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META-MODEL FOR VR-BASED DESIGN REVIEWS

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Abstract

The paper describes the development of a tool to make it possible to generate a Virtual Reality (VR) representation of the current state of an engineering project without additional effort. The VR tool extends the CAD and simulation programs used in the development process through a visualisation module. Making use of current geometry and calculation data, it provides direct visualisation in virtual environments. The tool developed is based on a meta-model generated from the data from different application programs. The tool concept and implementation are described for a configurator applied to energy systems.

Keywords: Collaborative design, Integrated product development, Virtual Engineering (VE), Visualisation

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1 INTRODUCTION

Today, reviews of virtual models on the periphery of mechanical engineering are a vital part of product development. They provide the users with substantiated feedback about product maturity in the processes prior to the manufacturing of prototypes and final products.
For some time now, it has been possible to review product geometries by means of VR and to check their functionality. The advantages over representation using conventional displays are 3D perception of the real-sized model and faster, more natural interaction with the observer (McMahan and Bowman, 2007).
Substantial time and work must be set aside for the preparation of a review in VR, so that investigations like these only make sense when a developmental milestone has been achieved. Because model preparation takes so much time, very often the underlying data no longer reflect the current state of development. Since VR devices are very costly, their use can only be financed by large enterprises. However, these financial hurdles are constantly decreased, since low-cost HMDs, such as Oculus Rift (Oculus VR, 2017), HTC Vive (HTC Corporation, 2017) or PlayStation VR (Sony Interactive Entertainment Europe Limited, 2017), are being used more frequently.
There is still a great demand for detailed development in the field of data conditioning prior to the VR review. This is the result of the huge data volumes necessary for complex models and the numerous applications that are required for various calculations and adequate representations of results. The variety of existing software demands equivalent visualisation and interaction metaphors, which are shaped by the individuals who develop and use the application programs during the development period. To observe geometry and calculation models, as well as associated calculation results, together, customised data structures and integration elements are needed.
The problems mentioned above may be dealt with by applying a suitable structure model within the scope of an R&D project. The model makes available the following solutions:

- Reduction of data conditioning time
- Overlap of geometry data with simulation results
- Data transfer into a VR tool to visualise various data for the review process to be done in cooperation

2 RELATED WORK

The design review has been established for some time in the product development cycle as a quality assurance tool. The standard BS EN 61160 (British Standards Institution, 2005) identical to German standard DIN) designated "Design review" is in principle based on the ISO 8402 (rejected in 2000) or the VDI guideline No. 2247 (rejected in 2012).
VR is an established tool for design reviews, in which individuals can experience and evaluate the future product as a virtual prototype. High-quality projection and full-size models, as well as increasingly integrated simulation and interaction, make it possible to perceive the virtual prototype in a way that is close to reality.
According to the standard, the design review is defined as follows: “A design review is an advisory activity. It is intended primarily to provide verification of the work of the design development team, and to provide recommendations where possible to improve the product or process and its realization. Thus design reviews should be considered as a confirmation and refining procedure and not as a creative one” (British Standards Institution, 2005). Design problems are recognised and documented. Particular measures to solve the problem are agreed upon.
Despite all expectations and generally positive experiences in use, design reviews carried out by means of VR are also seen critically in practice. The problems that may arise include:

1. *Substantial effort required to model from native geometry-, material- and surrounding data.* The work can be decreased if VR is understood not as the final result, but as an integral part of developmental stages. VR scenarios and the data used for generation have to be managed in an integrated Product Data Management (PDM) concept. This way, presentations can be generated from the current product data at any time (Stelzer et al., 2012).
2. *Doubts regarding the validity of evaluations, "superficial" interaction with virtual prototype, lack of tools to document virtual try-outs.* Individual perceptions in VR scenarios are investigated and

parameters that may affect or correct the VR representation are identified. Consistency in the evaluation of virtual prototypes will thus improve (Renner et al., 2015). Tools for recording and replay of interaction sequences in VR surroundings are under development to document evaluations in a traceable manner (Stelzer et al., 2014).

