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A METHODOLOGY SUPPORTING THE PREPARATION OF 3D-CAD DATA FOR DESIGN REVIEWS IN VR

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1. Introduction

In recent years new VR techniques managed to emerge from pure design review purposes via Digital-Mock-Ups (DMU) to complex analysis tools. Nowadays, virtual crash simulations allow the automotive and aerospace industry to replace expensive and work intensive physical prototypes by their digital representatives. VR also contributed to improved training and simulation environments by adding new interaction techniques and methodologies [Encarnação2000]. Although it offers advantages and opens new possibilities for its use, the technology is still not used as widespread within the engineering environment as one should assume. The reasons are obvious:

- the lack of efficient data acquisition within the engineering environment and coupling to it. Hence, the evolved tools have been restricted to specific target areas.
- based on 3D-CAD geometry suitable converters from a specific (native or neutral) CAD to a VR format are still not efficient enough to fulfil the requirements of a VR investigation. As with any conversion from one digital format to another, the resulting information is error prone and often needs manual repair.

Automatic data acquisition, preparation and presentation is only possible within integrated environments such as CAD/PDM-system and appropriate visualisation tools (e.g. CATIA V5/Enovia/DMU Navigator [Dassault2001]). Unfortunately, most other application areas where the aspect of realism is of greater importance (such as a design review within VR), impose much higher requirements on the quality of data visualisation and representation. Nowadays, these requirements cannot be fulfilled automatically, but need a major interaction effort and an advanced know-how on the respective problem areas and VR.

Within this paper, we present a methodology and architecture to automate the process of data preparation for the purposes of a design review session in VR. The implemented system supports an engineer to reduce time intervals of data acquisition and modification procedures. It should enable the engineers to modify the digital model on a semantical level that is known to the underlying system (CAD and PDM) and to enhance the representation of the digital product for design review processes.

2. State of the Art Technology for CAx/VR Integration

VR as extension to interactive graphics applications is the combination of real-time presentation and immersive interaction for the modification and evaluation of models and processes within a computer generated environment. The use of VR within different application areas ranges from modelling tasks and design review via digital prototypes and simulation of ergonomic requirements, installation or assembly tasks to functional simulations of products or process cycles. Nowadays, user may choose

from a range of VR software systems. The underlying concepts of those VR systems differ according to system and application area. Toolkits such as VirtualDesign2 [vrcom2000], Lightning [Blach1998], Avango [Tramberend1999] emerged during the last years, offering different functionalities for a range of application areas. Beside those frameworks, numerous VR tools targeting specific application areas have been developed especially within the engineering domain, i.e. EAI VisConcept [EAI2001] or Opticore's Opus Realizer [Opticore2001] for the purposes of design review to name few of a wide range of specific VR tools.
CAD vendors like Dassault, UGS, PTC support 'digital mock-ups' (DMU) resp. virtual prototypes with additional toolkits that allow to process and visualise huge data sets, like airplanes or complete cars. Dassault's desktop viewing tool 4D Navigator [Dassault2001] for CATIA version 4.x or PTC's visualisation module DIVISION MockUp 2000i [Division2001] are typical visualisation tools that supplement existing CAD functionalities for design review purposes. Although the quality of the visualisation and representation of the digital prototypes have inherently matured during the last years, only the new version of Dassault's CATIA V5 provides a framework for VR extensions and possibilities to include 3D input- and output devices typical for VR set-ups. A first approach for an integration and direct coupling of immersive VR applications into CATIA V5 is described in [Berta1999], [Rantzau2000]. The retrieval of CAD models for the purposes of a design review session is supported by efficiently coupling CAD system to an underlying product data management system (PDM). As centralised component within an integrated environment a product data management (PDM) system provides the information resulting from different steps within the product development. Besides geometrical and topological information a PDM system stores, concatenates and manages additional types of information. Most CAD vendors offer an integrated solution for data aquisition, representation and manipulation, thus it is quite easy for the users to undertake design review sessions. Within Dassault's environment CATIA V5/Enovia [Dassault2001] or PTC's ProE/Windchill [PTC2001] the user is able to select the product parts of interest within the underlying PDM system and to visualise the digital assembly. As the users do not have to manually interact with the virtual prototype related to the quality of visualisation and representation, a design review can be easily performed in automatic processes.
Unfortunately, a design review session within VR imposes much higher requirements to the quality of data visualisation. 3D-CAD systems are able to generate continuous surface or volume descriptions whereas rendering engines of VR systems process polygons or voxels. To lead a design review session in VR, CAD-models have to be retrieved and converted into a suitable VR-format. In most cases it implies to convert CAD data to a polygonal representation. This process is called *tessellation*. As with any conversion from one data format to another, different problems occur during this process:

