



THE EVOLUTION OF VIRTUAL REALITY TOWARDS THE USAGE IN EARLY DESIGN PHASES

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Abstract

The aim of the present work is to show possibilities with which 3D models in virtual reality (VR) can be created and exported. First an overview of the existing hard- and software is given. Subsequently, existing solution concepts are analysed which, however, are not used in product development. Based on these knowledge a concept for the creation of 3D models in VR and the export of these models is developed.

Keywords: virtual reality (VR), lean product development, computer-aided design (CAD)

1. Introduction

Today's product development is characterized by ever more complex products, which have to be developed in ever-shorter time. In order to deal with this development, the use of globally distributed teams in product development is becoming more and more important. The rapid development of communication media and IT has a supporting effect, but makes their use equally necessary. While the proportion of distributed project work in 2010 was still around 28 percent (Rump et al., 2010), it is now around two thirds (Kovacs, 2018). The work in distributed teams can cause problems e.g. in communication. One approach to solve the problems is the use of Virtual Reality (VR) (Stechert et al., 2019; Wolfartsberger, 2019; Rademacher, 2014). The first use of VR goes back more than 50 years with the "Sword of Damocles" (Sutherland, 1968). In the last decade, the availability of powerful (mobile)-devices in combination with the use of VR in computer games have led to a strong growth in the field of VR. Especially the development of modern head mounted displays (HMD) has improved the usability. However, the use of VR is still restricted to the later phases of product development, such as design reviews or ergonomics studies. Using VR in early phases leads to increasing quality while cost and development time are reduced. For this, the software needs some adjustments. This paper deals with creating and editing 3D-models in VR and export them into a suitable CAD-software. After this introduction, section 2 gives an overview about VR in general and its use in product development as well as necessary adjustments to use VR in early phases of product development. In section 3, existing options for creating and editing 3D-models and exporting them are analysed. Therefore, a list of requirements is used as a benchmark. Subsequently, possible improvements are shown. Finally, a summary and outlook is given.

2. A brief overview about virtual reality

In the last decades, VR has been defined in several ways. This paper adopts the definition by (Dionisio et al., 2013):

“VR is a Computer generated simulation of 3-dimensional objects or environments with seemingly real, direct or physical user interaction.”

Another definition is given by (Abdelhameed, 2013) who said:

“VR is a Human-Computer interface in which the computer creates a sensory immersing environment that interactively responds to and is controlled by the behaviour of the user.”

Thus, so called “integrated development environments”, e.g. (Stechert et al., 2007), which contain models for kinematic and multi body simulation are explicitly not considered in this paper. The next section describes the basics of VR. After this, the use of VR in product development will be demonstrated, with particular emphasis on necessary adjustments.

2.1. Basics

Every VR system has three main components. A broad overview of them is given e.g. in “State of the art of virtual reality technology” by Anthes et al. (2016).

- Every VR system requires a **software package**, which is divided in two components. The runtime environment is needed to ensure the communication between hardware and software. At Ostfalia, the runtime environment is delivered by Steam® and is called “SteamVR”. The second part is the VR engine. Through this application, the virtual world can be generated. This paper deals with WeAre a VR-software of WeAre GmbH, which is based on the unity gaming engine.
- **Input devices** are necessary to steer the system. The most common input devices are controllers, which allows the user to interact with the virtual environment. HTC offers the Vive controller, which consists of buttons, one touch panel and a trigger. Devices for gesture tracking or navigation are also available.
- **Output devices** are necessary to provide feedback to give the user information about virtual world. Moreover, they are also essential for the immersion experience. Classical output devices are displays, which are integrated in VR-glasses for example. More uncommon devices are e.g. data gloves, which provide haptic or force feedback.

The Virtual reality is often characterized by the following five characteristics, which are stated by (Abdelhameed, 2013; Rademacher, 2014; Giorgio et al., 2017).

- The entire computer generated space with all objectives is called **Virtual World**. The Virtual World is managed by some rules and relationships. The objects can be among others simplified CAD-models.
- **Immersion** describes the feeling of being involved in the Virtual World. The more senses are affected by the VR, the higher the degree of immersion is.
- In order to achieve a high degree of immersion, some kind of **feedback** is needed. Feedback is the response of the Virtual World to the input of the participants. It can be visual, tactile or acoustical.
- The ability to interact with the Virtual World also has an influence in the degree of immersion. **Interactivity** is the possibility that users can manipulate the Virtual World. This includes, for example assembly and disassembly processes.
- Immersion, feedback and interactivity refers to the **participants** of a VR-session. These people use devices to interact with and manipulate Virtual Reality.