3. *Insufficient and/or complicated evaluation feedback in the product development process.* VR systems provide more and more options to store selected constellations of reviews. Additional tools (Schwarz and Zupke, 2014) are anticipated to create, save and distribute annotations for further processing among engineering departments during VR reviews.

The issues mentioned above are significantly influenced and potentially ameliorated by the availability of adequate user functions (Kunz and Wegener, 2015). Lorenz et al. presented an approach to an automated conversion of CAD data to a VR system (Lorenz et al., 2015), reducing the afore-mentioned effort for design review preparation.

This paper suggests an approach to provide an integrated VR model preparation including relevant simulation data while further decreasing the preparation efforts. For this purpose, a meta-model containing an extensible variety of information is introduced.

3 VISUALISATION IN PARALLEL WITH DEVELOPMENT

Within the scope of the R&D project, digital product models should be visualised in parallel with development. The product models include not only geometry, but also simulation, calculation and PDM data. In a tool that is being engineered, all data have to be represented in a comprehensible way, so that they may be experienced and studied by engineers using VR techniques. The development of the software, subsequently called the VR tool, is also part of the research project, as is the development of a model from which the VR tool derives the information required for the VR presentation. As a result, it should be possible to carry out what we are calling mixed reviews, in which multiple users can utilize head-mounted displays (HMD) and 3D displays at the same time, without limiting their communication.

3.1 Meta-model concept

The VR tool is based on a structure model containing all of the information needed to integrate or link the data pools of various application programs generated during the development process. A model like this can be represented as a meta-model, since it brings together data structures that come from various applications (see Figure 1).

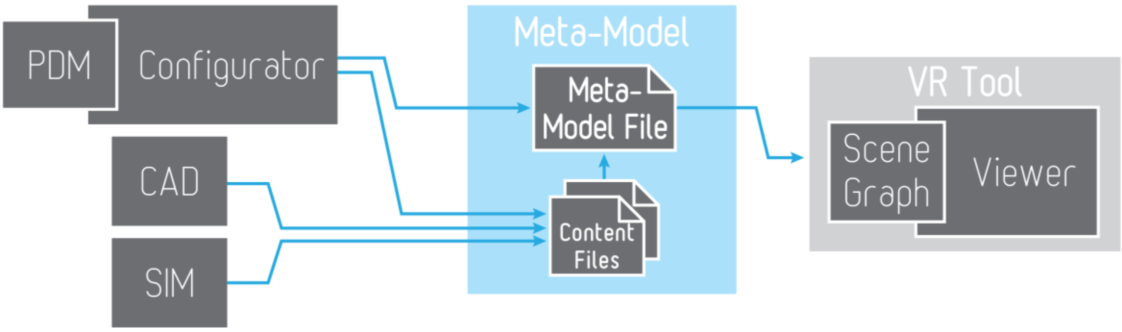

Figure 1. Current meta-model concept

The linked data (cf. Figure 1: 'Content Files') may include CAD geometries and various calculation and simulation data. A meta-model file is generated by a configuration tool, which can be understood as a PDM system.

In the case under consideration, the configuration tool is enhanced by a module to generate the meta-model file. The module creates a data pool that includes the total subassembly structure, the calculation and meta-data, as well as describing parameters, using the information available. Each parameter can be assigned a value or a file link. The file generated represents an Extensible Markup Language (XML-) structure, by means of which hierarchical structures like those of products can be profitably created. Parameters and values can be extended or modified at any time without having to modify the source code of the configuration tool.

In detail, the XML structure describes a collection of parts. These parts are integrated in an assembly, and extended by attributes. The XML structure also includes calculation models and result plots.

