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Building Bridges: Development of a redlining interface between VR and PDM

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Abstract. Virtual Reality (VR) has been used mainly as a complementary tool in the product development process for the depiction and evaluation of visual product features. Typical use cases are design review or assembly assessment. VR systems are usually used separately as stand-alone systems. Geometry data must be manually converted into viewable formats. If changes are necessary, the results are usually fed back to product developers in text-based reports or via screenshots with mark-ups. The objective of this approach is to achieve a continuous integration of these VR reviews into the product data management (PDM), which represents the core of the product development process. For this purpose, a VR redlining tool with a bidirectional connection to a PDM system was developed. This tool is able to automatically convert and show geometry data from the PDM database. In addition, properties such as part name, status or weight of the assembly components can be shown in VR based on connected PDM attributes. Redlinings created in VR, consisting of mark-up elements and voice-activated text fields, can then be transferred to the PDM system and processed in the internal viewer. Two methods have been developed for this purpose. One utilizes a 2D plane to position the redlining elements. The other allows them to be positioned freely including a camera to set the perspective. The research shows that an increased digitalization in the review process for product developers can be achieved between VR and PDM. However, further empirical studies comparing the different working methods are necessary.

Keywords: Product Lifecycle Management, Redlining, Virtual Reality.

1 Viewing and redlining in the product development process

One of the most important properties of project data is the visibility and availability of this data for everyone involved in the process [1]. This also applies accordingly to data generated during product development. Access to product data is greatly simplified by PDM software in the product development process. The use of PDM software provides

targeted access to product data for people involved in the development process by applying role and rights management. However, there are additional challenges for geometry data or 3D models. They are often stored in a wide range of formats, viewing and editing them basically requires the associated authoring software. While product developers are able to work with and have access to the appropriate authoring tools on a daily basis as part of computer-aided design, problems arise for other areas involved in the product development process, such as testing centers, manufacturing, marketing or sales. These departments usually do not have access to CAD software [2] due to high licensing and training costs. Accordingly, an application exclusively used for displaying purposes is not economically viable and even a disadvantage for these departments [2]. However, all people involved in the product development process should have access to the required models at their own workstations [1].

The use of specialized viewers is an alternative solution. They are based on a neutral data format and primarily used to display 3D models; changes to the displayed documents are not possible [2]. Many viewers have tools for manipulating the 3D models, such as rotating, measuring, section view, comparing between multiple 3D models, or disassembling and assembling components [3]. However, the fact that viewed models cannot be changed might sometimes be an undesirable circumstance. Especially when checking geometry, it is useful to include results of these checks as comments on necessary changes and marking of areas called redlinings. Therefore, viewers often have tools, which allow annotations to be attached as texts or graphics [2]. These viewers are called markup viewing software or redlining software. Even though these operations seemingly modify the original model, its data is not changed. Instead, the created information is stored separately on a different layer that can be deleted at any time. Alternatively, separate files containing the redlining data only can be created in addition to the model data [2]. The actual use of redlining is still characterized by severe technical difficulties. Nowadays, in addition to independent viewing and redlining software, simple screenshots are used as well. Some users add information through drawing programs or presentation software and send them via e-mail afterwards.

Consequently, linking viewing and redlining software with PDM systems is beneficial for multiple reasons. Firstly, stand-alone software can be omitted if the PDM system has its own viewing and redlining components. Secondly, a PDM software with integrated redlining capabilities can start further actions as part of the workflow automation. Workflow processes outside PDM systems can therefore be avoided. For this reason, redlining functions are often listed as service functions of PDM systems [2] and are considered to be important components of them [3]. Accordingly, numerous PDM software solutions have their own viewers.

The situation is different when using immersive virtual reality (VR). In VR, the user has the opportunity to influence or change the virtual environment (interaction). Via stimulating the user's senses, they are immersed in the environment (immersion). How well the virtual environment works depends largely on the user's imaginative power (imagination) [4]. Head mounted displays (HMDs) and CAVE systems (projection-based VR environments) are classified as such immersive VR systems [5].

