Transdisciplinary Engineering: Crossing Boundaries
M. Borsato et al. (Eds.)

doi:10.3233/978-1-61499-703-0-828

Interoperability and Visualization of Complex Products Based on JT Standard

Raphael BECKERS, Sarah GIESE, Alain PFOUGA and Josip STJEPANDIĆ [1]
PROSTEP AG, Germany

Abstract. With their response to the market and regulatory challenges, modern enterprises have introduced and continuously improved processes, methods and tools to feed the individual needs of their business domains, multidisciplinary teams and supply chain, mastering the growing complexity of virtual product development. As far as product data are concerned, data exchange, 3D visualization and communication are key processes for reusing manufacturing intelligence across lifecycle stages. User-friendly access to the increasing amount of information plays an essential role in business and leisure. Several CAD interoperability and visualization formats meanwhile have been developed to support product development strategies. Such activities also include national and international associations and standardization bodies. The emerged methods and systems aim to increase the performance, acceptance, and user experience of graphical data representations for a broad range of users. This paper analyses methods and tools used in virtual product development to leverage 3D CAD data in 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 various domains and disciplines.

Keywords. 3D, Visualization, Collaboration, Exchange, JT, STEP, PDF

Introduction

The gradual cyberization of physical products and predominantly the introduction of Computer Aided Systems have triggered a digital transformation movement in Manufacturing. Applying 3D CAD and PLM strategies has fundamentally led to higher productivity, better quality and a simultaneous reduction of overall development time and costs [1].

Meanwhile, product development methods such as Concurrent Design, Simultaneous Engineering and Systems Enginnering have widely been adopted [2]. They tend to manage complex development tasks in such a way that independent units can be processed concurrently to build an optimal technical solution designed for a complex issue. They ensure inherent behavior of each unit as well as system-wide interactions according to weighted objectives [3] [4].

The principle advantages provided with above-mentioned 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 amount of data and the quantity of knowledge inserted in virtual product data are now reaching exponential growth [5] [6] [7].

[1] Corresponding Author, E-Mail: josip.stjepandic@opendesc.com

Attaining better performance and accuracy while providing product data to the right party in the context of his current application is essential for greater time-to-market. As de-facto reference of the physical product, from which downstream data are derived, the 3D product representation deserves a particular interoperability attention [8]. Modern organizations thus invest in activities required to achieve seamless experience with 3D data across applications, disciplins and supply chains [9]. These main activities are: the exchange of product relevant data across aforementioned layers; the visualization of cyberized products with purposely disclosure of source intents and the communication [10][11][12].

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 [13], engineering domains, methods and tools of the different parties participating at product life, while safegarding all current investments (Figure 1) [14][15][16].

The paper is organized as follows. In section 1, the business challenges in interoperability and visualization are briefly described. Section 2 discusses in more detail the current approaches for 3D-based collaboration. Deployment of JT and practical experiences is highlighted in section 3. Section 4 contains a summary and ideas for further research.

1. Business challenges in interoperability and visualization

In the past several interoperability data formats arose. 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 suitably protected. Due to their lack of openness they are essentially less appropriate for collaboration in the extended enterprise. They will no longer be considerered in the context of this paper.

		Viewing				Viewing + PMI							Viewing + PMI + Kinematics								
Product Lifecycle Phases	**Generic processes**	Viewing	Bidding and inquiry	Material specification	Packaging	Drawingless manufacturing	Supplier integration (OEM2SUppl.)	Finite Element Analysis	Difa: Factory DMU	Difa: Factory buiding planning	Difa: Plant Development	Tolerance studies	High-end Visualization	Difa: Material handling	Difa: Manufacturing planning	Supplier integration (Suppl.2OEM)	Non-hybrid design in context	Installation Feasibility	Multi Body Simulation (MBS)	Hybrid design in context	Archiving
1 Acquisition	Bidding and Inquiry	×	×	×	×	×	×	×	×	×						×					
2 Enigneering (Product Development)	DMU	×		×	×	×	×		×	×	×	×	×			×		×			×
	Design in context	×	×	×	×	×	×		×	×	×					×	×			×	
	Simulation	×		×		×	×	×			×	×		×	×	×		×	×		×
	Digital factory processes	×		×		×	×		×	×	×			×	×	×					
4 Production	Production-Planning + -Control	×		×		×															
	Manufacturing+ Assembly	×		×		×															
	Logistics	×				×															
5 Sales	Marketing material	×		×									×								
6 AfterSales	User manuals	×																			
	Repair instructions	×		×		×												×			

Figure 1. Potential application of 3D formats during product lifecycle.