However, in light of the expected data volume and the readability of the meta-model file, it is inconvenient to completely represent geometries or calculations in the form of a single XML file. Accordingly, the data are given as file links. Those files, however, employ the storage formats for the typically used application. Using the links provided in the meta-model file, a visualisation tool accesses the associated files and presents them in a VR scene. This VR tool consists of a module to establish a scene graph and a viewer. Each part description within the meta-model file includes not only file links, but also meta-data. The latter, in turn, comprise the information required for handling the linked files within the VR tool. Thus, for instance, the part can be automatically aligned in the VR tool using the attributed information such as position, centre of gravity and centre point.
An extract from the XML file according to Figure 2 explains the meta-model structure. The hierarchy follows a logical structure and is largely flat, so that all information is legible.


```xml
<?xml version="1.0" encoding="utf-8"?>
<Assembly>
  <Attributes>
  <Created>2017-03-28T18:15:21.3113218+02:00</Created>
  <Parts>
    <Part>
      <Attributes>
      <Files>
      <FilePng>
      <FileStl>
      <FileObj>
        <Path>Files\00000000-0000-0000-0000-000000000000\01_B5_Bearingcase_Inlet.obj</Path>
        <Size>2302851</Size>
        <Type>.obj</Type>
      </FileObj>
      <FileFbx>
      <Geometry>
        <Bounds X="320" Y="600" Z="150" />
        <Center X="158" Y="0" Z="75" />
        <Gravity X="151.7" Y="0" Z="87.3" />
        <Mass>76.3</Mass>
      </Geometry>
      <Guid>00000000-0000-0000-0000-000000000000</Guid>
      <Interfaces>
      <Transformation V11="1" V12="0" V13="0" V14="0" V21="0" V22="1" V23="0" V24="0" V31="0" V32="0" V33="1" V34="0" V41="-468" V42="175" V43="0" V44="1" />
    </Part>
    <Part>
•••
  </Parts>
  <Results />
  <Software>FabBertelmann.PowerGen.Plugins.VR</Software>
  <User>henke</User>
</Assembly>
```


Figure 2. Meta-model structure in an XML file

The scene graph comprises all the objects that are part of the scene. In the viewer, the visible 3D objects are rendered using Unity *v5.4.2f2*. Reading the XML file in the VR tool, the part files in the scene graph are instanced as objects. The triangular geometries belonging to the parts are loaded as 3D objects and are linked with the meta-data in the scene graph. The identification number (cf. Figure 2: 'Guid') is required for an unambiguous assignment.
During a review, view settings, such as colour assignments, transparency settings and sectional views are often changed. All visual changes applied in the VR tool by the user are temporary (see Figure 3). In order to avoid unintentional changes to the meta-model file, the structure file is not intended to be changed at this point of time. Until now, the VR tool has not included an option to store these changes. However, this option will be included at a later stage of the project (cf. 3.4 Mixed Review).

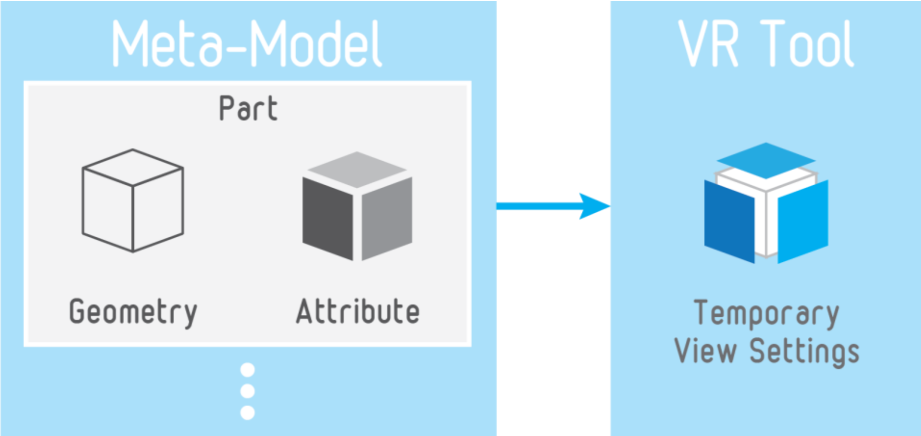

Figure 3. Changes in the VR tool are temporary and do not affect the meta-model file

3.2 Generation of the meta-model and content files

Established CAD programs make it possible to export parameterised models in the STL (Standard Tessellation Language) format, whereby the parametrically represented surfaces of the model are approximated by a predefined chordal deviation through triangles. The generated STL files comprise the coordinates of vertices and the normals of triangles. In our case, the configuration tool deals with CAD geometry but also provides a corresponding STL file to each geometry.