VR technology is already used in various fields of application in product development. The use of VR is mainly limited to the depiction and evaluation of visual product properties [6]. These are individual and isolated applications; a comprehensive or even cross-industry use of VR has not yet taken place. In some industries such as the automotive sector, VR has already been used for a long time. Typical applications for VR in product development are:

- Product presentation in the customer environment [7] and marketing [8],
- Design-Review processes [5][9],
- Evaluation of design alternatives [10],
- Education and training of maintenance staff [8],[11],
- Visibility studies [9],
- Ergonomics studies [9], [10],
- Assembly and installation studies [10][12],
- Visualizations of Finite Element Method and Computational Fluid Dynamics calculations [9],[10],
- Comparison of variants [10].

Very similar fields of application can be found in industrial manufacturing or in the digital factory [13]. It can be seen that the application fields of VR largely overlap with the application fields of classic viewers and redlining software. Design reviews are the most prominent application area for redlining. The design review is defined as a target/actual comparison at certain milestones of the product creation process. In a team and in the presence of higher management staff, the properties of the product are compared with its requirements. If those are met, the product is released for further process steps. The design review is also used between the milestones for internal releases [14]. The choice of VR as a form of presentation for design reviews and comparable areas of application can be justified by the high degree of immersion. Dimensions and shapes can be validated more accurately by the true-to-scale depiction in VR than with desktop viewers [15].

2 Research approach and requirements for solutions

Despite the use of VR within some redlining applications, there has been no integration of VR into PDM systems to date, which is usually common for desktop viewers with redlining functions. Accordingly, there is a media disruption in the workflow. Annotations can only be summarized in text-based reports and, if necessary, enriched with screenshots. Such an externalization of work processes result in a higher probability for errors due to the existing interfaces. The exclusion from further processing in PDM systems and the loss for later reference could be the consequence.

The target of the presented approach is to investigate how VR redlining can be integrated profoundly into the PDM structure in order to avoid externalization of work processes and to achieve an increased information consistency in the product development process. The importance of such considerations is increasing due to the technological developments of the last 5 years, such as enhanced computing power and developments

in the pixel density of displays. In theory, these developments make it possible to deploy low-cost VR HMD systems at any workstation. Extensive investments, such as in CAVE systems, are no longer required by companies in order to utilize the technology of immersive VR.

To achieve this objective, requirements for a PDM-VR coupling in the application area of redlining can be derived. VR systems usually work with data formats that do not correspond to the data formats commonly used in CAD. In order to ensure an unrestricted workflow, it is necessary to provide an automated conversion into VR-capable data formats within PDM systems. Furthermore, it must be ensured that redlinings generated in a VR environment can be transferred back into the PDM environment. This crucial step enables further processing in workflows within PDM. Although this requirement appears to be trivial, it is associated with diverse challenges. Saving VR redlining results exclusively in PDM systems is accordingly classified as insufficient. This would require everyone involved to have a VR system at their workstation in order to view the annotations that have been made. The problems of authoring systems described at the beginning would also apply here, further complicated by the hardware requirements. Such an approach is therefore not viable. Consequently, it must be ensured that redlinings created in VR are stored in a desktop-compatible manner. The creation of screenshots or the conversion into redlining for desktop viewers are possible approaches.

3 The VR Redlining Tool

Based on these requirements, a VR redlining tool was developed as a demonstrator with a bidirectional interface to the PDM software (see Fig. 1). Initially, the technical structure of the VR environment and the functionality will be described from the user's point of view. The implementation of two approaches for redlining will be discussed separately.

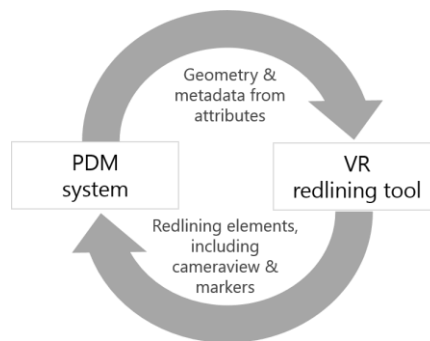


Fig. 1. Bidirectional interface between PDM and VR

3.1 Technical design

The VR environment is based on the development environment Unity, which is widely used for commercial graphics and VR applications in the gaming industry. The commercially available HMD system “HTC Vive” has been utilized as VR hardware. This device offers a tracking system, which is able to detect the position of the HMD in a 3 by 4 meter grid. Additionally, the system includes several controllers that provide the required interactive capabilities with the VR environment for redlining.