On the other hand open formats are often designed to enable interoperability between applications. They provide descriptions 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 standards ratified by a recognized international organization are stable by nature and may slowly evolve [17]. Open standards however, enable the reduction of total cost of ownership and ensure independence from specific vendors by making sure that the data they encapsulate is always capable of being leveraged downstream and recoverable from an archive repository [18].

It hereby goes without saying that formats such as IGES, DXF, STEP, 3D XML or JT are being widely accepted and have helped to improve dynamics in product development [19][20].

IGES defines a vendor-neutral file format by information structures for the digital representation and exchange of information like product definition data. It supports exchange of geometric, topological, and non-geometric product data beneath CAD/CAM systems such as: administrative identifications, design or analysis idealized models, shapes, processing and presentation information. It is used for applications such as traditional engineering drawings and design as well as models for simulation analysis.

The development of STEP started in 1984 as a worldwide collaboration. The initial plan was to define a mechanism that is capable of describing product data throughout the lifecycle of a product, independent from any particular system. This type of attempt was made for the very first time. By nature of its specification STEP is 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 design, CAM (computer-aided manufacturing), CAE (computer-aided engineering), PDM (product data management)/EDM (engineering data management) and other CAx systems. STEP appeals 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 [21], ship building [22], oil and gas, process plants and others. Unlike modern formats like e.g. JT, STEP has not the option "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 that were used prior to the widespread industrial acceptance of STEP. It is developed and maintained by the ISO technical committee TC 184.

The JT format described in ISO 14306:2012 is used mainly in industrial use cases as the means for capturing and repurposing lightweight 3D product definition data [20]. The development of the binary file format JT started in 1990. It 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) [23] and generalized visualization, more commonly referred to as view/measure/mark-up (VMM).

Due to its container structure JT shows "duality": it is able to be used in cases where data exchange from one application to a second, as well as in cases where visualization is desired.

JT is actively used with fast rising trend. As of today several millions of JT files are managed in automotive PDM systems alone covering a multitude of engineering use cases. It has emerged to a major 3D format in automotive collaboration, which requires a particular interoperability focus to maintain the stringent process and quality requirements of its different applications [24].

As a matter of fact, among all the aforementioned proprietary and open formats, none delivers overall versatility and capabilities by its own to equally sustain the varied demands of collaboration [25] in the extended enterprise and further, beyond product development stages of product lifecycle (Figure 2). Either they are not easily accessible or they do not have sufficient capacity for sharing dissimilar representations of same product (e.g. 2D/3D CAD, CAM, BoM, etc) across different applications, domains and teams. Or they aren't providing sufficient tools and SDKs to support and adapt the collaboration experience. Or their industrial use is very low or they just are not ratified by a recognized standards body, which makes them strategically unsustainable for modern organizations.

