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AN INITIAL APPROACH OF A STANDARD BASED FRAMEWORK TO MANAGE REALISTIC PRODUCT REPRESENTATIONS

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Keywords: product lifecycle, virtual reality, photorealistic visualization, realistic representation, high-end visualization

1. Introduction

The current situation for companies operating on a national as well as global scale is characterised by an increasing external and internal complexity of all business areas [Schuh 2005]. The external complexity is based on different aspects like high volatility of emerging markets, a higher need of mass customisation or a growing competitive intensity [Schömann 2012]. Due to an increasing mass customisation, the variation of products and their derivatives is still growing [Burmann and Kohtes 2014], which should fulfil existing and create new needs for customers in various regions and countries by offering new models and products [Renner 2007].
Beside these external factors of complexity, internal challenges have to be managed, which are caused by numerous approaches in modelling, archiving and managing of products and their information. Especially in the area of the product definition and the first transfer of an initial product idea into a virtual form, a great amount of changes can be observed, regarding style, shape and appearance of a product [Braess and Seiffert 2007]. Particularly in early stages of a development process, styling and engineering design teams and departments are involved in the definition of components, products and overall systems, which should equally add their input to create a successful product [Vajna 2014].
In order to manage recent and upcoming challenges in an efficient and effective manner, it is necessary to develop novel business processes, methods and techniques, which enable all involved business partners to work in an interdisciplinary and collaborative environment by running jobs in parallel, speeded up work and by implementing a well-organised project management [Ehrlenspiel et al. 2014]. In the current, competitive environment of enterprises, simultaneous, interdisciplinary and collaborative work is based on an effective backbone of virtual tools such as product lifecycle management (PLM) systems and methods to enhance the connection of development partners, allowing an easy and standardised data exchange or the management of all required information. In this context, Model-Based Systems Engineering (MBSE) enables a sophisticated opportunity to link different domains of a product or entire system by a connection of requirements, functions or behaviour along the complete lifecycle. This holistic approach provides comprehensive, computer based models and methods in early stages of the development process to support planning, specification, design, analysis and verification of a product as well as its related representations and dependencies [Eigner et al. 2014].
In order to widen the technically focused view of a model-based system lifecycle, this paper shall point out an initial approach to generating, managing and connecting advanced information regarding the appearance of an entire product and enable new virtual opportunities for the cooperation between styling or mechanical design departments. Besides, this paper should present the main aspects of a standardised

approach to handle all relevant information of virtual reality (VR) applications and realistic product visualisations by linking all up- und downstream processes and integrate the included parties to define the fundamentals of the underlying framework. For this purpose, recent approaches of managing product information of an advanced visualisation will be analysed concerning the current and upcoming opportunities, which can be found in section 2. In section 3, the basics of a realistic product representations framework shall be defined by seven main requirements. These requirements provide a useful basis for a preliminary study of currently available solutions with respect to a holistic approach. Based on these results, section 4 will illustrate the main components of the proposed approach and some details of the recent work. Section 5 summarizes the main facts of the paper and will provide an outlook to further research activities.

2. State of the art of realistic representation within the virtual product lifecycle

As described by Rademacher, recent development processes are characterised by numerous efforts in order to further enhance the former serial process chain with simultaneous and cooperative methods and models. Across the product development, virtual prototyping and VR techniques are widely integrated into the daily work to satisfy these needs [Rademacher 2014]. In this context, Kulkani et al state that virtual prototypes are used to decrease the amount of physical mock-ups by replacing real with digital prototypes, which allows an enormous reduction of cost and time by avoiding physical studies [Kulkani 2011]. One of these areas of virtual representation of digital product twins is the realistic visualisation of products in different stages of the product lifecycle, as seen in Figure 1.