There are three different VR-Systems, which are frequently used in industry. These systems are presented in order of their degree of immersion, starting with the lowest.

- The **Powerwall**-system (see Figure 1) consist of just one or more paired large displays. In order to create a perception of spatial depth, the displays have to be coupled with 3D-glasses
- **CAVE** (see Figure 2) stands for Cave Automatic Virtual Environment. Here, the participants are in a room, where all walls are made up of displays. In combination with shutter-glasses, the users can move through the presented scenery.
- The third system are the **HMD's** (see Figure 3). HMD's shield the user's field of view. This provide a high degree of immersion. The Virtual World is created on a classical desktop PC. Therefore, powerful machines are necessary. The system consists of two displays through which the world is perceived. In order to determine the position in the real area, sensor boxes are usually required. Modern devices have cameras attached to the outside of the HMD that capture the surroundings. This is called inside out tracking.

Due to the huge number of possible combinations of software and hardware, in addition to the high demands on ergonomics and usability, only HMD devices like the HTC Vive are considered in this paper.



Figure 1. Powerwall (TH-Nürnberg)

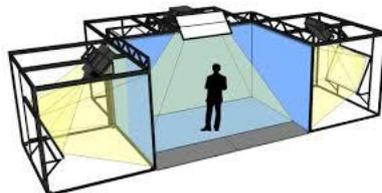


Figure 2. CAVE-System (visbox)



Figure 3. HTC-Vive HMD (HTC)

2.2. Virtual reality in product development

In business environment, VR is mainly used in the Architecture-, Engineering- and Construction-Industry [AEC-Industry] (Hilfert and König, 2016; Zaker and Coloma, 2018; Lorenz et al., 2016). However, due to interdisciplinary and distributed collaboration in combination with increasing product complexity and shorter development times, VR also plays an even greater role in product development. So far, VR is mainly used in the context of design reviews. In this use case, many advantages are gained: Through VR, it is possible to present a model to the customer without having to be physically present. In addition, it enables the involvement of other stakeholders such as external customers or suppliers in the development process. Since no physical prototype is required, changes can easily be reworked and represented (Abdelhameed, 2012). After a successful design review, the software can be used to simulate assembly and maintenance work. This includes a complete risk assessment of the required activities, which optimally prepares the staff for upcoming tasks (Berg and Vance, 2017; Gong et al., 2019; Kassem et al., 2017; Wang, 2002).

Nevertheless, VR is commonly used in later stages of product development. However, the use of VR comes with a couple of problems, which are divided in two main groups. The first one summarizes the application related problems: As already mentioned a powerfull PC is needed to guarantee a constant frame rate of at least 60 frames per second (fps) or even better 90 fps. Frame rate below 60 fps are perceived as jerking and reduce ease of use. Furthermore, such jerkers favour the occurrence of motion sickness, which is a general problem for some users and has many reasons, as shown by (LaViola, 2000; Stechert et al., 2019). Some of them are the latency in general or the gender and the age of the participants.

The second group summarizes software related problems: VR systems contain a variety of tools for interacting with the Virtual World (e.g. tools for grapping parts, for writing or meetings). These features are useful in late phases of product development, such as design review. However, in order to use VR during concept development, existing tools have to be adapted and new tools have to be implemented. These new tools are listed below.

- For the determination of dimensions and for space allocation, it is important to **create simple 3D models** such as cuboid, spheres or cylinders directly in the VR.
- In order to use the allocated spaces and interface models for detail design, it must be possible to **export the created 3D models** to a CAD-system. In addition, the objects available in the VR as surface models must be automatically converted into solid bodies, so that they can be used in CAD.
- Overlapping geometries in the virtual world can cause problems. Therefore, a **collision detection** must be integrated.
- The precise arrangement of object in VR is difficult due to the inaccurate control. Therefore, as in Microsoft PowerPoint, an **automatic alignment** of edges and axes must be implemented. This can be switched on and off at the touch of a button.