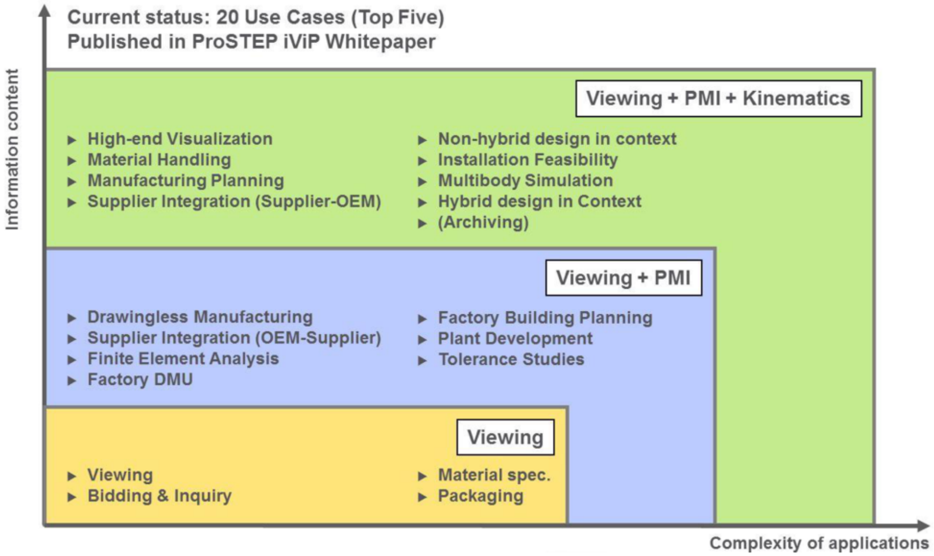

Figure 2. Schematics for Use Case Structure.

The industrial application of these 3D formats have moreover been around the transport of specific data sets 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 is finally translated into a proprietary format of a third party application for use in e.g. design, validation, and viewing or long term archiving.

Normally and as far as engineering collaboration is concerned, different parts describing an affected request and their virtual product data are delivered through diverse 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 also used [26].

Basically, this approach is a limitation to leveraging product data across lifecycle stages, domains and supply chains, because the necessary information is supplied 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 workspace of the receiver. The missing link between these parcels, though, is an issue that leads for many organizations to unnecessary bureaucracy. As far as manufacturing is concerned, this means that the development partners must support several systems and configurations and are additionally busy adapting and integrating data instead of using them right away.

2. Current approaches for 3D-based collaboration

Lifecycle Collaboration should be more versatile than providing chunks of data [27]. It is more than disconnected product structure, visualization or 3D design! It is the logical combination of all relevant data flows put in context with a recipient consuming these data to better perform a set of product development tasks. Under this consideration, research and industrial communities are investigating approaches incorporating different types of information [25].

Pushing the practical penetration of JT in engineering downstream has enormous potential for manufacturing. Regarding this, 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, which incorporates not only 3D visualization but also process relevant capabilities. The manufacturing community has recognized that JT itself can only reach its full potential by applying it in combination with smart XML functionalities of the Application Protocol (AP) 242 of the STEP standard [24]. 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.

Detailed information hereto can be found within the JT Workflow Forum (JT-WF) [28], a joint project group established by the ProSTEP iViP Association and the VDA (German Association of the Automotive Industry) in 2005. The objective of the forum is to drive the requirements relating to the application of JT and the accompanying format STEP AP242 XML, to validate them, to document the processes in use cases and to harmonize the necessary characteristic of the used JT as well STEP AP242 XML data content. JT Workflow Forum has already described 32 use cases for implementation [28]. One of the most important drivers for future development and deployment of JT is Daimler, where JT is the central resource for provision of 3D data (Figure 3).

The advantages provided with JT however do not have a life cycle coverage yet. Still today, most organizations are seeking for concepts and best practices in reusing their product data not only in product engineering but e.g. also in facility, product planning and manufacturing execution, where STEP and other formats for instance are already applicable. This situation is enforced with lack of standards for data exchange and interfaces between cross-domain systems used there, which are fundamental for collaboration with external partners in production (digital manufacturing).

The lack of direct support for JT causes for instance requests for translation to perform machining operations.

The recommendation 4953-2 is an implementation 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 [29]. The scope of this recommendation is a document-based container, which includes mandatory and optional contents with 3D data streams and their linked technical metadata. The aim is to eliminate the need existing in many areas of derivation and management of 2D-based collaboration and technical documentation.