While the configurator generates the meta-model file from the meta-data stored in the PDM system, it also converts the corresponding STL files into a format that is suitable for the VR tool, thereby creating the associated content files.

The VR tool is based on Unity. Unity is a powerful 3D rendering engine that supports popular output devices, such as the HTC Vive or Oculus Rift. Thanks to the active community, the engine is currently being incorporated not only into numerous games but also into research projects (Sivanathan et al., 2014) as it provides great flexibility and usability.

The engine enables a high-performance representation of 3D objects in the FBX (*Filmbox*) and Wavefront OBJ file format. Both formats contain surface meshes consisting of triangles, and are thus similar to the CAD data exchange format STL. The FBX file format, which is widely used in the animation software domain (Autodesk, 2017), was developed by Autodesk. Both FBX and OBJ files are suitable as an import format for 3D geometries in Unity. Additionally, FBX files may contain animations, whereas OBJ files contain vector and material data only.

During the development of the VR tool, both OBJ and FBX file formats were tested for their suitability for geometry exchange between CAD and VR. An essential requirement is the possibility to change geometric objects at runtime of the VR-Tool. The ideal file format would enable loading arbitrary mesh geometry dynamically. Research shows that FBX files are internally converted by the Unity editor. Thus, changing the FBX files at runtime of the VR tool does not replace the actual files loaded in Unity. Instead, a customized OBJ file parser makes dynamic mesh generation possible.

The STL data are converted into OBJ files using Blender, an easily automatable software. A python script initiates the batch conversion of all required STL files in Blender (see Figure 4).

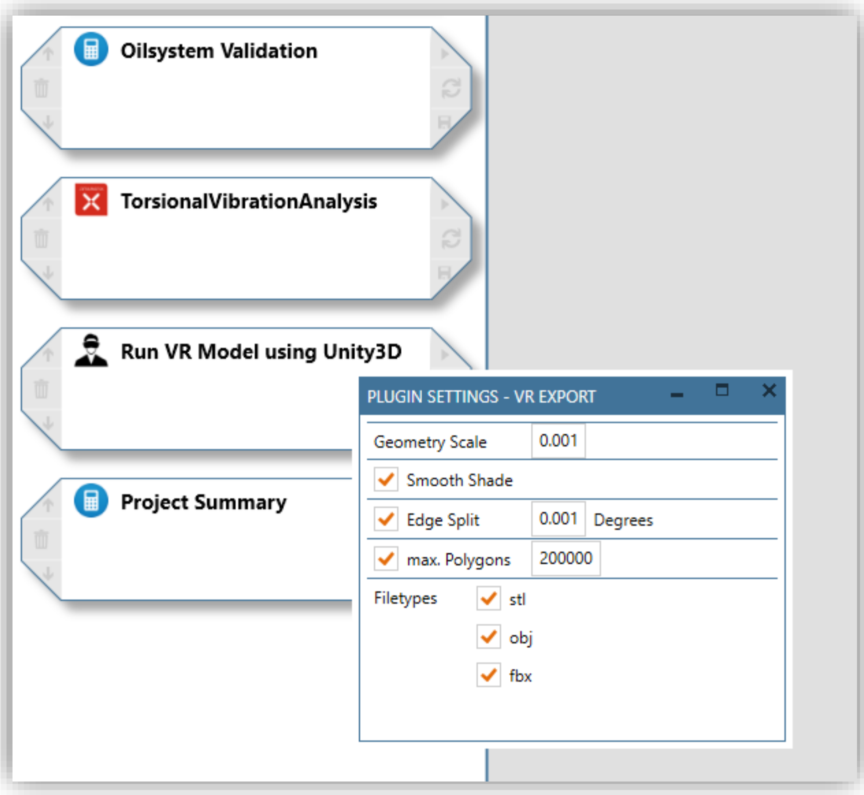

Figure 4. Graphical User Interface of the STL file converter included in the configurator