2.3. Virtual reality for lean and distributed product development

Product development is usually structured following a certain formal process. Product development processes for mechanical design often basing on VDI guideline 2221 (2019), Pahl/Beitz or even the axiomatic design approach. Software, electronics and system design again have their own standard processes. Some common product development processes from these four disciplines have been analysed and exploited in (Stechert et al., 2019). It has been shown by the authors, that a common modelling approach is the key linkage of different processes for an effective interdisciplinary product development.

In addition, (interdisciplinary) product development needs to be efficient. Due to that reason, more and more lean strategies -originally developed for production phase- are entering the product development departments. The authors successfully introduced a lean product development system at a railway manufacturer (Stechert et al., 2019). However, in nowadays-distributed teams, lean strategies are difficult to manage. Mainly because of a lack of real-time communication, both formal and informal. Figure 4 shows an example on how to arrange and visualise the outcomes of different product development methods in a virtual project room. An Ostfalia student team used the virtual project room to design a transmission gear from idea to design review. Ideally, the visualisation follows a half-circle. Clarification of task and final design review are therefore located vis-à-vis and can refer directly on each other.

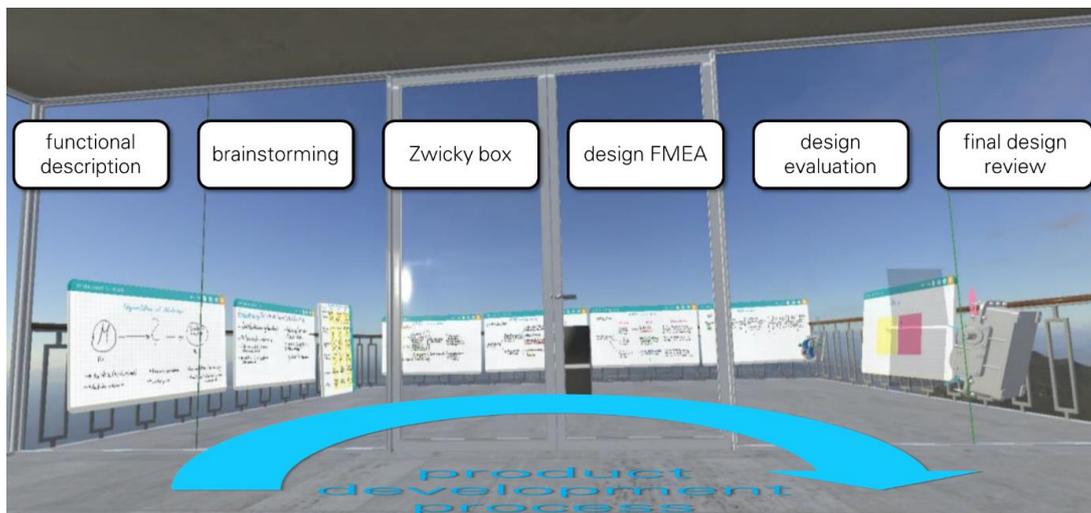


Figure 4. Example for the visualisation of method outcomes along the product development process in a virtual project meeting room

Figure 5 gives a schematic overview for the use of 3D-CAD models in VR. During task clarification, simple geometries are produced directly in the virtual project meeting room. These models serve as space allocations for the future conceptual and detail design in the CAD-system. The space allocations are consecutively augmented by interface models along the conceptual design.

During CAD, design models are regularly imported back into the virtual project meeting room to serve as the reference for validation and quality assurance. Necessary changes or adjustments are directly annotated in Virtual Reality and exported back into the CAD system.

