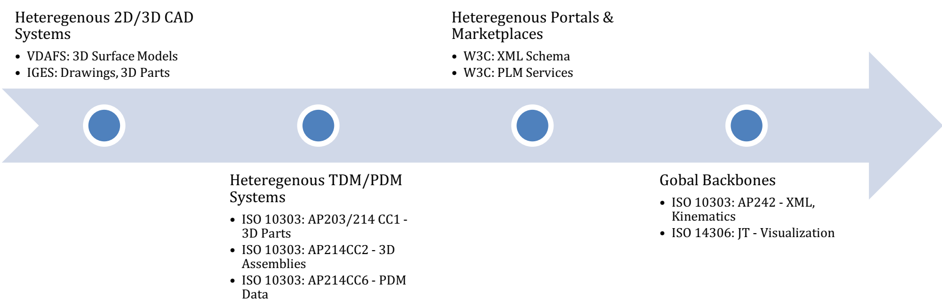

Figure 1. Continuous development of collaboration standards[6].

It hereby goes without saying that these formats (Figure 1) such as IGES (Section 1.1), DXF and STEP (Section 1.2), 3D XML or JT (Section 1.3) are being widely adopted and have contributed to greater momentum in product development.

1.1. IGES - Initial Graphics Exchange Specification

IGES is a file format, which defines a vendor neutral data format establishing information structures for the digital representation and exchange of product definition data. It was initially published in 1980 by the U.S. National Bureau of Standards (NBS) as NBSIR 80-1978. It supports exchanging geometric, topological, and non-geometric product definition among Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) Systems such as: administrative identifications, design or analysis idealized models, shapes including their physical characteristics, processing and presentation information. Applications supported by IGES thus include traditional engineering drawings and design, models for simulation analysis and other manufacturing functions.

1.2. STEP ISO 10303 – STandard for the Exchange of Product data.

The development of STEP started in 1984 as a worldwide collaboration. The goal was to define a mechanism that is capable of describing product data throughout the lifecycle of a product, independent from any particular system. This kind of attempt was made for the very first time. The nature of its description makes STEP suitable not only for neutral file exchange, but also as a basis for implementing and sharing product databases and archiving.

Typically STEP can be used to exchange data between CAD, Computer-aided manufacturing, Computer-aided engineering, Product Data Management/EDM and other CAx systems. STEP addresses product data from mechanical and electrical design, geometric dimensions and tolerances, analysis and manufacturing, with additional information specific to various industries such as automotive, aerospace, building construction, ship building, oil and gas, process plants and others. Unlike modern formats like e.g. JT, STEP does not consider “lightweight” representations of a product or object, nor does it concern itself with compression. This makes STEP not first choice for visualization in downstream processes.

STEP is the most important and largest effort ever established in the engineering domain and has replaced various CAD exchange standards that were established before its wide industrial adoption. It is developed and maintained by the ISO technical committee TC 184.

1.3. JT ISO 14306 – Jupiter Tessellation

The JT format described in ISO 14306:2012 is used primarily in industrial use cases as the means for capturing and repurposing lightweight 3D product definition data[4]. It is a binary file format, whose development started in 1990. JT is used as both a data exchange format between design partners and manufacturers, as well as for visualization applications such as digital preassembly (also called digital mock-up or DMU) and generalized visualization, more commonly referred to as view/measure/mark-up (VMM).

According to Opsahl [5], one of the key characteristics that distinguish JT from other formats is this "duality" of being able to be used in cases where data exchange from one application to a second, as well as in cases where visualization is desired.