During the generation of the meta-model by the configurator, a check is done to see what CAD data already exist in the OBJ format. Missing or out-of-date files have to be converted by the configurator, before the file will be stored in the meta-model. Prior to the conversion, certain parameters of the target mesh can be adjusted: Blender's smooth shade option simulates a smooth surface by readjusting face normals. The edge split option sets a threshold to the angle between adjacent triangles that the smooth shader is applied to. Additionally, the user can specify a scale value and a triangle limit that will reduce the number of triangles of each object, thereby significantly increasing conversion speed and scene start up performance in Unity but decreasing mesh resolution (see Figure 5).

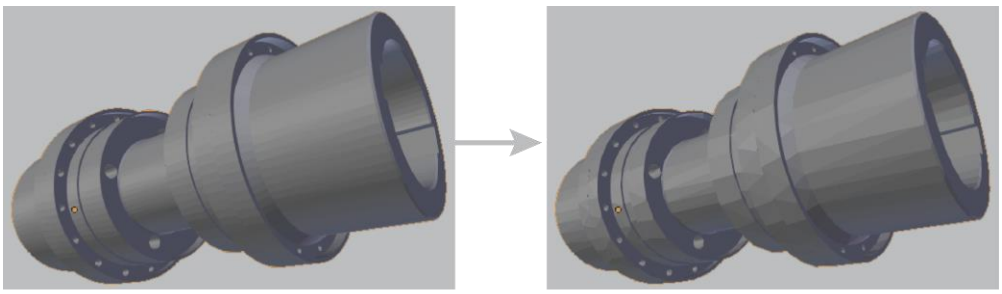

Figure 5. Simplifying a mesh from 20,537 to 8,000 triangles

A test with an assembly consisting of 23.7 MB of STL data produces 48.9 MB of OBJ data at a conversion time of 98 seconds (computer specifications: Intel® Core™ i7-860, 12 GB RAM, 512 GB SSD, Microsoft Windows 10; conversion settings: smooth shade option enabled, edge split threshold 5°, no vertex limit). Starting up the VR tool with this assembly consumed additional 22 seconds, whereas the scene performance was not significantly decreased once it had completed start up. The resulting assembly is illustrated in Figure 6.

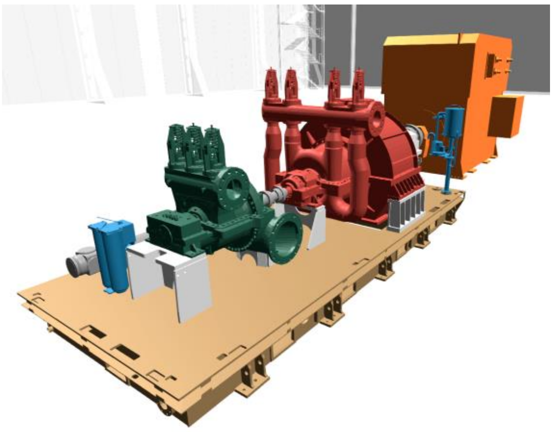

Figure 6. Assembly automatically loaded in the VR tool

3D objects often appear more realistic by applying material properties. While these materials are usually already defined in the design process of the CAD model, they cannot be stored in the STL file. For that reason, the material properties are stored as a material attribute in the meta-model. Unity generates a material definition from this attribute and applies it to the corresponding model in the VR tool.

The use of the meta-model and its creation via the configurator make it possible to transfer the geometry data to the VR tool automatically and reduce the time required for data conditioning. The current CAD data can be visualised at any time and experienced in VR. Information that is usually discarded during the conversion process can be transferred by using specific attributes of the meta-model.

3.3 Integrated representation of geometry and simulation data

In reviews, it is frequently not enough to observe the model geometry. In fact, during product development, further details are investigated. These details are also relevant for the review and have to be visualised.

Simulation results can often be represented only within the application in which they are generated. The meta-model is used again to integrate these results into a single view with the geometry data in the VR tool. The meta-model contains attributes that are used in the VR tool to generate and place graphical objects, descriptions or images. Those images illustrate calculation or simulation data and are provided as links in the meta-model file.