CIM Database 15.4 from Contact Software GmbH was used as the preferred PDM system. In addition to the usual functions of PDM systems, this solution also includes an internal viewer with redlining functions. Therefore, it is possible to integrate the VR redlining into the workflow application.

3.2 Functional design and mode of operation

The structure of the VR redlining tool was designed to provide a complete user experience and to create an independent workflow. This user experience starts and ends accordingly in the PDM system CIM Database. All intermediate steps occur in the VR redlining environment. The entire user experience can be divided into the following work steps:

1. Preparatory measures
2. Analysis of the product or assembly
3. Creation of redlinings
4. Editing and saving progress locally
5. Uploading VR redlinings into the PDM system
6. Triggering further workflows in the PDM system

Preparatory measures. If a user decides to work with the VR redlining environment, the PDM system is capable to provide all the required data for use in the VR environment locally. This mainly includes the CAD geometry, which is automatically converted into a VR-compatible format via the PDM system. This VR redlining environment uses the FBX format, in order to preserve the geometry as well as the assembly structure for the use in VR. Not only the geometry but also additional meta-data is transferred from the PDM system to the VR environment in this demonstrator. This includes the part numbers of the assembly or component to be viewed, as well as the part numbers of all existing subassemblies. This data is retrieved to enable distinctive identification of the geometry being viewed and the part numbers are also used to enable targeted data transfers in later process steps.

Analysis of the product or assembly. After the preparatory tasks have been carried out, the user can start to work in the VR application using an HMD. To analyze the product or assembly, the user is provided with common tools for viewers. These include the capabilities to move the object via translational and rotational movement, scale it or measure distances. In addition, a metadata display has been integrated that enables

the user to retrieve attribute values for individual parts from the PDM system within the VR environment. When the user touches a component of the product or assembly with a controller, it will be highlighted and selected attributes such as designation, status, material, editor or weight will be displayed for this component. Fig. 2 shows an example of the display presenting attribute values out of the PDM system. As soon as the VR application is started, the data is retrieved from the PDM system based on part numbers of the chosen assemblies. This enables an up-to-date status of the attribute values, even if the download of the geometry into the VR environment was performed a few days or weeks ago.

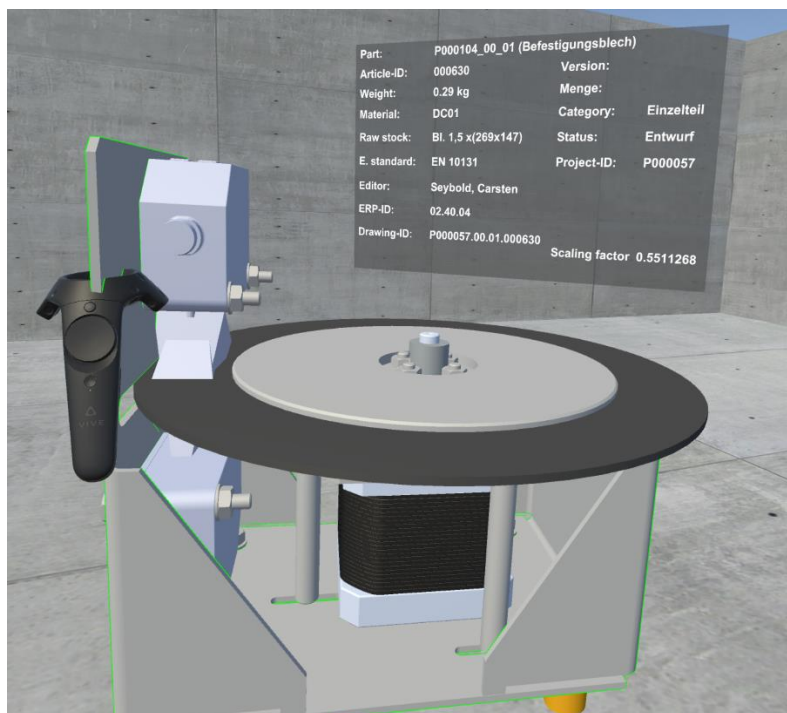


Fig. 2. Display of metadata in VR from the PDM system CIM Database for individual components by touching them with the controller (green edge highlight)