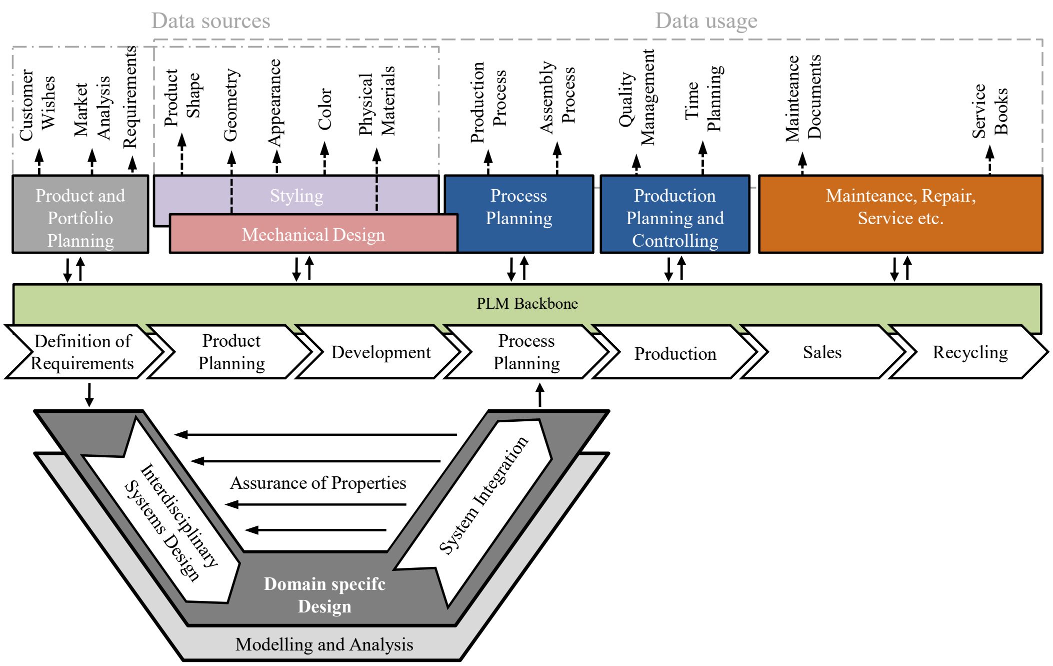

Figure 1. Product appearance and material information on the product lifecycle with data sources and usage, related to [Eigner et al. 2014] extended with Rademacher 2014] and [Stef et al. 2013]

Those realistic virtual visualisation techniques are commonly used within early studies of the conceptual phase [Rademacher 2014] or within process planning decisions [Stef et al. 2013] up to the possibility to configure and visualise entire products with help of product configurators of diverse types such as sales, product or design configurators [Paunu and Mäkipää 2014].

As illustrated by the combination of the V-model [VDI 2004] and the product lifecycle, products are completely specified by the early stages of their lifecycle, which symbolises the overall data source of all downstream activities [Eigner et al. 2014]. This first part of the product lifecycle starts with the definition of product requirements, e.g. appealing materials regarding the product appearance, and ends with a final product and production description [Stef et al. 2013]. These processes are mainly characterised by iterative procedures and can overlap in their chronological order such as a simultaneous generation of a parametric 3D-geometry considering a concept design and the selection process of interior materials by a styling department [Braess and Seiffert 2007].

2.1 Realistic product representation within the product lifecycle management

The fundamentals of virtual product data are mostly based on efforts in the design phases of a development process, which are often still depicted by specific 3D-data formats and specified in further documents as described by a variety of authors, e.g. [Feldhusen and Grote 2010], [Ma et al. 2011] or [Beutner et al. 2013]. In this case, the traditional and common way to obtain and handle a realistic representation comprises the three main steps of generating, preparing and presenting 3D-models [Purschke et al. 1998]. This classical process has been optimised in such a way that already created computer-aided design (CAD) models are often used to generate a tessellated geometry representation to be able to handle big data sets more easily. After a conversion into a specific process 3D-data format, surface materials will be applied, which consist of colours, various texture images and they may be based on different visualisation methods and photorealistic rendering techniques such as ray casting or tracing [Dörner et al. 2013]. The common points of a realistic visualisation for all use cases are the depth perception of visualisations and the immersive interaction of products within VR sessions. In accordance to Lawson et al, the immersion of users can be enabled through the usage of enriched multisensory VR environments, textured backgrounds and by the applied vivid colours and materials [Lawson et al. 2015]. Thus, these essential elements should cover the main aspects of the mentioned material information in addition to the positioning and scaling of surface textures and images [Dörner et al. 2013]. In consideration of realistic visualisations, these visual material information represent a central element of additional information, which have to be handled by a PLM-backbone consisting of product data management (PDM) functions and extended by other applications for managing requirements, maintenance or service [Eigner and Stelzer 2009].