- loss of semantics (e.g. loss of product and model structure),
- inconsistent model quality (e.g. wrong surface orientation, cracks),
- redundant model complexity (e.g. precision of tessellation, unnecessary or multiple geometry).

The time to adequately prepare 3D-CAD data for a design review session using VR is inherently influenced by the underlying methodology of product modelling, data acquisition, and highly dependent on the complexity of the digital model and quality of conversion. To manually prepare the data without an automated mechanism is tedious and cumbersome. Thus, it is crucial to support the engineers with a semi-automatic mechanism that significantly reduces the time for data acquisition, conversion and editing.

3. Methodology to prepare 3D-CAD data for VR

Our envisaged solution imply different issues that have to be addressed by a methodology to integrate prepare 3D-CAD data for VR:

- Efficient data aquisition (espc. from an underlying PDM system)
- Representing the product/model structure in VR (high quality data conversion)
- Use of adequate VR formats
- Appropriate data preparation methodologies

To accelerate the rendering performance of a VR system, a global optimisation of all polygonal data is performed that usually destroys the logical product structure. Typically, the product structure is part oriented, i.e. tree structures are built with a root presenting the product going down, for instance, to modules or packages, assemblies and finally to the nodes that represent single parts being references to external CAD models. In addition different variants and configurations have to be taken into account. As the above mentioned optimisation process destroys the logical structure of a product model, a selection or extraction of single parts and the access to meta information of those is no longer possible. The key concept is to keep the link between the product and a VR presentation through the mapping of the product or model structure managed in, e.g. a PDM system, to a VR format based on a scenegraph: The hierarchical product structure can be rebuilt by group nodes of the graphical representation. Product sub-structures used more than once are built equivalently by using the multiple referencing mechanism supported by most graphic formats. Versions on any hierarchical level are mapped to switch nodes. As CAD models of a part in the PDM system might be references to externally stored CAD models, the VR representation of a part is itself referenced as external file. Thus it is easy to facilitate also the multiple use of single parts within one VR scene. Finally, transformations maintained in PDM can be applied to the corresponding group node of the VR scene. Figure 1a shows the mapping of product structure to a scenegraph based graphic format.

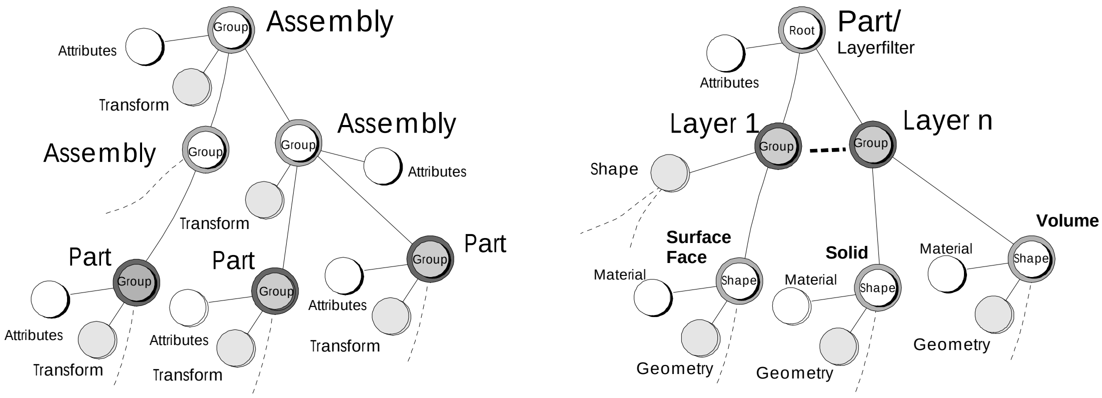

Figure 1. a/b Presentation of product and model structure in a scenegraph

To rebuild the model structure an equivalent approach might be used. Beside other techniques of filtering, CAD systems offer to filter out unnecessary elements for certain purposes using layer filter. Hence, this filter is mapped to the root node of a part (CAD model). A sub-structuring of the model in different layers might be achieved by mapping all or selected (filtered) layers to group nodes which in turn contain the appropriate 3D elements in a bulk of shape nodes. Thus, individual material information is easily applied to the shape representations. All other kind of meta information is stored in an information node related to the corresponding root of the scene graph in order to be available during a VR session (Figure 1b).