Creation of redlinings. In order to highlight identified issues or to provide a request for clarification about aspects of the model, it is possible to create redlining elements within the VR environment. The environment basically provides marking circles and rectangles to high-light areas of interest. In addition, the user has the option to create annotations on panels, which can be positioned according to the needs of the user. The creation of the annotations is based on a speech-to-text approach, without breaking the immersion by removing the HMD. An example for these functionalities can be seen in Fig. 3 as well as the prospective final result within the PDM environment. In order to implement a desktop-compatible storage format for VR redlinings as described at the

beginning, two different approaches were implemented to create said redlinings. These will be explained in more detail after the general functionality of the VR environment is introduced.



Fig. 3. VR redlining during creation and depiction in the PDM system CIM Database

Editing and saving progress locally. Users are able to save and load their work progress locally on the client. Accordingly, work can be carried out at different times. All manipulations to the VR environment, such as the position and orientation of the object, measurements and redlining elements, are stored. If changes occur during editing, the positions of redlining elements can be changed or deleted.

Upload VR redlinings into the PDM system. After the completion of the VR redlining process, the user can click a button to transfer the created redlining to the PDM system. However, the redlining objects themselves are not transferred, only a configuration file is transferred to the PDM software. The VR redlining results in a group of objects in 3D space. Since the PDM redlining is basically a 2D picture of a 3D model with lines and shapes on top, it is necessary to convert the VR results into a PDM compatible format. For example, the rectangle is converted into 2 sets of 3D coordinates for its top left and bottom right corners. The configuration file is then used to automatically generate the redlining elements in the PDM system based on the internal class structure. The PDM system then creates a new rectangle based on the given data. Accordingly, geometry or graphics are not transferred. This reduces the amount of data, which has to be uploaded and the redlinings remain interchangeable in the PDM system.

Triggering further workflows in PDM. The remaining steps have to be done on a desktop workstation. At this point it is possible to access the VR redlinings via the internal PDM viewer and to edit them if necessary. The user will be able to trigger the regular workflows in the company via the PDM system and initiate further processing. Fig. 3 shows a comparison of a redlining during creation in VR and the corresponding depiction in the PDM system CIM Database after the transfer.

The presented user experience shows that an integration of VR redlining into existing redlining structures is feasible. In order to achieve this, the strategic approach of how VR is used has to be adapted accordingly. The two approaches of redlining generation implemented here will now be briefly presented.

3.3 Differences between conventional and immersive redlining in VR

The creation of redlinings, possible in stand-alone viewers or in PDM-internal viewers, usually generates a two-dimensional picture of the object of interest. During the analysis phase, the geometry is freely movable in space for the user, but if the user decides to place annotations or other redlining elements, the perspective is fixed relative to the object of interest. The user's viewpoint is thus a fundamental part of the entire redlining process. Redlining elements are created perpendicular to the user's view on one or more planes between the 3D object and the user's viewpoint. Fig. 4 shows the schematic structure of conventional redlinings. Besides the spatial coordinates of the redlining elements, the coordinates of the virtual viewpoint, its field of view and other factors have to be stored.