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

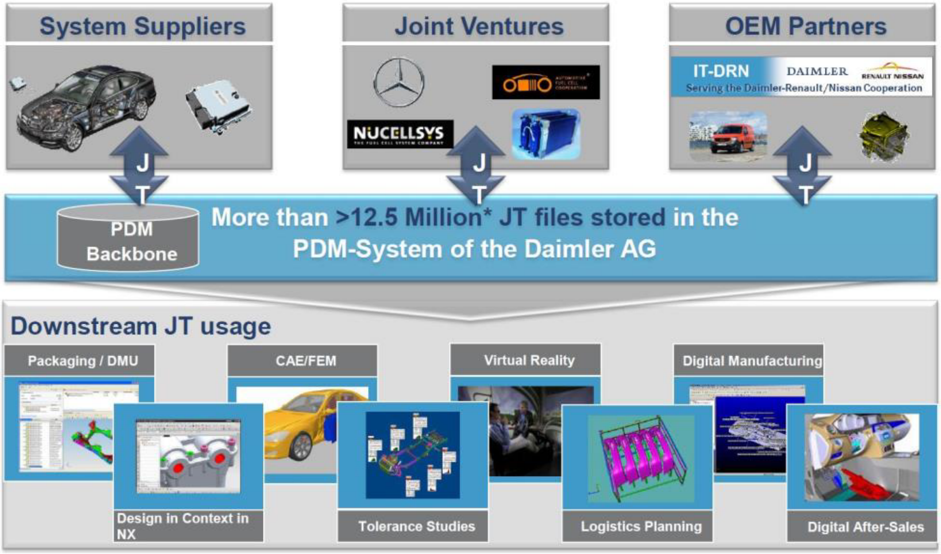

Figure 3. Scenarios and processes for JT deployment at Daimler.

Based on a similar concept, a further German automotive OEM Volkswagen has published and presented such a container using PDF as container and JT for storing 3D product data. An external viewer is launched interactively to present and query 3D JT objects such as PMI and technical descriptions from the PDF/A presentation layer. Meanwhile, it is used as a basic tool for various internal downstream processes.

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 [30]. Thus, 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 [18] [31]. MBE in its core is truly not pushing a format or a tool [32]. 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.

These particular interoperability formats are selected by various manufacturing organizations to achieve the vision of a Model Based Enterprise at numerous levels: which basically is reducing the significant manual intervention in the supply chain to go from product design through product lifecycle downstream such as manufacturing or quality inspection.

Despite the industry MBE vision to become model-centric, 2D drawings is still playing a fundamental role for technical documentation between OEMs and their suppliers. Many among them still exchange design data in the form of full-annotated-2D drawings combined with 3D-shape-geometry model. Only a small percentage of the manufacturing actors use just a 3D model with embedded 3D-PMI partly due to following barriers [33]:

- 2D Drawing is still considered the master versus the 3D Model by many in industry.
- There is a significant learning curve to effectively embed PMI into a 3D CAD.
- There is an overall supply chain work to consider before adopting 3D PMI in the development process.
- Many application program interfaces (API’s) do not adequately support downstream processes due to lack of PMI.

VDA recommendation 4953-2 in chapter [29] is an instantiation of the model-based design principles.

3. Deployment of JT and practical experiences

In the past few years JT was widely adopted by many global enterprises, in particular in the automotive industry. They have built a JT-based infrastructure which allows that each authorized user can access the JT data during the product lifecycle. Large enterprises report on successful implementation and deployment [34]. Among others, JT is primarily used in the following downstream processes: Design in Context, Data analysis, Multi-CAD, High-end visualization, Supplier Integration, Geometrical search, Assembly validation/DMU, Archiving.

In combination with STEP AP242 XML, JT has become a powerful means for support of many engineering tasks, as reported from interviewed users (Figure 4) [28].

Users are unanimous in their assumption that approximately 30 percent of the costs currently incurred for CAD licenses can be saved permanently as the result of introducing the neutral standard format. This is especially true for companies who are forced, for various reasons, to implement a number of different CAD systems. Some of these implementations may then no longer be needed, provided the exchange of data with partners and customers for certain purposes can be changed over entirely to JT.