In the case under consideration, the VR tool visualises the shaft torsion, whose angular difference of individual cross-sections around the rotary axis was calculated. The results are added to the meta-model file by the configurator. The VR tool accesses this information and colours the shaft according to the results so that torsion can be recognised (see Figure 7).

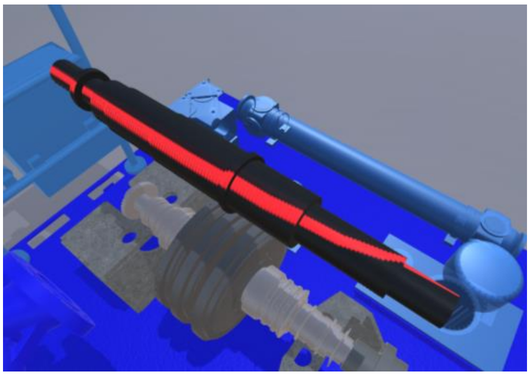

Figure 7. Colouring discretised shaft segments visualises shaft torsion

By animating the oscillation of the shaft segments between the torsion maximum and the shaft's zero position, the calculation can be visualised especially comprehensibly.

3.4 Mixed Review

Unity supports the representation of the scene in several displays. The displays show the scene's content from different perspectives, all independent of one another. From each perspective, the assembly's representation parameters can also be set. Thus, the users can mark a part and draw the attention of other users to it (see also Figure 8). In this case, a user employs an HMD (HTC Vive) and thus utilises the advantages of high immersion, whereas other users see the scene from an independent view on a 3D screen.

The VR tool can be operated on a stationary display by means of mouse and keyboard, on the HMD by the controllers set aside for this function (two HTC Vive Controllers).

The display of two views also allows for an assigned setting of the elements' visibility in the corresponding view. Thus, for instance, the HMD user perceives the manually guided and tracked controllers in his display. If other users do not want to see them in their view, this can be correspondingly adjusted in the VR tool. For this purpose, the VR tool works with representation planes. Three layers are created in the scene graph: One is for elements that are shown on both displays, and each of the others can only be seen on one of the displays. It is possible to intentionally render elements visible to a certain camera by assigning the appropriate layer to it.