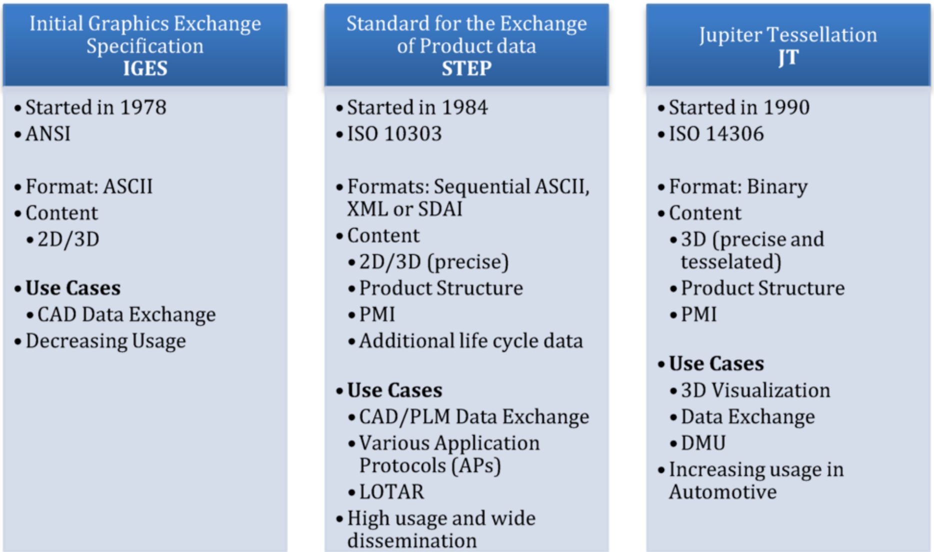

Figure 2. Capabilities of the widely used CAD Data interoperability standard formats.

As a matter of fact, among all the aforementioned proprietary and open formats, none has the versatility and capability on its own to equally sustain the diverse requirements of engineering collaboration [7] in the extended enterprise and, further, beyond product development stages of product lifecycle. Either they are not easily accessible or they do not have sufficient capacity for sharing all relevant product data across different applications, domains and teams. Or they aren't providing sufficient tools and SDKs to support and customize the collaboration experience. Or their industrial use is very low or they just are not ratified by a recognized standards organization, which makes them strategically unsustainable for modern organizations.

The industrial application of these 3D formats have moreover been around the transport of specific data set mainly for the purpose of visualization, data exchange or bulk migration (Figure 2) in downstream processes, whose underlying goals are presentation and transformation of native 3D CAD geometry from an authoring application into an alternative format. The resulting data are finally translated into a proprietary format of a third party application for use in e.g. design, validation, and viewing or long term archiving.

In normal case and as far as engineering collaboration is concerned, different parts describing an affected request and their virtual product data are submitted through different channels and towards quite a lot of authoring systems; be it a request for information, work, change or approval. E-mail, CAD and various data exchange applications as well as a bunch of data communication channels are used likewise.

Fundamentally, this approach is a limitation to leveraging product data across lifecycle stages, domains and supply chains, because the required information is delivered in disconnected parcels. They have to be collected systematically, and re-aligned to each other on reception to effectively consume them. In many cases, they have to be translated into the recipient's workspace. The missing link between the parcels, though, is an issue which leads to an unnecessary management overhead for many organizations. As far as manufacturing is concerned, this means that the development partners having to support different systems and configurations are busy adapting and integrating data instead of using them directly.

2. Current approaches for improved 3D-based engineering collaboration

Lifecycle Collaboration is more versatile than providing chunks of data. It is more than disconnected product structure, visualization or 3D design! It is the consistent combination of all relevant data streams put in context with a recipient consuming these data to better perform a set of product development tasks. Regarding this, research and industrial communities are investigating approaches incorporating different types of information.

2.1. JT/STEP Integration

There is one effort – the first of its kind – aiming at the smart combination of the two international standards STEP and JT to establish a process oriented solution for supporting automotive data exchange requirements. The manufacturing community has recognized that JT itself can only reach its full potential by applying it in combination with the smart XML functionalities of the new Application Protocol (AP) 242 of the STEP standard [4]. In this perspective, STEP AP 242 should become the process backbone for e.g. assembly, metadata and kinetic, whereas JT is enabler for lightweight visualization of 3D data.

2.2. VDA recommendation 4953-2

The recommendation 4953-2 is a proposal of the German Automotive Association (VDA), which describes concepts and means to replace the conventional 2D drawing (as a leading carrier of product information) by documentations on the basis of a technical data container [8]. The scope of this recommendation is a document-based container, which comprises mandatory and optional contents using 3D technologies and providing linked metadata. It aims at eliminating the need existing in many areas of derivation and management of 2D-based collaboration and technical documentation (Figure 3).