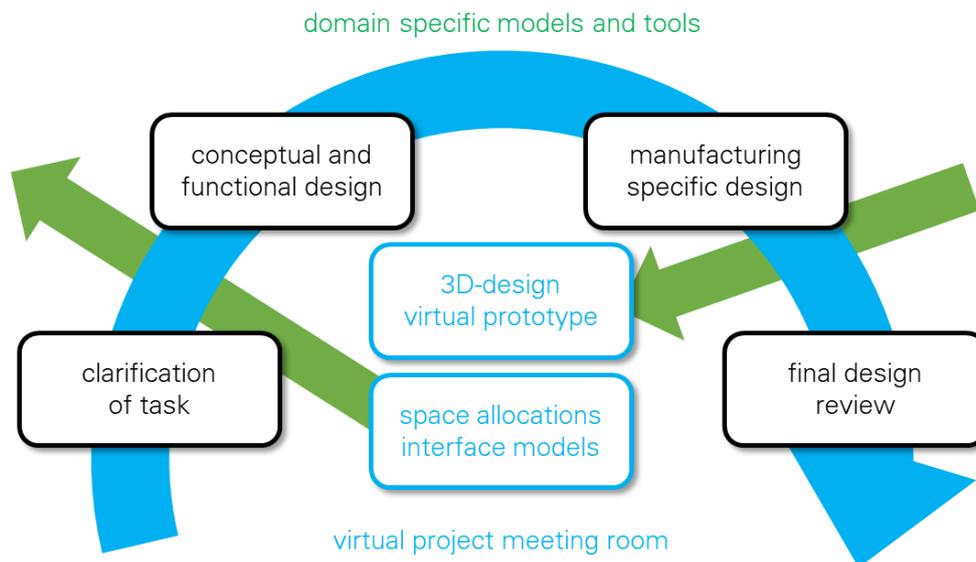


Figure 5. Overview of a lean product development arrangement with model import and export for 3D-CAD-models

3. Analysing of concepts

Distributed product development usually works with digital models. Therefore, it is important that these models can be created and edited in a virtual environment. VR-system from the design area already enable the creation and editing of models more easily, but are limited in the area of distributed working. In the following, two important systems for the creation of 3D objects in VR are introduced. Based on this, in the second part requirement lists for tools are created, which enable the creation of 3D objects in VR. Furthermore, it is described how such tools have to be designed. Another point that is considered is the export of 3D models from VR- to CAD-systems. The challenge is to convert models, which are available as surface models into CAD-readable volume models. Therefore a concept is presented.

3.1. Existing software for editing and creating 3D-models in VR

In this section, Google Blocks and Gravity Sketch are presented. This are two VR-Designing tools, which enable the user to create 3D objects. Mention that both software solutions are not specifically designed for the use in distributed product development.

3.1.1. Google Blocks

Google Blocks is a free graphics software that was released by Google in 2017. The software allows the insertion of five prefabricated objects into the virtual reality from a kind of library. The models consist of a small number of polygon. In addition, textures and lighting are not displayed. Figure 6 shows the software environment with the associated workbench on the left side. The workbench consist of six different function: shape, stroke, paint, modify, grab and erase. These tools are used to form the basic bodies by machining the surfaces, edges and points. Moreover, the polygon surfaces can be divided to create shapes that are more complex. The so created objects can be stored as animated GIF or OBJ file on a cloud server. This makes industrial use more difficult, as there is no guarantee of compliance with European or company data protection guidelines. Furthermore, the software is designed for single use, so that working in distributed project teams cannot be supported. Beside these main problems, there is no information about the performance when importing large and complex models from a CAD-software and a model size reference is missing. This leads to the fact

that the use of the software in distributed product development turns out to be difficult. Nevertheless, this Software shows that the creation and editing of 3D objects in VR is possible in principle.

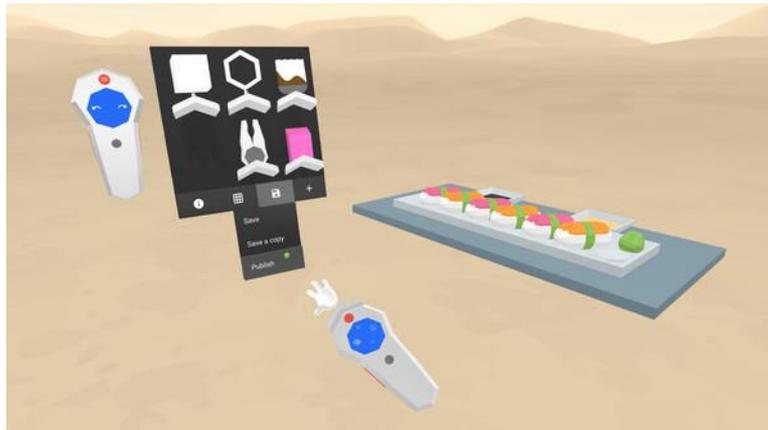


Figure 6. Tool selection (Google Blocks, 2017)