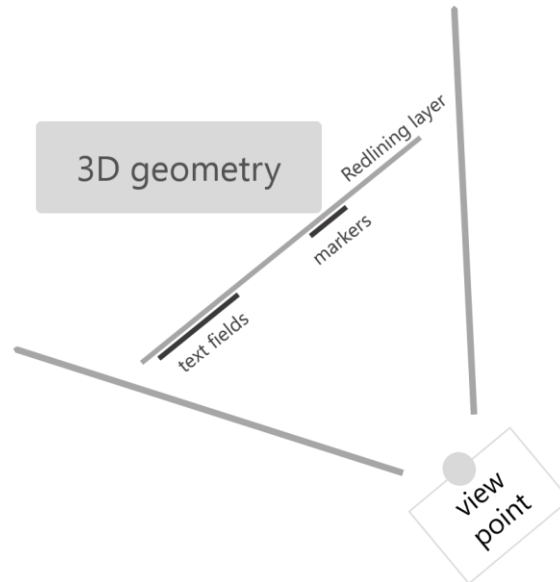


Fig. 4. Schematic structure of conventional redlining

Creating a graphical screenshot of the view is the easiest way to avoid having to save coordinates of the point view. The redlining elements are then placed on the image. However, such a storage of redlinings does not allow any subsequent changes and is thus not considered any further.

When using an immersive VR environment, the creation process for redlinings can be fundamentally different. For instance, when using HMDs, the field of view within VR is controlled by the user's position and perspective. In order to avoid issues such as motion sickness the orientation of the viewpoint is not restricted. The perspective of the redlining can therefore not be determined by the users point of view alone. Theoretically, it would be possible for the user to position redlining objects and the point of view freely. However, it must be ensured that the redlining objects are perpendicular to the chosen perspective and are not obscured by other objects such as parts of the geometry. Accordingly, two different approaches were developed, which allow the free positioning of redlining objects and still enable interchangeability with desktop viewers.

Approach 1: The camera - projection screen principle. The camera - projection screen principle allows the user to position the redlining objects freely in space in the form of marking rectangles, marking circles and annotation fields. In addition, the user is provided with a schematized camera object in the virtual environment. This camera represents the point of view for the redlining. In order to check the perspective, the VR environment has a screen that represents a preview from the point of view of the virtual camera. The virtual camera can be freely positioned by the user, and the preview is displayed in real time. In addition, when the position and orientation of the camera changes, the redlining objects are also realigned in real time. Accordingly, these objects

always remain perpendicular to the viewing direction of the camera and upright to the camera orientation. Fig. 5 shows the first approach and names some elements of the environment.

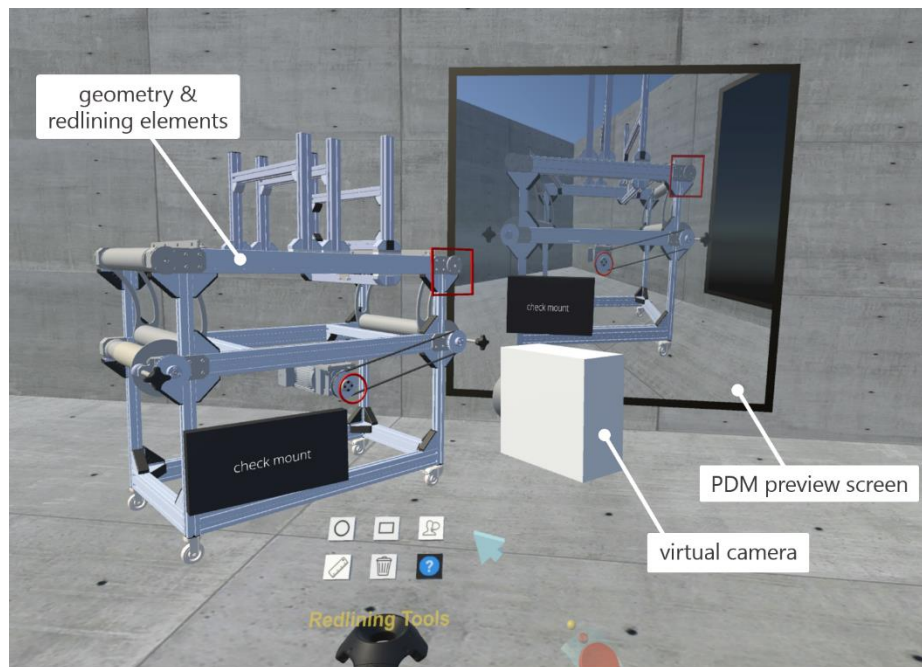


Fig. 5. Redlining approach 1: *camera-projection screen principle* – redlining elements arranged freely in space, user menu in front of the view