Generated 3D-geometry data sets are not typically limited to conventional design tools such as CAD-systems. Across all disciplines and sectors, earlier design and styling stages should also be considered as a part to enrich product concepts with the stated additional information e.g. with computer-aided industrial design (CAID) or computer-aided styling (CAS) tools. Faißt et al already developed and evaluated several points to include styling aspects and wordings in the environment of a technical development, which might lead to continuous and connected process chains. Nevertheless, these aspects are more focused on geometry and do not fully address the management of properties of realistic visualisations [Faißt 2011].

In contrast to the mentioned tool specific 3D-formats, scientific approaches and industry use cases aim at the usage of multiple systems with standardised 3D-formats (hereinafter called Open-3D) as an exchange fundament [Anderl and Christ 2014] such as JT, STEP, 3D-PDF, 3D-XML, or X3D, which should be more capable for complex virtual processes [Ding et al. 2007], [Beckers et al. 2011]. For this purpose, JT might be the most promising solution regarding interfaces and the ability of conversion [Friedewald et al. 2011] and due to opportunities for industry applications and use cases [Katzenbach et al. 2015]. Furthermore, JT should be already able to support recent and upcoming data process chains in combination with an Extensible Markup Language (XML) data format such as STEP AP242XML for a transfer of additional information [Handschuh et al. 2013]. To satisfy future needs of information sharing, an integration of PLM functions into web-based applications and the ability of standard formats to visualise information should be also taken into account during an evaluation of formats [Kim et al. 2015].

2.2 Challenges and opportunities

The dissemination of virtual and augmented reality as well as other related applications in scientific research, industry and consumer products is still in progress. However, the usage of high end visualisation in immersive environments or static renderings for e.g. marketing images is highly dependent on the variety of recently available software tools to generate and visualise model data [Frost and Petrovski 2015]. As mentioned above, it is still time-consuming and cost-intensive to prepare scenes and models with additional information all over again and the implementation of bidirectional interfaces from VR sessions to a data generating system is a complex process due to the different data formats and software interfaces [Feldhusen and Grote 2010]. As described by Ma et al, an automated data generation for VR applications is mostly unavailable because of time consuming preparations of product data and limitations of PDM-systems. In these cases, central data management systems are not implemented in a way to involve persons and departments within an acceptable range and there is still a need to integrate the management of additional data like used material appearance or the status of products with respect to releases [Ma et al. 2011]. According to Seiffert and Rainer beside efforts for modelling and further preparations of products for VR and other applications, pre-processing is also limited by insufficient data quality and availability as well as open process chains within the development and lifecycle processes [Seiffert and Rainer 2008].

Concerning these challenges, Birkhofer et al states several aspects that have to be considered for a comprehensive digital representation of product data such as standardising the overall data representation of the PLM-backbone, a seamless exchange of digital information or a consistent product data definition [Birkhofer 2011]. Additionally, Ovtcharova identifies at least two dimensions for further improvements like the integration of new software solutions in the existing IT and process infrastructure and the methodological approach to choose a matching technology for specific tasks and use cases. It is also stated that VR users should work together collaboratively and based on the context of specific product configuration [Ovtcharova 2010]. Thus, all involved development partners have to clarify their data input, structure, formats, and versions to standardise the fundamentals of efficient processes [Beutner et al. 2013].

The investigation of a broad field of current research activities in the area of PLM, VR and especially literature related to realistic visualisation identified a lack in research regarding a holistic solution. The analysed publications might not provide a complete and detailed definition to fulfil all industry use cases of managing complex and high variant products sufficiently. However, the research findings will help to specify the main requirements of such a holistic solution. The results of investigation are used to define a description of necessary tools, processes and interfaces characterised by the requirements. Thus, these requirements can enable an initial analysis of recent solutions of managing realistic product representations. For this purpose, the next section should explain the main requirements with regard to the research findings and recognised challenges and it will present a first classification of existing approaches and solutions.