3.1.2. Gravity Sketch

Gravity Sketch is an immersive 3D design tool founded by Sketch Limited 2014. The software enables, similar to Google block, the creation of ready-made 3D objects, extended by tools for the creation of free-form surfaces. Furthermore, there is a fade-in grid, which supports the creation of straight lines and flat planes. Every object consist of support nodes, which are connected. In order to change the shape of created models, these support nodes can be edited and moved. It can be stated, that gravity sketch is more extensive then google blocks. Due to the range of different design tools, gravity sketch is suitable for solving industrial design tasks. On the other hand, the complexity of the software leads to a low usability. Especially the distinction between drawing and non-drawing hand turned out to be less intuitive. An important aspect of using VR in distributed development teams is the possibility to work collaboratively. This is not supported by the software. Another point that leads to the situation that this software cannot be used in engineering design is the fact that imported object cannot be edited extensively enough. There is a difference in the number of nodes between imported files and files created directly in the software. For imported files, significantly fewer nodes are displayed. In addition, the performance when importing very complex objects decreases dramatically. In some cases the whole software crashes. A detailed description of the range of functions can be found in the user manual (Gravity Sketch, 2019).

In general, neither Gravity Sketch nor Google Blocks offer the possibility to write comments, which can be exported in a PM-system. This is necessary to be able to track needed/ planned changes even outside the VR session. Moreover, an easy transfer from VR into common CAD-systems is not possible.



Figure 7. Sketch painted in Gravity Sketch (Robbins, 2018)

3.2. Concepts for improving the use of VR in product development

In this section, concepts for the implementation of the tools “editing and creating of simple 3D-model” and “export of simple 3D-models from VR into CAD” are presented. As foundation for this, a software is used, which is characterized by a high reliability and is specially designed for distributed working in product development. Besides these two major adaptations, some minor modifications, such as importing PDF templates and the implementation of a collision detection are necessary but not focused in this section.

3.2.1. Editing and creating of simple 3D-models in VR

Based on the analysis of Gravity Sketch and Google Blocks, a list of requirements is created. The basic list thus created is extended by additional points and is shown in Figure 8.

| Requirement | Priority |
|--|----------|
| The object is available in a format that is exportable to CAD programs. | 5 |
| The reference coordinate systems of all displayed components are visualizable. | 5 |
| The shape of the generated objects will be selected using an object library. | 4 |
| The scaling of the objects is adjustable | 4 |
| Created objects are related to other objects | 4 |
| Surfaces, edges and nodes of the created objects are editable. | 3 |
| The alignment of models is automatically based on edges and points. | 3 |

Figure 8. List of requirements for a creation and editing tool

The used VR software is unity-based, so the 3D-objects are created as OBJ-file. An OBJ-file contains all-important information of a surface model represented as a specially formatted text file. Based on this information, such models can be redesign in a CAD-Software (see 3.2.2). However, this file format has one decisive disadvantage. The size and volume of the file increases exponentially with the complexity of the object. As example, to describe a cuboid 40 lines with information are needed. A simple hammer needs 200.000 lines. In order to keep the software comfortable and high performance, only simple models (few surfaces and nodes) should be created and edited. Since the level of abstraction in the early phases of product development is still relatively high, such models are sufficient to represent initial concepts and solutions. Therefore, according to Google Blocks simple objects like cuboids, cones, etc. are available as foundation for further editing.

In order to simplify the later export of the created and edited objects, it is necessary to add them to a global reference system. Thus, the positioning can be determined independently of the software. For this purpose, it must be possible to represent both a global coordinate system and the coordinate systems of each model that is shown in the virtual reality. This could be visualized by means of a Head-Up-Display (HUD). For ergonomic handling of small models, it is necessary to be able to scale objects. This can be realized using a drag and drop function. Moreover, tools that can link different objects together are useful. A good basis for this are fade-in grids and alignment tools how are available in Google Blocks and Gravity Sketch.

3.2.2. Export of simple 3D-models from VR into CAD

In order to use the VR-models in all areas of product development, they must be usable in CAD-systems. Therefore, a tool must be developed which allows a CAD model to be derived on basis of the existing VR-models. Figure 9 shows the requirements list for such a tool.

| Requirements | Priority |
|--|----------|
| The program must be useable with just a few clicks (< 10). | 5 |
| The exporting object type is selectable. | 4 |
| The transmission time is less than 10 seconds. | 4 |
| The export is possible to different CAD programs. | 4 |
| The position of the object is automatically calculated. | 3 |