This methodology imposes certain requirements on the use of graphic formats. Currently, there are only two VR formats that support the concept of external or multiple referencing. The first is Open Inventor (OIV) which is a 'de-facto' standard for Open GL based rendering systems [SGI2001]. The second is VRML, a standardised format for the representation of polygonal 3D data for Internet and Web applications. All other graphic formats are missing either an equivalent to the switch node or do not support external references or both. The problem of mapping general configurations and variants to a corresponding scene graph representation is still unresolved.

The data conversion process converts 3D-CAD data into a tessellated VR representation. As described before, there are some crucial drawbacks within this step. To achieve adequate conversion results and to keep the consistency between the mathematical exact CAD model and approximated VR representation two issues have to be addressed:

- enabling the 'healing' of CAD data respectively model complexity and quality for a VR session.
- keeping the semantical information of the CAD model structure.

We provide an approach to retrieve the necessary CAD data via the CAD systems’ API but use an intermediate parametric representation to maintain the underlying mathematical representation before mapping to a VR format. This approach allows higher flexibility for two reasons:

- different VR instances might be generated with different accuracy in the following tessellation process.
- precise geometric adjustment of faulty elements (e.g. orientations of faces) can be carried out within the mathematical rather than the polygonal domain. This ensures precise geometrical operations.

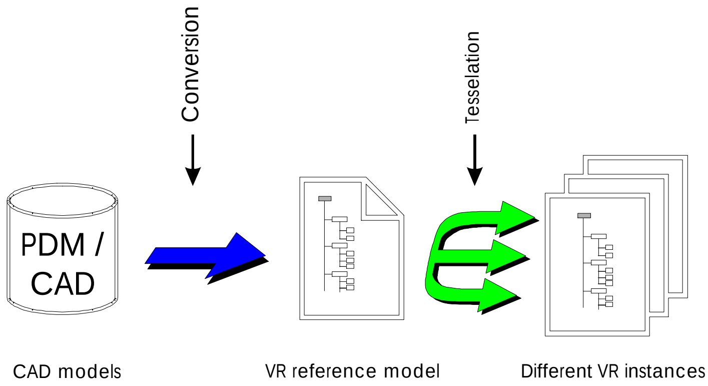

Figure 2. CAD2VR conversion via an intermediate representation

Hence, we should speak in the context of an intermediate VR representation as VR reference model and in the case of derived VR files with different tessellation accuracy of VR instances (Figure 2). In this case we have to consider a graphic format that support parametrical representations. Beside the concept of referencing, OIV offers the possibility to represent trimmed surface data by its parametric description. It supports NURBS (Non Uniform Rational B-Splines) surfaces that are trimmed by closed loops of NURBS curves in the parameter space of the surface. Another graphics format to support parametric surface information is Open GL Optimizer that extends Cosmo 3D [SGI2001]. Optimizer supports a more sophisticated set of surface representations endowing users for the implementation of converters. Similar to Inventor, Optimizer supports trimming in parameter space only. However, the only format supporting explicit representation of topology is Open GL Optimizer, which makes it thus the first choice for storing VR data in an intermediate parametric representation.
Having retrieved the CAD data and converted it to a VR reference model, we are able to work on different instances resulting from different tessellation accuracy. In the past a number of tessellation algorithms have been developed for transforming parametric geometry into polygonal representations [Tan2000]. In general these algorithms are based on some kind of error measure as topological tolerance and edge deviation in such a way that the user can control the trade-off between geometrical correctness and performance using these parameters. The degree of reducing the number of polygons is commonly based on parameters like the percentage of a simplification, absolute number of remaining polygons or the deviation of normals.In the following chapter we describe our approach and solution to the above methodology.