3. Basis of a standardised framework to manage realistic representations

The definition of tools, interfaces and processes is essential for the virtual development of complex products within collaborations. In order to establish an optimal framework based on recent research, seven main requirements divided into tools, interfaces and processes will be proposed in this section. These requirements should be suitable for various use cases in scientific and industrial environments and represent an initial orientation for the evaluation of overall software solutions.

3.1 Requirements

(1) MULTI CREATION (Tool). For companies working with different partners and collaborations, a software independent 3D-data creation processes and the assignment of additional information should be considered. In the context of realistic visualisation, all CAx tools have to be integrated in consideration to ensure synergies of different departments and to avoid or reduce overtime.

(2) REALISTIC VISUALISATION (Tool). An integration of at least one high end rendering tool is needed for realistic visualisation of VR sessions in an immersive environment and the generation of photorealistic images and animations within the lifecycle processes.

(3) MULTI VISUALISATION (Tool). Due to the fact that each VR software tool has its own limitations regarding the required functions, a comprehensive approach has to consider the integration of various VR and other visualisation systems. Furthermore, a connection to web interfaces has to be available to ensure location-independent collaborations of different users.

(4) VIRTUAL REALITY INTERFACE (Interface): Interfaces that supply VR applications with both geometrical and additional data have to be available. Besides, these interfaces should offer functions to

transfer data to an arbitrary VR system and equally back to a central data management system. The data transfer should ensure various functions but at least an exchange of colour parameters, information of texture positions and different colour and material variants.
(5) OPEN STANDARD FORMATS (Interface): A main aspect of a comprehensive process for realistic visualisation across the entire lifecycle is a complete standardised data exchange based on standard formats. As mentioned in the previous section, several open data formats for CAD-, PLM- and VR-exchange are currently available on the market. A few formats or a combination of formats which will be able to fulfil a wide range of required industry use cases including the ability of realistic product representations should be selectable.
(6) DATA STRUCTURING (Process): A complete process has to guarantee an application independent structuring of geometric models for diverse visualisation cases, e.g. high-end visualisation (HEV) or service documentation in order to provide improvements for several stakeholders of realistic visualisations.
(7) VISUALISATION DATA MANAGEMENT (Process): Data management of all information regarding the visualisation covers a respective field of tasks, which has to be considered. Thus, all functions and methods needed in the recent development processes to control and manage data should be taken into account. These aspects include particularly functions of generating and storing data, the version control of components and associated information, controlling of product variants and groups [Vajna et al. 2009] as well as methods of process and integration management of applications such as CAD- [Braess and Seiffert 2011] or CAID- and CAS-systems. Visualisation requirements have to cover all information that is needed to visualise 3D-product data in a realistic environment.

3.2 Analysis of recent solutions to manage realistic product representations

As already indicated above, the requirements proposed will be used to evaluate existing solutions regarding a holistic and standardised process. Concerning this, Table 1 illustrates the consolidated analysis of these results. The table consists of four columns, where each describes a group of available software approaches or solutions. In this context, PLM vendors represent holistic software solutions of companies like Autodesk, Dassault Systèmes or Siemens PLM etc. [Florica and Draghici 2012], which offer a broad product portfolio for an entire lifecycle. The evaluation of product configurator vendors are mostly based on findings of Brinkop and additional investigation with respect to the requirements proposed. Brinkop clarifies product configuration as a combination of existing product components and a product configurator as a tool to support the configuration task. These tasks can begin within CAD-systems and end within a web application with photorealistic images [Brinkop 2014]. Collaborative solutions gather a combination of different software tools across several tool vendors in order to connect different software systems from CAD over PDM to VR. One of these examples is a solution of nVIZ that combines NX as CAD source, Teamcenter as PDM backbone and an interface to VRED as VR component [Rehfeld 2013]. Moreover, few industry approaches were investigated, which are mainly focused on concepts and consider the utilisation of open 3D-standard formats such as JT within a proof of concept by Ford or Opel [Weitzer 2012].