VDA 4953 describes the structure and the handling of product data embedded in a technical container as well as its architecture. A 3D content with annotated geometry representation is a major mandatory content, where JT (ISO 14306) is recommended for use. A structured metadata content, which isn't embedded into but linked with the 3D content, is building another mandatory part. VDA 4953-2 recommends STEP AP242 BO XML-Format (ISO 10303-242) for storing metadata and PDF/A (ISO 19005) for their presentation inside the container. Optional contents can be embedded and should be of any file format that can be used for long-term archiving.

The German automotive OEM Volkswagen has published and introduced such a container using PDF as container and JT for storing 3D product data. An external viewer is launched interactively to present and query JT objects from the PDF/A presentation layer for metadata.

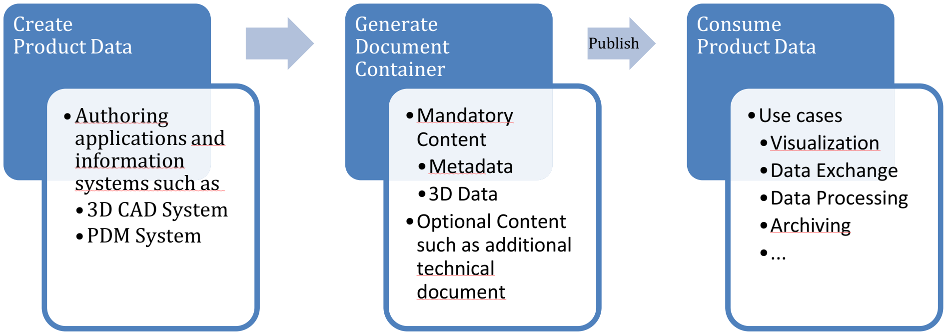

Figure 3. Processes addressed within VDA 4953-2.

2.3. Model-Based Definition

Model-Based Definition (MBD) is a concept of managing engineering and manufacturing information using 3D models as primary source and record of authority of all other product data related to design, process planning, manufacturing, test, services and overall product lifecycle [5] [10]. MBD in its core is truly not pushing a format or a tool. It is rather defining a "3D Master" with its associated descriptions and technical files to push interoperability one step further. It thus can be implemented with various standard formats such as STEP, JT or PDF.

3. Improving lifecycle collaboration with 3D PDF

3D PDF describes a PDF/E (ISO 32000, ISO 24517) document containing 3D data in PRC (3.1) or in Universal 3D (ECMA-363) format. Unlike traditional interoperability formats, PDF supports the creation of authored fit for purpose documents used for distribution, display and collection of data relevant to fulfill a job role. This information is represented in the way of 3D information, in such data types as 2D drawings, audio, video, animations and images (Figure 4) – all encapsulated in a ubiquitously consumable form that includes forms, templates, digital rights management and signatures [5].

As a "transport container" and besides the ubiquitous availability of the Adobe acrobat Reader in almost any organization, PDF provides the options to consume 3D without the need of an extra plug-in or application or to get product data such as 3D geometry and metadata through an exchange process or to a specialized visualization application, thereby leveraging the relevant infrastructure. An entire business logic defining interactions with embedded data of any type can be implemented through programmatic routines in languages, which are supported by reader applications such as JavaScript (ISO-16262).

As far as manufacturing is concerned, a 3D PDF document provides fundamental descriptions to achieve simultaneous engineering and concurrent design based on virtual product in aerospace, automotive or shipbuilding. It is used to improved visualization and productivity in architecture and construction (AEC) through enhanced collection and delivery of information. It is likewise applicable in 3D based medical imaging workflows to improve 3D diagnosis and therapy.