Data exchange between native formats often results in the need for reconditioning to correct any transfer errors. Once an agreement regarding the use of JT has been reached, the number of transfers required between native formats will be subject to a significant decrease. This means that the amount of work currently required for reconditioning the data from internal and external partners will also decrease markedly.

The smaller size of the JT files and the simple, often automatic, conversion make it much easier and at the same time faster to exchange data between different CAD systems, for instance for design in context. However, the size of the JT file heavily depends on its configuration.

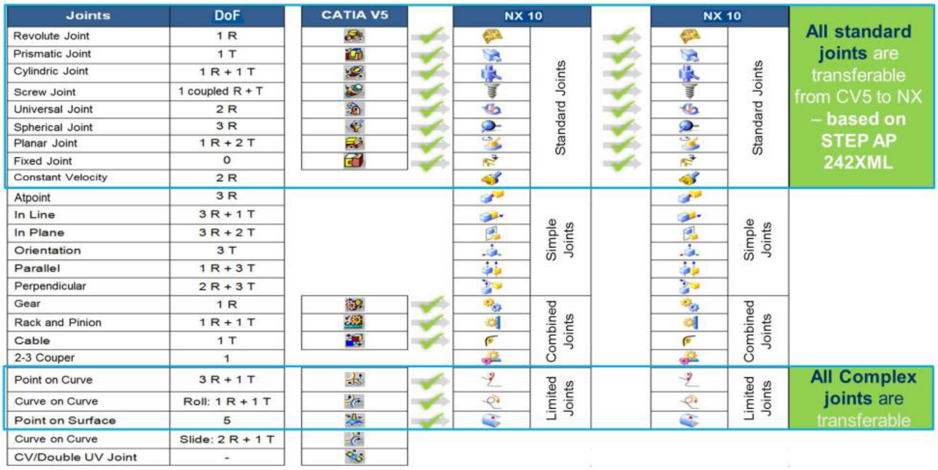

Figure 4. Exchange of kinematics data via STEP AP242 XML.

All those involved expect the processes that can be supported in the future as a result of the availability of JT to improve dramatically and, above all, be easier to use. The ability to rely on not words but visual support across departmental borders, in non-technical process and via the Internet will release a considerable amount of energy that was previously inevitably required to search for data, explain documents and disseminate information. In the same way that NetMeeting supports telephone and video conferences and 3D-PDF allows the creation and processing of a wide variety of documents, so can JT become a core element in collaboration scenarios that involve engineering data.

4. Conclusions and outlook

This contribution has addressed the state of the art activities for establishing JT as universal process format for interoperability and visualization of complex products. 3D interoperability is an important contribution to engineering collaboration. Several formats made to for this purpose successively deal with challenges of their time. Some of these such as STEP are very detailed formats, which gradually encapsulate all information necessary to define a product, its manufacture, and lifecycle support. Others focus mainly on lightweight visualization use cases and endure better with increasing size and complexity of data. The status of JT is very promising. Its application has reached high level of maturity with a eco-system consisting of developers, adopters and users. However, in the era of lean and agile, seamless collaboration needs continuous planning [35].

There are further requirements for 3D formats for the visualization and downstream processes, and complementary formats in order to exchange meta-data, structure data and kinematics data as well as open and standardized formats to reduce total cost of ownership and to minimize dependency of single vendors. As shown in Figure 5, the exemplary scenario for exchange of product structure, geometry and meta-data expresses that the data exchange based on JT and STEP AP242 XML is possible with few weak points (translation and proper interpretation of attributes).