Approach 2: The 2D redlining panel. In this approach, a two-dimensional auxiliary plane is used to create the redlining objects. The user can freely position this semi-transparent plane in the VR environment. Redlining objects such as markers and annotation objects can only be created on this plane. It is possible to subsequently change the position and orientation of the plane including the generated redlining objects. In order to determine the later point of view for the redlining, the auxiliary plane has a semi-transparent schematic image of a virtual camera. The final perspective of the redlining is determined by the virtual camera. The result can be previewed if the user aligns the perspective of the HDM with the virtual camera. Fig. 6 shows the structure of the second approach.

3.4 Critical comparison of the approaches

Many differences can be found by comparing the two approaches. By working with multiple participants and using several data sets different advantages and disadvantages of the respective approaches could be determined.

Approach 1 offers the user a greater degree of freedom in the positioning of redlining objects. However, there is still the possibility that redlining elements can be obscured by other objects. Approach 2 does not have this issue. However, to get a preview has proven to be difficult and error-prone. Manual positioning of the HMD by the user at the exact point of view is difficult. A deviation in the perspective of a few centimeters or degrees can lead to a very different expectation of how the redlining will look like.

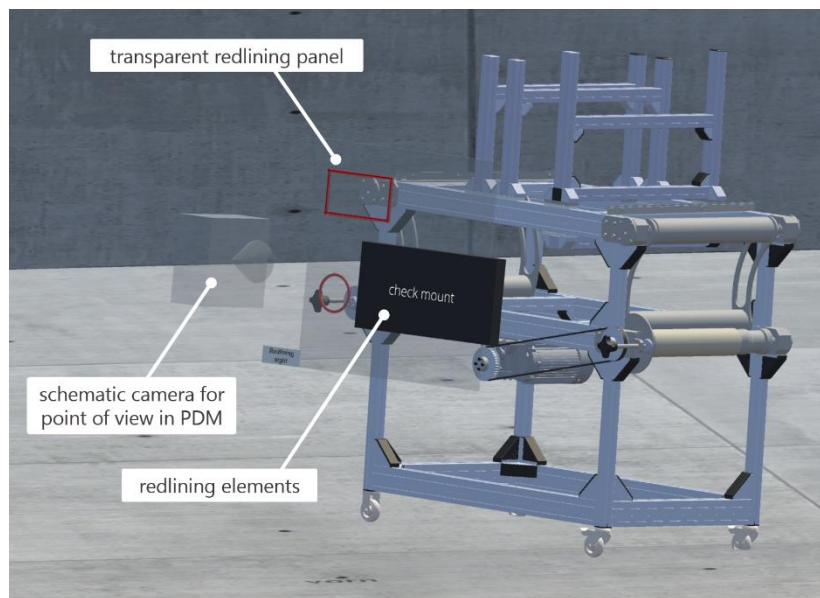


Fig. 6. Redlining approach 2: *2D Redlining panel* – Redlining elements can only be arranged on this panel

In conclusion, both methods are suitable for creating redlinings even without special prior knowledge. To minimize the training effort in a practical application, a combination of both approaches would be the best solution. This would work like the second approach but it includes the virtual screen of the first one in order to simplify the pre-view process.

4 Conclusion and approach for 3D redlining

The discussed approach has shown that it is possible to generate redlinings in VR in a manner that enables their integration into an existing workflow and their assessments in conventional viewers. In principle, redlinings generated in conventional viewers are limited to one perspective. This is also the case for VR redlinings, which can be created according to the approaches described above. A fixed perspective can only convey information that is visible from its point of view. If the user wants to create a redlining for a spatial problem a single redlining might no longer be sufficient. Therefore, multiple redlinings have to be created. The perspectives should be chosen in such a way that

ambiguities for markings in redlinings are avoided. Nevertheless, all relevant areas must be covered. This is even more difficult if the redlining is supposed to cover a three-dimensional space.