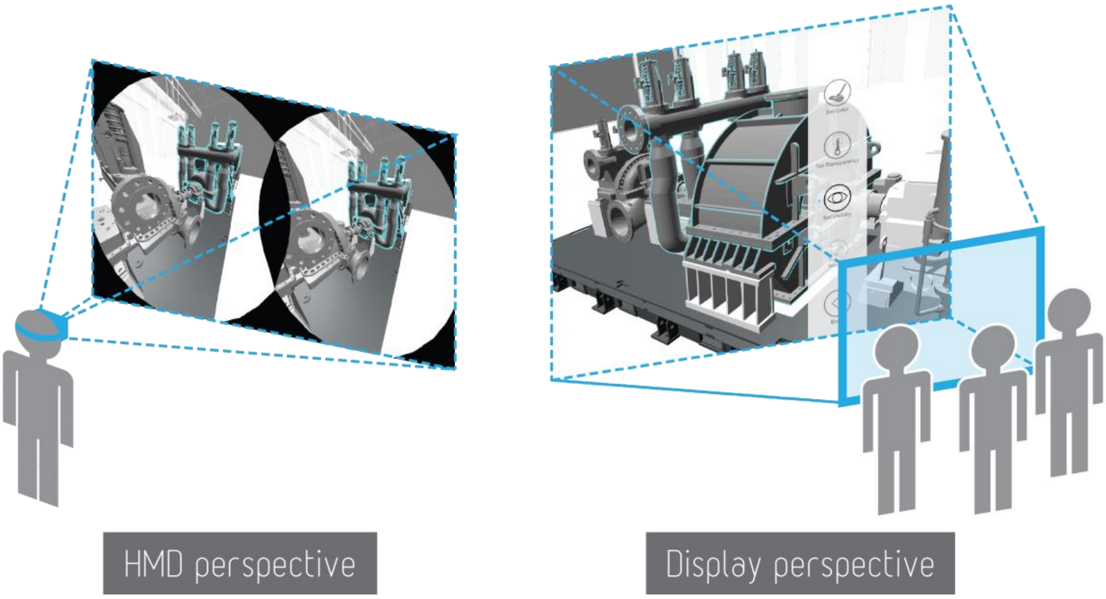

Figure 8. Different perspectives and separate interactions in mixed reviews

In the future, the meta-model will be embedded into the mixed review by storing settings and results in it: During the review, the users will set their appropriate perspective individually, place remarks on the model and change the model representation through sectional views, as well as the colouring and transparency of parts. To back up these settings and to make them retrievable later, they are stored in the meta-model file or an additional content file. This way, the VR tool is used in addition to the other applications that make the data available for the meta-model (Figure 9).

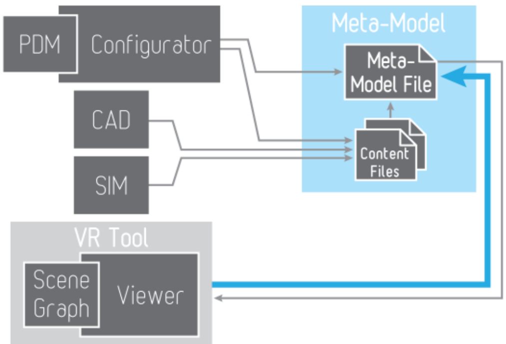

Figure 9. Enhanced meta-model concept

4 TECHNICAL APPLICATION

The meta-model described is generated in cooperation with a software provider developing a configurator for energy equipment. Typically, the machines are made of subassemblies, individually composed by the service provider according to a catalogue system and diverse dimensioning and proof calculations. The service provider wants to virtually show the customers the configuration in preparation of the order, therefore using a new feature of the configurator. Based on the underlying model data, however, neither can a uniform visualisation of the geometries and calculation results be achieved, nor can a data status close to development be presented. The data come from various highly specialised programs. Although problems can be clearly seen in the corresponding applications, they cannot be represented in context in a way that moves beyond the borders of a program.

The presentation of the machine configuration takes tremendous effort, and complex relationships can scarcely be visualised in a holistic manner. The largely automated bundling of all collected data in a meta-model makes it possible to visualise current data statuses, and to represent them in a collective geometry model. Thanks to the simultaneous engineering of a Unity-based visualisation environment, furthermore, the latest technologies for representation can be linked. This way, in future, the service provider's customers will have the chance to experience a holistic product presentation in VR and to evaluate the configuration collectively with colleagues.

5 OUTLOOK

The presented approach of an automatically created meta-model with integrated geometry, simulation and calculation data enables an immediate VR representation of model data in parallel with development. Research is to be done on the specification of more complex calculation and simulation data than presented in this paper. However, the latest experiments suggest that with proper visualisation metaphors and result specification, this can be accomplished.

The mixed review described in Chapter 3.4 will make it possible in future to store the settings executed in the VR tool. The information has to be stored as s*tates* at the same hierarchy level as parts rather than changing the original data coming from the configurator, in the meta-model. When doing this, the use of part identification numbers is crucial, since, for instance, colours in the state are assigned to the corresponding parts by means of this number and can be called up in the VR tool.

If the meta-model is updated via the configurator, then the states can be maintained and thus be applied to updated data states. Practically, this results in the option of marking a part that has to be revised, and, in a later review, it is possible to immediately examine the new revision.

Up to now, the VR tool has permitted the simultaneous output of the scene both on an HMD and another display. Due to the integration of an avatar representing an HMD user in the virtual space, several HMD users are imaginable in the same tracking area. In the literature, the use of at least two Vive-HMDs in the same interaction space is mentioned (Brekelmans and de Mooij, 2016). The presence of virtual avatars makes interaction among the users possible, and a spatial movement with no collision is guaranteed. The extension of the role model to several interaction spaces at different locations also has to be evaluated: connecting the VR tool to a network would enable the cooperation of several users in widely separated places.