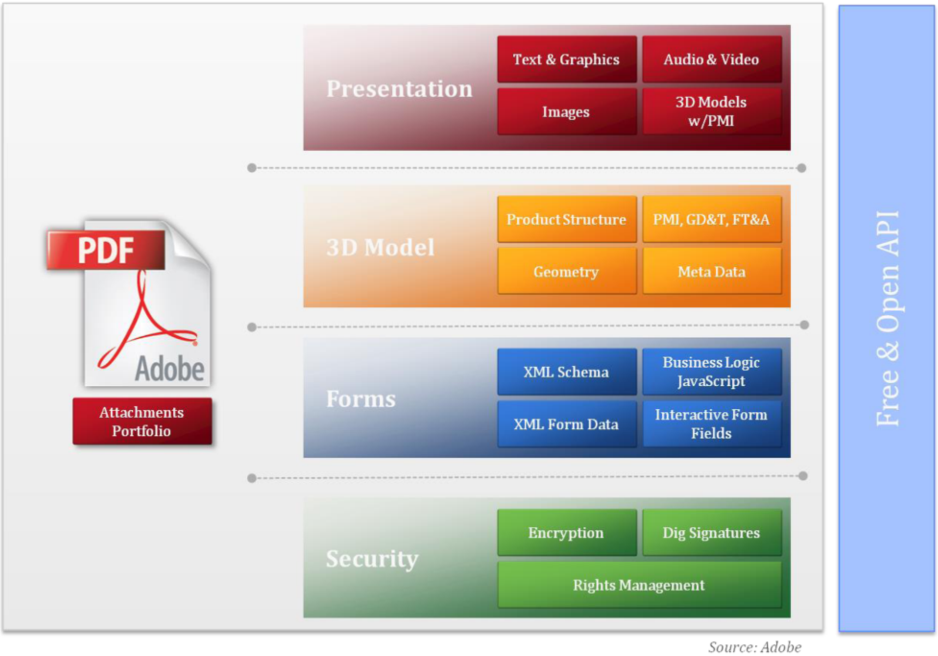

Figure 4. Contents of a 3D PDF document.

3.1. PRC ISO 14739 – Product Representation Compact – The PDF/E 3D interoperability format

PRC is a compact 3D file format that can be used independently for representing 3D CAD-based models. It is designed to be included in PDF (ISO 32000) and other similar document formats for the purpose of 3D visualization and exchange [9]. It can be used for creating, viewing and distributing 3D data in document exchange workflows.

With PRC, documents can be created that are interoperable with computer aided applications such as CAD or CAM. In this regards, PRC is by many extents equivalent to traditional CAD formats such as STEP or JT (Figure 5). It is optimized to store, load and display various kinds of 3D data, especially that coming from CAD systems. It can deliver much higher compression rate for large CAD files without losing accuracy, quality or efficiency. PRC unites features to handle CAD product structure, 3D visualization and accurate graphical description of virtual products as well as Product and Manufacturing Information (PMI). PMIs are non-geometric attributes, which are available in CAD models and which are necessary for manufacturing components. These include geometric dimensions and tolerances, 3D annotations, surface finish and material specifications. The PRC format offers semantic PMI’s in machine-readable data structures, which can be processed in downstream phases.

Capabilities	3D CAD Formats			3D PDF	
	IGES	STEP	JT	U3D	PRC
Open standard	ANSI	ISO 10303	ISO 14306	ECMA	ISO 14739
Geometry type	BREP 2D & 3D	BREP 2D & 3D	BREP + Tessellated 3D	Tessellated 3D Only	BREP + Tessellated 3D
Texture, material, light, animation	Partial	Partial	Partial	Full	Partial
Assembly tree, physical properties, meta data	No	Full	Full	Partial	Full
Model Views, PMI and GD&T	No	Full	Full	No	Full
CAx interoperability	Full	Full	Full	No	Full
Measurement accuracy	Full	Full	Full	Partial	Full
Very large assembly size	Partial	Full	Full	Partial	Full
Compression	No	No	Partial	Partial	Full
Low-end visualization & publishing	No	No	Partial	Full	Partial
High-end visualization & interoperability	No	No	Full	No	Full

Full support Partial support No support

Figure 5. Comparison of the different CAD interoperability formats.