Figure 9. List of requirements for an export tool

First the available VR-models and its file format must be considered. The VR-models are available as surface models, which are stored as OBJ-file. As mentioned above this file contains information about the model like Points [v], texture points [vt] normal vector [vn] and surfaces [f]. Like STL files, there is a lack of information about the model such as symmetry or central axes, which are necessary when working with CAD-systems. In addition, the model surface is composed of many individual surfaces (aka tessellation), which leads to the facts that, for example, curves cannot be represented exactly. For this reason, the object must be recreated in the CAD environment based on the data stored in the OBJ file. While simple objects like cubes have a manageable number of entries (~40), a hammer already has more than 200.000 entries in the OBJ-file. This makes the manual reconstruction of models very time-consuming. For this, an automatic solution is desired. The problem here is the lack of a mathematical approach to describe infinitely complex geometries. For consequence, only geometries with limited complexity can be used. Models that are more complex have to be divided into several basic bodies and separately transferred to CAD. After this, the bodies will be put together with e.g. Boolean operations. In order to show that the development of such a tool is feasible, the process of creating a cube in CATIA V5 based on an OBJ-file is shown below.

```

5 v 1.000000 1.000000 -1.000000
6 v 1.000000 -1.000000 -1.000000
7 v 1.000000 1.000000 1.000000
8 v 1.000000 -1.000000 1.000000
9 v -1.000000 1.000000 -1.000000
10 v -1.000000 -1.000000 -1.000000
11 v -1.000000 1.000000 1.000000
12 v -1.000000 -1.000000 1.000000
13 vt 0.375000 0.000000
14 vt 0.625000 0.000000
15 vt 0.625000 0.250000
16 vt 0.375000 0.250000
17 vt 0.375000 0.250000
18 vt 0.625000 0.250000
19 vt 0.625000 0.500000
20 vt 0.375000 0.500000
21 vt 0.625000 0.750000
22 vt 0.375000 0.750000
23 vt 0.625000 0.750000
24 vt 0.625000 1.000000
25 vt 0.375000 1.000000
26 vt 0.125000 0.500000
27 vt 0.375000 0.500000
28 vt 0.375000 0.750000
29 vt 0.125000 0.750000
30 vt 0.625000 0.500000
31 vt 0.875000 0.500000
32 vt 0.875000 0.750000
33 vn 0.0000 1.0000 0.0000
34 vn 0.0000 0.0000 1.0000
35 vn -1.0000 0.0000 0.0000
36 vn 0.0000 -1.0000 0.0000
37 vn 1.0000 0.0000 0.0000
38 vn 0.0000 0.0000 -1.0000
39 usemtl Material
40 s off
41 f 1/1/1 5/2/1 7/3/1 3/4/1
42 f 4/5/2 3/6/2 7/7/2 8/8/2
43 f 8/8/3 7/7/3 5/9/3 6/10/3
44 f 6/10/4 2/11/4 4/12/4 8/13/4
45 f 2/14/5 1/15/5 3/16/5 4/17/5
46 f 6/18/6 5/19/6 1/20/6 2/11/6

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Figure 10. Cube represented in an OBJ file

The OBJ-file, which describes the cube, is given in Figure 10. The values marked in green or red are relevant for the export. The green values are the coordinates of the corner points of the cube. The red values define the cube surfaces. Since the surfaces are square, they are described by their respective corner points. For example, the surface presented in line 41 is described by the points 1 [line 5], 5 [line 9], 7 [line 11] and 3 [line 7]. CATIA V5 offers an interface for automation via macros where VBA is used as programming language. Therefore, the data stored in the OBJ-file are transferred into an EXCEL-table. This table can be read into CATIA. Due to the selected object type (cuboid), a sketch will be created where all points that lay in a plane are inserted. These points are connected by lines. This results in a square. The object depth is determined based on the other points. Finally, the sketch is extruded by the depth value. This procedure shows, that it is possible to create simple CAD models based on VR data. The next step is to increase the complexity of the model in order to estimate the impact on the process.

4. Summary and outlook

The paper gave a brief overview of the use of Virtual Reality in the early phases of product design especially when working in distributed teams. The analysis showed that some approaches and tools already exist to support development teams during meetings or even in designing simple geometries. However, it is not possible to export geometries from the virtual world back into a CAD-system in such a way, that geometries can be re-used or further processed by standard CAD-features. Future research will focus on the definition of a consistent and lean process for a reasonable use of 3Dmodels during the distributed product development. Moreover, tools and features to create geometries in the virtual world and to export these geometries back into a CAD-system will be developed.

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