4. VR Data Preparation

In this section we describe a tool that was developed (and already commercialised) in collaboration with vrcom, GmbH. This VR data preparation tool is targeting Virtual Design 2 (VD2) as VR system for the design review, that was developed at the Fraunhofer-Institute for Computer Graphics and is distributed by vrcom [vrcom2000]. As this VR data preparation tool was tailored to VD2, the name Virtual Design Data Preparation (VDDP) was given to our solution.

4.1 Architecture

The approach taken during the realisation is based on CATIA V4. We make use of the API supplied by Dassault and the modules related to the conversion are based on the functionality delivered by the CATIA API. The loaded models are converted, tessellated and written to the Cosmo Binary as well as Open Inventor format. As a 1:1 mapping of the CAD geometry structured in solids and volumes to a

VR graphic format is not possible an appropriate method to derive a face representation of the geometry has been implemented. Those faces are thus converted into a NURBS presentation to comply with industrial requirements. Moreover, the conversion process enriches the data with additional semantic information through the maintenance of the product and model structure according to the already described methodology.

VDDP consists of the following implemented modules (see Figure 3). A conversion manager is responsible for the start and administration of the CAD2VR converter. It also steers the import from CATIA models via an underlying PDM system. This is realised through a graphical user interface and allows to access and collect the models of interest to be converted.

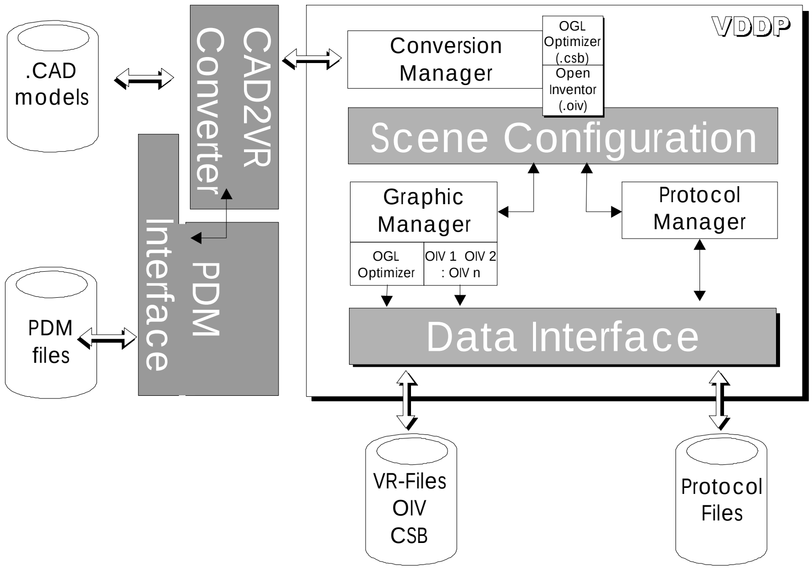

Figure 3. Architecture of our solution for a VR data preparation tool

Another module is the graphic manager that comprises all methods for the visualisation and manipulation of VR data. All functions for the interactions on the VR model are realised within this module.

A protocol manager is responsible for the administration of action lists that contain information about the interaction steps taken by the user related to the manipulation of the model. Whenever the user ends an interaction, the protocol manager is informed and generates a new entry in its action list. It also comprises undo and redo operations thus maintaining a history list of user interactions. Having finalised certain manipulations on the model the generated action lists are stored as protocol files, which are associated with the appropriate model. The use of these protocol files applied to other VR instances (based on different tessellation accuracy) maintains the consistency among the instances of the same model related to the user interactions taken (e.g. erasing certain faces in the model, reversing orientations, etc.). Hence, this mechanism prevents the user from repetitive work on different model instances.