Table 1. Analysis of recently available solutions with respect to requirements for a standardised approach of managing realistic product representations

● Fulfilled ◑ Partly fulfilled ○ Not fulfilled

No.	Requirements	PLM Vendors	Configurator Vendors	Collaborative Solutions	Industry Approaches
1	Multi Creation	◑	◑	◑	●
2	Realistic Visualisation	●	◑	◑	●
3	Multi Rendering	○	○	◑	◑
4	Virtual Reality Interface	◑	○	●	●
5	Open Standard Formats	◑	◑	◑	●
6	Data Structuring	◑	○	◑	◑
7	Visualisation Data management	◑	○	○	◑
	Sum	◑	○	◑	◑

By gathering and analysing a respective field of recent software solutions, it can be seen, that the suggested requirements are not completely implemented in industry processes. These findings also capture the known challenges, which are already determined by current efforts in scientific research. The most noticeable weaknesses can still be found within the multi tool creation, visualisation data managing and the connection of multi visualisation and rendering tools with aid of standardised interfaces. A possibility to support multiple tools to create 3D-geometry can be found within certain industry approaches. Nevertheless, there is still a lack in the management of variants by these approaches. Configurator tools for the product definition also provide opportunities to edit parameters of existing components but in most cases exclusively for geometrical changes. This aspect explains the poor support functionality with respect to data structuring, visualisation data mangement or VR interfaces. A bidirectional connection between VR or product visualisation tools and PDM systems are available in diverse solutions but limited to few software applications. PLM vendors offer sophisticated solutions with a high performance but they are still focused on in-house solutions without adequate cooperation or a consolidation of mutual interfaces and open data formats.
In order to improve recent solutions and postulate a more extensive approach, a conceptual framework should be presented, which covers limitations and challenges of the current situation. This conceptual framework is based on the illustrated evaluation findings and should be used as a guideline to establish a holistic solution.

4. Conceptual framework to manage realistic product representations

Despite numerous improvements of VR processes and realistic visualisation techniques with respect to the data exchange and preparation, a holistic approach based on standards to manage the entire system is still missing. As described, the system has to cover at least the proposed requirements to increase the recent performance and define an agile IT infrastructure by providing software independent process chains. To implement this kind of system, a conceptual framework is suggested.

4.1 Conceptual framework

The fundmentals of the proposed framework are formed by the generation and structure, variation and configuration, exchange and visualisation as well as processes and management, as seen in Figure 2.