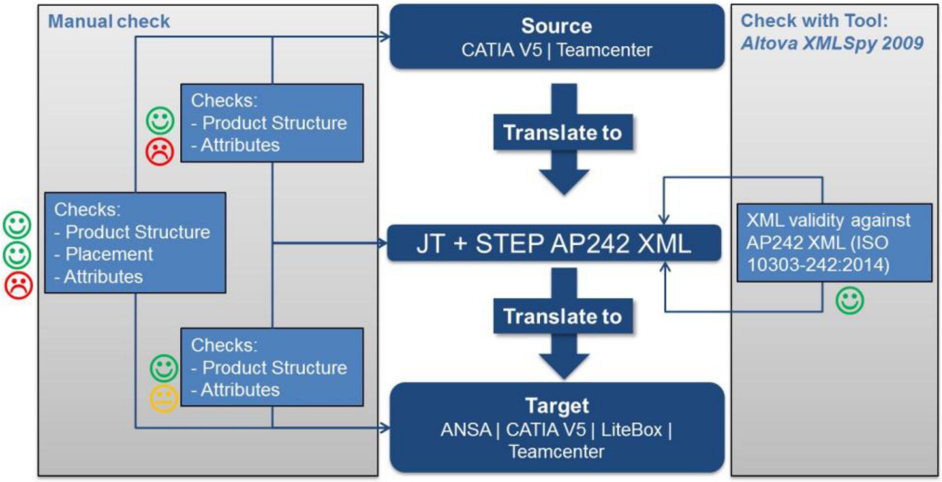

Figure 5. Data exchange scenario with JT and STEP AP242 XML.

Further implementation and integration of remaining use cases with the accompanying format STEP AP242 is the major forthcoming task for JT development. In version 2.0 JT will adopt further representations of geometry model. Further development is preserved by international bodies which include implementer fora.

References

[1] J.Z. Li, *CAD, 3D Modeling, Engineering Analysis, and Prototype Experimentation Industrial and Research Applications*, Springer International Publishing Switzerland, 2015.

[2] M. Eigner, D. Roubanov, and R. Zafirov (eds.), *Modellbasierte virtuelle Produktentwicklung*, Springer-Verlag, Berlin Heidelberg, 2014.

[3] S. Alguezaui, R. Filieri, A knowledge-based view of the extending enterprise for enhancing a collaborative innovation advantage, *Int. J. Agile Systems and Management*, Vol. 7, 2014, No. 2, pp. 116–131.

[4] A. McLay, Re-reengineering the dream: agility as competitive adaptability, *Int. J. Agile Systems and Management*, Vol. 7, No. 2, 2014, pp. 101–115.

[5] J. Stark, *Product Lifecycle Management. Volume 1: 21st Century Paradigm for Product Realisation*, 3rd edition, Springer International Publishing Switzerland, 2015.

[6] F. Elgh, Automated Engineer-to-Order Systems A Task Oriented Approach to Enable Traceability of Design Rationale, *Int. J. Agile Systems and Management*, Vol. 7, 2014, Nos 3/4, pp. 324 – 347.

[7] M. Germani, M. Mengoni and M. Peruzzini, An approach to assessing virtual environments for synchronous and remote collaborative design, *Advanced Engineering Informatics*, Vol. 26, 2012, pp. 793–813.

[8] R.M. Kolonay, A physics-based distributed collaborative design process for military aerospace vehicle development and technology assessment, *Int. J. Agile Systems and Management*, Vol. 7, 2014, Nos 3/4, pp. 242 – 260.

[9] X.L. Zhang, T. Simpson, M. Frecker, and G.Lesieutre, Supporting knowledge exploration and discovery in multi-dimensional data with interactive multiscale visualization, *Journal of Engineering Design*, Vol. 23, 2012, No. 1, pp. 23-47.

[10] E. Hietikko, E. Rajaniemi, Visualized data—tool to improve communication in distributed product development projects, *Journal of Engineering Design*, Vol. 11, 2000, No. 1, pp. 95-101.

[11] Y. Shen, S.K. Ong, and A.Y.C. Nee, Product information visualization and augmentation in collaborative design, *Computer-Aided Design*, Vol. 40, 2008, pp. 963–974.

[12] C.-H. Chu, C.Y. Cheng, and C.-W. Wu, Applications of the Web-based collaborative visualization in distributed product development, *Computers in Industry*, Vol. 57, 2006, pp. 272–282.