3D redlinings can provide a solution if they are not limited to one perspective. This would require that the user is able to place spheres of interest and annotations and still allow a free three-dimensional view of the geometry.

There are numerous possibilities to accomplish this. Markings of corresponding areas can be achieved for example by creating semi-transparent spheres or rectangles. The utilization of contour marking for components is also conceivable. Annotation fields can be provided with an anchor point, which establishes a relative position to the geometry while positioning all annotations in a circle around the object. The circle would have to always face the user. This way, the annotations are not influenced negatively if the perspective changes. Fig. 7 shows an example of such a 3D redlining.

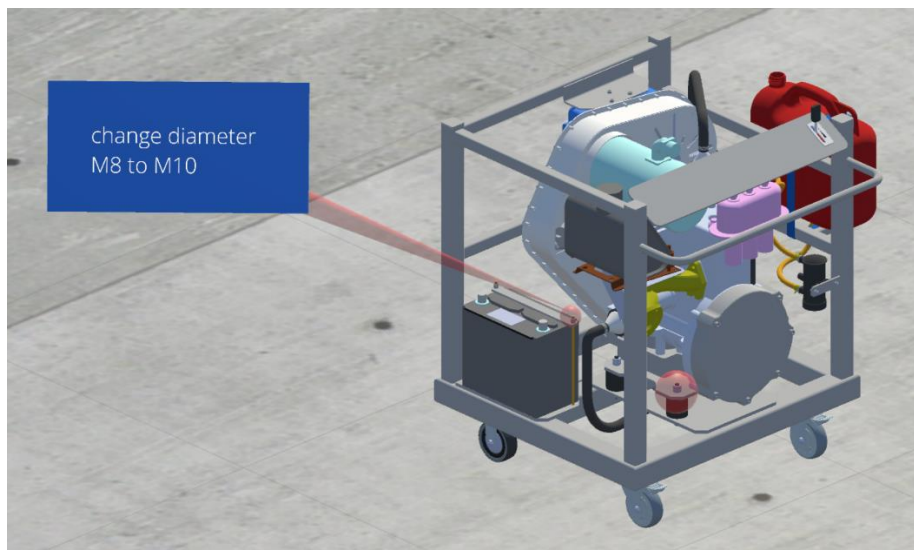


Fig. 7. Prototype for a 3D redlining in VR enabling a change of perspective using transparent spheres and view following comments

However, the creation of 3D redlining requires appropriate authoring software. The implementation in desktop applications is likely to be associated with an increased training effort for the user in terms of how to operate the application and how to create redlinings. These increased expenses have to be compared to the increased quality that a 3D redlining can provide.

Due to the high immersion and intuitive controls as well as an object which is true to scale, VR environments appear to be a suitable tool for the creation of 3D redlinings. This might lead to slightly higher costs due to the need to acquire VR hardware. However, these could be justified as part of a frontloading strategy [14][16]: According to the rule of 10 every mistake found and fixed early is worth a lot of time and in the end money.

5 Summary & Outlook

This paper presented an interface between PDM and VR redlining. The objective of the approach presented here was to achieve increased consistency in the following workflow when using immersive VR and to prevent media disruptions in redlining processes. Characteristics of desktop-based redlining systems were presented, and key aspects of using VR technology in the area of product development were highlighted. A demonstrator was developed, which allows the creation of redlinings in two different ways, which can be further processed and translated for desktop-bound viewers. Core features of the developed VR redlining environment are:

- the automated conversion into a VR-capable format from the PDM system,
- the retrieval of attribute values of parts of the assembly from the PDM system and
- the transfer of VR redlinings to the PDM system.

The demonstrator shows that a continuous workflow can be achieved by using VR for redlining. In addition, a 3D redlining approach was presented that makes it possible to alleviate the limitations of conventional redlining structures. However, the benefits of a 3D redlining compared to a conventional redlining need to be evaluated in further research. Additionally, further research is necessary to discuss how a more general approach could be implemented in order to increase the compatibility with other PDM and VR systems. This will require a standardized model, which has to define how VR, the product and its redlinings are to be connected, and which information has to be transferred.

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