3.2. Scenario and use cases

The following scenario outlines the great value of 3D PDF technology in the extended enterprise. It describes a solution where a universal representation of the digital product is required for different kinds of downstream users, but without a need to unnecessarily disclose a vast amount of native CAD data. Using PRC and 3D PDF, the built solution provides a reliable 3D reproduction for geometric features, views, annotations and product configurations, which is fundamental to support visualization, paperless inspection and reporting, faster approval and review. The underlying application of 3D PDF technology furthermore leverages existing CAD and PLM cornerstones systems, while maintaining compliancy to corporate policies like such related to data quality, exchange and intellectual property protection. The scenario, which can be reduced or extended to real world research and business cases, is described in Figure 6. Reference process for 3D PDF based collaboration. This process covers various aspects specified with VDA4953-2 recommendation, except that it relies on PRC instead of JT for geometry representation and is not restricted to the use of STEP AP 242 for the representation of engineering metadata. 3D PDF furthermore is a key enabler for MBD providing all required functions to reuse and leverage 3D data in downstream processing.

In this scenario, a designer, who manages the product data inside a corporate information system, creates geometrical shapes using a 3D CAD system. He also designs views and annotations, which are needed to derive comprehensive fit for the purpose of technical documentation for downstream usage.

Documents published in the information system are translated automatically to 3D PDF using predefined templates and agreed upon XML standard descriptions for metadata. Additional technical documents and forms aiming at seamless collaboration with the document can be embedded inside the PDF container (Figure 4).

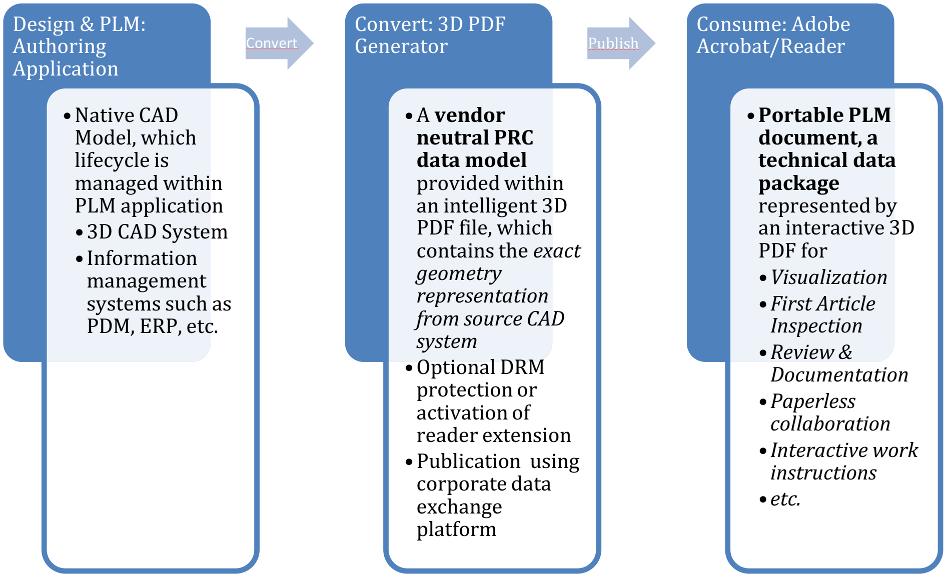

Figure 6. Reference process for 3D PDF based collaboration.

The Conversion layer provides optional encryption and extensions mechanisms, which are useful to grant or reduce access to data embedded inside the 3D PDF container [11].

The 3D PDF document generated thereon can be consumed internally or sent to development partners through corporate data exchange mechanisms for engineering data. In both cases, recipients have the ability to easily visualize embedded contents and interactively interrogate product data from within the free Acrobat Reader. They can extract files as well as machine-readable data or synchronize PDF data with third-party applications. The 3D PDF document can furthermore be enriched through insertion of animations and supplementary data required to support interactive work instruction use cases from further systems.

The final document is a rendition of multiple data gathered from many applications and through form fields, which are accessible from a single technical data package within the Acrobat Reader used to consume these product data. Further detailed information on 3D PDF use cases can be retrieved from sources [12] [13].