To integrate additional simulation results into the geometry representation, the intention is to refine the possible metaphors for visualisation. It should be possible to represent interactions at arbitrary positions of all parts in order to visualise the reaction forces or the forces affecting connected parts. Moreover, the representation of vibrations of the model in the virtual operation is planned. These model reactions are often very complex and demand time-consuming simulation calculations. However, for easy-to-understand visualisation, simplifying metaphors should be considered.

REFERENCES

McMahan, R. P., Bowman, D. A. (2007), "Virtual Reality: How Much Immersion Is Enough?", *Computer*, Vol. 40, No. 7, pp. 36-43.
<https://doi.org/10.1109/MC.2007.257>

Oculus VR, LLC. (2017), "Rift", viewed 12 April 2017.
<https://www.oculus.com/rift/>

Sony Interactive Entertainment Europe Limited (2017), "PlayStation VR", viewed 12 April 2017.
<https://www.playstation.com/de-de/explore/playstation-vr/>

HTC Corporation (2017), “Vive”, viewed 12 April 2017. <https://www.vive.com/>
British Standards Institution (2005), “BS EN 61160: British Standard Design Review” (IEC 61160:2005). <https://doi.org/10.3403/30101057>
Stelzer, R., Steger, W., Petermann, D. (2012), “The VR Session Manager: A Tool to Co-Ordinate a Collaborative Product Development Process in a Virtual Environment”, *Proc. ASME. 45011: 32nd Computers and Information in Engineering Conference*, Vol. 2. <https://doi.org/10.1115/DETC2012-70998>
Renner, R. S., Steindecker, E., Müller, M., Velichkovsky, B. M., Stelzer, R. H., Pannasch, S., & Helmert, J. R. (2015), “The influence of the stereo base and its adjustment on sighted and blind reaches in a virtual environment”, *ACM Transactions on Applied Perception*, Vol. 2, Issue 2, Article 7, New York, USA. <https://doi.org/10.1145/2724716>
Stelzer, R., Steindecker, E., Arndt, S., Steger, W. (2014), “Expanding VRPN to Tasks in Virtual Engineering”, *Proc. 34th Computers and Information in Engineering Conference*. <https://doi.org/10.1115/DETC2014-34277>
Schwarz, O., Zupke, O. (2014), “bee® – Eine Software zur Integration von VR im Planungs- und Montageprozess”, *Tagungsband Entwerfen Entwickeln Erleben*, ISBN 978-3-944331-66-9, TUDpress.
Kunz, A., Wegener, K. (2015), “Die Mensch-Maschine-Schnittstelle als Schlüsselelement für VR/AR-Anwendungen”, *3. Fachkonferenz zu VR/AR-Technologien in Anwendung und Forschung an der Professur für Werkzeugmaschinen und Umformtechnik*, Chemnitz, Germany, pp. 17--26. <https://doi.org/10.3929/ethz-a-010561390>
Lorenz, M., Spranger, M., Riedel, T., Pürzel, F., Wittstock, V., Klimant, P. (2015), “CAD to VR - a methodology for the automated conversion of kinematic CAD models to virtual reality” *Procedia CIRP 41*, pp. 358-363. <https://doi.org/10.1016/j.procir.2015.12.115>
Sivanathan, A., Abdel-Wahab, M., Bosche, F., Lim, T. (2014), “Towards A Cyber-Physical Gaming System for Training” In the Construction and Engineering Industry, *Proc. ASME.: 34th Computers and Information in Engineering Conference*, Vol. 1B. <https://doi.org/10.1115/DETC2014-34930>
Autodesk Inc. (2017), “Adaptable file format for 3D animation software”, *FBX Overview*, viewed 11 April 2017. <http://www.autodesk.com/products/fbx/overview>
Brekelmans, J. and de Mooij, J. (2016), “Collaborative VR experiment with multiple Valve/HTC Vive headsets”, VR Perception Blog, viewed 11 April 2017. <https://vrperception.com/2016/01/15/collaborative-vr-experiment-with-multiple-valvehtc-vive-headsets/>

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