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

[14] N. Figay, C. Ferreira da Silva, P. Ghodous, and R. Jardim-Goncalves, "Resolving Interoperability in Concurrent Engineering", in J. Stjepandić et al. (eds.) *Concurrent Engineering in the 21st Century - Foundations, Developments and Challenges*, Springer International Publishing Switzerland, pp. 133-163, 2015.

[15] C.-H.Chu, P.-H. Wu, and Y.-C. Hsu, Collaborative 3D Product Development with Multiple Levels of Detail in Visualization of Design Features, *Computer-Aided Design & Applications*, Vol. 3, 2006, No. 6, pp. 789-801.

[16] N. Li, W. Xu, and J. Cha, A Hierarchical Method for Coupling Analysis of Design Services in Distributed Collaborative Design Environment, *Int. J. of Agile Systems and Management*, Vol. 8, 2015, Nos. 3/4, pp. 284-304.

[17] P. Pfalzgraf, A. Pfouga, and 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, pp. 753-763, 2013.

[18] Y. Chen, Industrial information integration—A literature review 2006–2015, *Journal of Industrial Information Integration*, Vol. 2, pp. 30–64, 2016.

[19] A. Katzenbach, S. Handschuh, and 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, pp. 41-52, 2013.

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

[21] D.S. Cochran, M.U. Jafri, A.K. Chu, Z. Bi, Incorporating design improvement with effective evaluation using the Manufacturing System Design Decomposition (MSDD), *Journal of Industrial Information Integration*, Vol. 2, pp. 65-74, 2016.

[22] K. Hiekata, M. Grau, Shipbuilding, in J. Stjepandić et al (eds.) *Concurrent Engineering in the 21st Century - Foundations, Developments and Challenges*, Springer International Publishing Switzerland, pp. 671-700, 2015.

[23] G. Sun, A digital mock-up visualization system capable of processing giga-scale CAD models, *Computer-Aided Design*, Vol. 39, pp. 133–141, 2007.

[24] A. Katzenbach, S. Handschuh, R. Dotzauer, and 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, pp. 287-318, 2015.

[25] Z.M. Qiu, K.F. Kok, Y.S. Wong, and J.Y.H. Fuh, Role-based 3D visualisation for asynchronous PLM collaboration, *Computers in Industry*, Vol. 58, 2007, pp. 747–755.

[26] S. Casera, P. Kropf, Collaboration in scientific visualization, *Advanced Engineering Informatics*, Vol. 24, 2010, pp. 188–195.

[27] M.C. Cölln, K. Kusch, J.R. Helmert, P.Kohler, B.M. Velichkovsky, and S. Pannasch, Comparing two types of engineering visualizations: Task-related manipulations matter, *Applied Ergonomics*, Vol. 43, 2012, pp. 48-56.

[28] N.N., *JT Workflow Forum*, VDA & ProSTEP iViP Association, http://www.prostep.org/en/projects/jt-workflow-forum.html, 2015.

[29] N.N., *VDA 4953-2 Zeichnungslose Produktdokumentation*, VDA, Berlin, https://www.vda.de/en/services/Publications/Publication.~1263~.html, 2015

[30] F.A. Salustri, N.L. Eng, and J.S. Weerasinghe, Visualizing Information in the Early Stages of Engineering Design, *Computer-Aided Design and Applications*, Vol. 5, 2008, No. 5, pp. 697-714.

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

[32] R.C. Beckett, Functional system maps as boundary objects in complex system development, *Int. J. Agile Systems and Management*, Vol. 8, 2015, No. 1, pp. 53–69.

[33] D. Lenne, I. Thouvenin, and S. Aubry, Supporting design with 3D-annotations in a collaborative virtual environment, *Res Eng Design*, Vol. 20, 2009 , pp. 149–155.

[34] R. Dotzauer, S. Handschuh, *Leveraging 3D Virtual Product Data with JT as Standard Process Format*, ProSTEP iViP Symposium, Stuttgart, 2016

[35] T. Suomalainen, R. Kuusela, and M. Tihinen, Continuous planning: an important aspect of agile and lean development, *Int. J. Agile Systems and Management*, Vol. 8, 2015, No. 2, pp. 132–162.