However, core of our solution is the scene configuration module. It is based on a central process control module and comprises functions for the management of user interface methods based on WIMP-metaphors (e.g. windows, icons, menus, dialogs, etc.) as well as a module for the manipulation of geometry (geometry manager). To allow a re-tessellation of certain instances the geometry manager encapsulates all necessary methods to manage the intermediate, parametric file representation given in Open GL Optimizer, that will be tessellated and converted in the following steps to an OpenInventor scenegraph for the purposes of visualisation. Hence, parametric geometry can be tessellated with user defined parameters such as a reduction of the number of polygons or crack free tessellation along adjacent faces. An intelligent reversing of surfaces within the parametric space of a surface (group of surfaces) or the deletion of redundant geometric objects is supported via an appropriate GUI. The central process module establishes and steers the communication between all the other modules at a given time thus maintaining the status of the system during the runtime of a session.

5. Realisation

Currently, VDDP supports an online integration with BMW's system PRISMA. The realised client allows users to navigate through the product structure and to select entries for conversion on all levels of product representation managed by PRISMA.

Figure 4 shows the start of a data preparation session. The user selects different models from a chosen source (PRISMA or local/remote file system) and uploads them to the assembly manager of VDDP. The product structure maintained in PRISMA is rebuilt by a corresponding Open Inventor scene graph. As the conversion of any assembly with different complexity might be time consuming VDDP supports the conversion of larger selections in batch mode allowing to upload numerous models over night. The management of different versions and configurations within one scene graph is not realised yet.

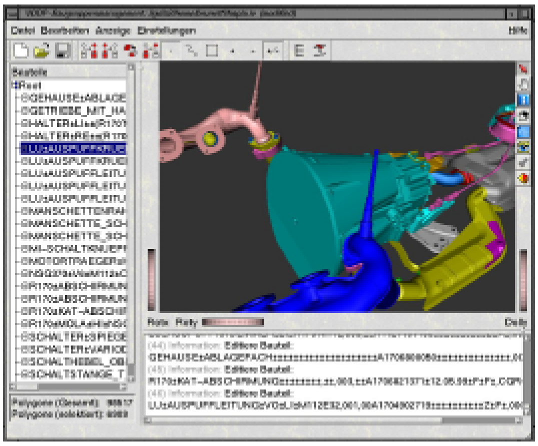

Figure 4. Assembly manager of VDDP after uploading of different models; left: product model structure

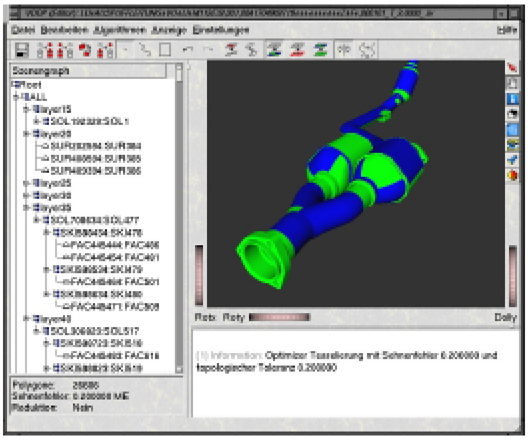

Figure 5. Part Editor of VDDP after uploading a specific part; left: CAD model structure rebuilding semantic information; right: colour coded rendering mode is used for visualising the surface orientation

To edit and modify selected parts of the product model, the user is able to start the part editor (see Figure 5). The model structure can be seen within the left side of the editor. With the assistance of the part editor the user is able to re-tessellate the model with different accuracy. Moreover, a rubber band selection mechanism allows him to select certain parts of interest either within the graphic representation or the logical model structure in the left side of the window. For the correction of face orientations, VDDP offers the functionality to revert faces in direction of the viewer. Figure 6 shows the reversal modus of the graphical editor to assist the user and easily identify wrongly oriented faces (colour coded: wrongly oriented faces are displayed in blue colour). Furthermore, it supports different strategies for reducing the complexity, e.g. interior removal, and eliminating overlapping faces of a model. This editor is the core of the VDDP implementation.

6. Conclusion and Outlook

This paper presented a methodology that complies with the requirements for an efficient CAD/VR integration. Our solution of the data preparation tool represents the current state of our approach to the problem area and is enhanced in collaboration with the automotive industry and the vrcom, GmbH to address different construction methodologies. An effective integration of VR technology into the engineering environments is crucial for the success of the virtual product development.

VDDP as presented above is commercially available and further developed by the vrcom, GmbH. The future developments will focus on a broader range of import formats. It is envisaged to support native as well as neutral CAD formats.

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