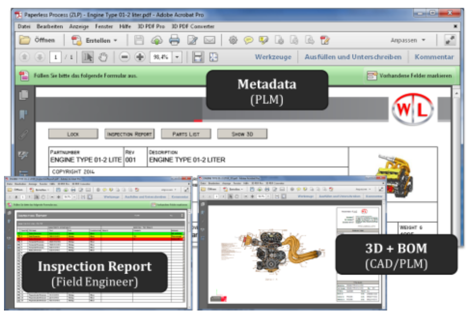

Figure 7. Example of a 3D PDF container having multiple data streams.

4. Summary and closing thoughts

3D interoperability makes an important contribution to engineering collaboration. Several formats made to that end successively deal with challenges of their time. Some of these such as STEP are highly verbose formats, which gradually encapsulate all information necessary to define a product, its manufacture, and lifecycle support. Others are focusing best on lightweight visualization use cases and endure better with increasing size and complexity of data [5]. Traditional formats like STEP and JT, though, are not capable of supporting the publishing activity in even broader fashion. New tendencies therefore are aiming at strengthening these individual formats through combination with complementary standards or by using document-based approaches.

Unlike STEP or JT, 3D PDF can serve multiple purposes and leverages 3D data downstream throughout the product lifecycle to create, distribute and manage ubiquitous, highly consumable, role-specific rich renditions. 3D PDF is a fundamentally different approach from traditional experience established in product development – it is an exceptionally proficient contextual aggregation of multi-domain and multi-disciplinary product data. The manufacturing community should embrace it as an addition and great improvement to current engineering collaboration standards. All engineering components required for its descriptions are meanwhile published international standards.

References

[1] J. Kluger, *Simplexity: Why Simple Things Become Complex (And How Complex Things Can Be Made Simple),* Hyperion Books, 2008.

[2] P. Pfalzgraf, A. Pfouga, T. Trautmann, Cross Enterprise Change and Release Processes based on 3D PDF, in J. Stjepandić et al. (eds.) *Concurrent Engineering Approaches for Sustainable Product Development in a Multi-Disciplinary Environment*, Springer-Verlag, London, 2013.

[3] A. Katzenbach, S. Handschuh, S. Vettermann, JT Format (ISO 14306) and AP 242 (ISO 10303): The Step to the Next Generation Collaborative Product Creation in E. Kovács, D. Kochan (eds.) *Digital Product and Process Development Systems - IFIP TC 5 International Conference, Proceedings*, Springer-Verlag, Berlin Heidelberg, 2013.

[4] *ISO 14306 - Industrial automation systems and integration — JT file format specification for 3D visualization*, ISO 2012.

[5] D. Opsahl, *Positioning 3DPDF in Manufacturing - How to Understand 3DPDF when Compared to Other Formats.* White paper by 3D PDF Consortium, 2012. (http://www.3dpdfconsortium.org)

[6] A. Katzenbach, Automotive, in J. Stjepandić et al (eds.) *Concurrent Engineering in the 21st Century - Foundations, Developments and Challenges,* Springer International Publishing Switzerland, 2015.

[7] A. Fröhlich, *3D Formats in the Field of Engineering — a Comparison*, White Paper, PROSTEP AG, 2013

[8] VDA 4953-2 Zeichnungslose Produktdokumentation, VDA Recommendations, 19 March 2015 https://www.vda.de/en/services/Publications/Publication.~1263~.html

[9] Document management – 3D use of Product Representation Compact (PRC) format, ISO 2012

[10] F. Tian, H. Zhang, X. Chen, H. Zhou, D. Chen, A graphical symbol for machining process information description using Model-Based Definition technology, Trans Tech Publications, Switzerland, 2014.

[11] Data Security and Know-How Protection, PROSTEP AG (White paper http://www.3dpdf.com/nc/en/server-solution/white-paper-data-security.html), 2014

[12] 3D PDF technology, PROSTEP AG (White paper http://www.3dpdf.com/nc/en/server-solution/white-paper-3d-pdf-technology.html), 2012

[13] A. Katzenbach, S. Handschuh, R. Dotzauer, A. Fröhlich, Product Lifecycle Visualization, in J. Stjepandić et al (eds.) *Concurrent Engineering in the 21st Century - Foundations, Developments and Challenges,* Springer International Publishing Switzerland, 2015.