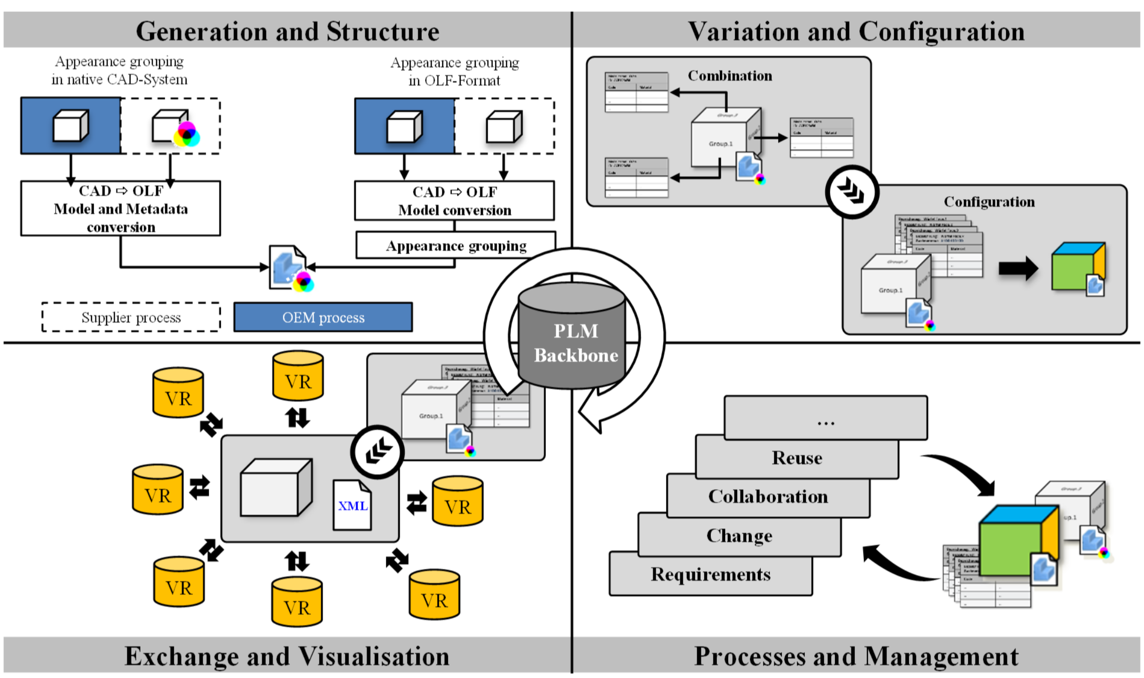

Figure 2. Conceptual framework to manage realistic product representations

GENERATION AND STRUCTURE. A first realisation of digital geometry should be also the starting point of the realistic visualisation of a product. Software tools for 3D-data generation have to be able to create models and assign them with additional information about the structure and usage of models and their surfaces. Therefore, it should allow users to handle different visualisation use cases such as consumer focused view or service oriented view by dividing models in components based on attributes. The structure might be provided by material groups in CAD- [Erler 2012], or other CAx-models but in contrast to recent attempts, a solution should be supported by numerous interfaces and standardised formats. Therefore, the needed attributes should be used to ensure a conversion of additional information of a native 3D-model into a standardised form. The reason for a data exchange based on standardised formats is the low number of conversions compared to a conventional exchange from specific formats into other specific formats [Rieg and Steinhilper 2012]. Those additional data sets should use standardised functions of Open-3D formats to implement it in the existing processes. For this purpose, a conversion of CAD, CAID or CAS attributes (which contain further information) into a standardised format like JT or STEP will be promising.

VARIATION AND CONFIGURATION. Most visualisation use cases are based on the evaluation of a product appearance and in this context, a comparison of different appearance variants is needed. A combination of the 3D-data structure and the internal enterprise knowledge of variants can fulfil the required function. In recent data management systems, the geometrical variation is already considered. This consideration has to be widened by the variation of the appearance combined with the geometrical variation. For this reason, the mentioned structure within an Open-3D data format has to be combined with the enterprise knowledge about the visual variation of a product and thus, it's external appearance. In this case, attributes within a 3D-model should represent the associated groups of appearance variants by assigning geometrical entities with a group identifier and form a specific variant with the aid of underlying enterprise knowledge within the PLM-backbone. Due to this process, the variation of the product can be created and extended without an initial link to a specific 3D-data format. In this context, it is only necessary to define the needed appearance group identifier of a data set. Independently of the geometry creation, appearance variants could be defined with colour and texture parameters and assigned with codes or conditions, that specify the usage of a variant. These methods would also allow the configuration and combination of existing visualisation variants without any significant effort.

PROCESSES AND MANAGEMENT. Besides the advantages already mentioned, an early grouping in CAx-systems enables further benefits especially for the data management process. After geometrical changes, it is only necessary to assign new geometrical entities with the additional information because the already defined connection between an existing appearance group and appearance variants within the PLM-backbone is still available. Moreover, if geometrical entities are removed, the used appearance groups will be removed as well. In the case of change regarding the variation or the definition of appearance groups, the information about appearance groups within the native CAx-file also has to be changed. The separated processes of generating 3D-models and creating appearance variants enable the possibility to work concurrently, which allows an earlier definition of variants and more suitable development revisions. It also ensures a simultaneous development of geometry and visual variants in a more flexible virtual collaboration environment. Furthermore, already defined appearance variants can be reused in subsequent processes and other components.

EXCHANGE AND VISUALISATION. As already mentioned, a multiple exchange can only be guaranteed in an efficient way by a process that is supported by standard formats. In this context, an Open-3D format should enable comprehensive functions and it should be known and used in the industry in order to support and accelerate its implementation. Hence, JT or STEP might be used as an Open-3D format to transfer the geometrical information to a visualisation application. The additional data sets and parameters should be transported separately by an implicit data representation. A XML-based format such as STEP AP 242 XML is a well known format for PLM-information exchange for industry purposes and thus, it should be considered in further examinations. It also has to be able to store various attributes to visualise a scene. At least, these attributes should cover colour parameters, links to texture images, information about the position and scale of textures and information about changes of a scene, done within a visualisation application. Those changes may cover light settings, environment settings, pre-calculated shadows or the rendering techniques used.

4.2 Initial implementation within the suggested framework

With respect to the suggested framework, a pilot project was initiated, which covers the implementation of a process chain with different software systems, as seen in Figure 3. The fundament of this solution is formed by the JT format as the standardised exchange format for 3D-geometry and the XML-based PLMXML format for product structures.

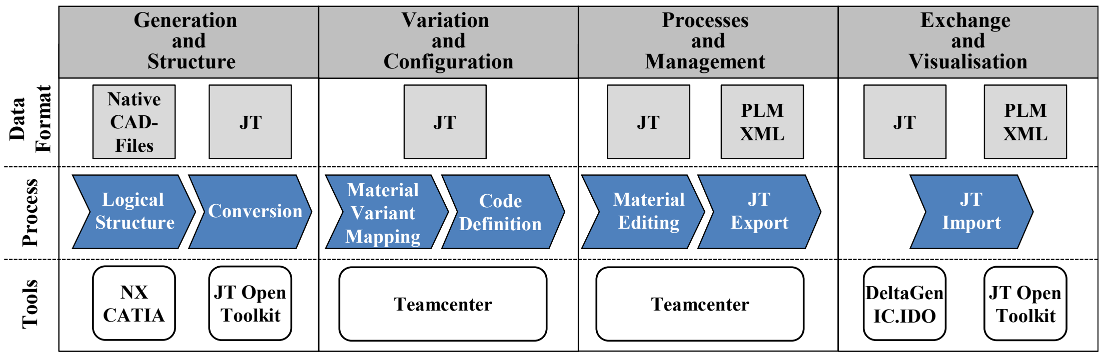

Figure 3. Initial software implementation within the suggested framework

Within this implementation, the generation of 3D-geometry is based on CAD systems such as NX or CATIA in order to enable multi CAD use cases. This first approach uses NX and CATIA attributes, which have to be converted to JT attributes to handle all relevant information in a standardised form. In this context an automated post-processing is used to enable a performant access to the structure elements of the 3D-geometry within a JT file, which is implemented with the JT Open Toolkit standard library. By the definition of new business items and the enhancement of functionalities of Siemens Teamcenter, a link between the 3D-data and the visual information can be ensured. The integrated visualisation is managed via a Rich-Client application based on the underlying enterprise knowledge. By providing a unique identification of structure elements within 3D-models, the mapping of geometry elements and material variants can be guaranteed.

The first implemented connection of VR systems and the enterprise backbone is based on advanced JT materials and the ability of JT Open Toolkit methods. Nevertheless, it only allows an up to date data stream from the database to the visualisation systems.

These mentioned efforts are generally focused on the technical implementation of the interfaces and the connection of different software applications. Thus, the underlying processes cover the standard functionalities of PDM software systems such as change workflows, which can be accessed by a customised Teamcenter environment. An enhancement of these functionalities have to be a task for future work in order to enable development departments with more efficent and suitable workflows.

5. Conclusion and future work

First, this paper briefly explains the need of a realistic product representation within different stages of a product lifecycle and it presents the main challenges and opportunities to enhance the performance of collaborative work on complex, high variant products. The findings of this research study can be used to evaluate existing solutions with respect to realistic visualisations and to develop a matching approach for the proposed requirements. This approach is illustrated by a framework that covers four main components like data generation and structure, variation and configuration, exchange and visualisation as well as data processes and management aspects. These components were shortly examined by research investigation and were realised within an initial software implementation.

On further proceedings, the proposed components will be enhanced and tested in more detail in order to specify and implement the needed parts of a holistic solution within the suggested framework. An investigation of other CAD as well as CAS or CAID software systems with the ability to structure 3D-geometry as mentioned will be one focus of future work as well. In the following research activities, fundamental resources of a PLM backbone have to be examined. This examination has to cover an evaluation of alternative resource solutions, which should be more suitable in a dynamic development environment. Another important component of a holistic solution will be the enhancement of the exchange between a central PLM-backbone and visualisation application.

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