Generic integration of VR and AR in product lifecycles based on CAD models

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ABSTRACT

Augmented Reality (AR) and Virtual Reality (VR) play an important role for the implementation of Industry 4.0 - especially in the area of virtual prototyping, manufacturing and maintenance. Thus, a holistic integration of these technologies in existing processes structures is essential to ensure future competitiveness of companies. Current research mostly focuses on some aspects of the lifecycle and not on the whole process. Furthermore, mostly specific tools are developed to create AR and VR contents instead of using already existing and widespread programs for example the 3D CAD software Inventor [1] or game engines like Unity [2]. The tools are used to create VR content providing a user-friendly environment with limited options for content creation. On one side the use of these programs decreases the required knowledge to create Mixed Reality applications, however they are associated with high implementation and running costs. This increases the entry barrier for small and medium sized enterprises (SME) to adopt AR and VR into their value chains significantly.

The presented work discusses concepts and proposes information models for adding VR-specific information directly in CAD environments. A generic model of necessary interaction options as well as VR properties is created and applied to a use case in the Industry 4.0 model factory at FH Aachen, Germany. Furthermore, a workflow for combined evaluation of product and equipment developments is developed focusing on VR integration.

Keywords: Industry 4.0, VR, AR, Integrated Engineering, Product Lifecycle Management, Virtual Prototyping.

1. INTRODUCTION

Anyone who speaks about Industry 4.0 can hardly avoid VR and AR. Current studies show that the demand for VR and AR emerging technologies will increase significantly in the next few years, while at the same time more and more extended reality products will reach the consumer market and the industry [3-5]. The mass production of VR and AR equipment makes them affordable and economically viable even for SMEs. The fields of applications for virtual helpers are numerous, ranging from virtual prototyping, AR-supported assembly, to maintenance tasks. [6]

While technical breakthroughs continue to happen thanks to technological advancements, customers' expectation for new products intensifies as product lifecycles are greatly shortened. In order to maintain and expand the competitiveness of companies, it is necessary to accelerate development services through integrated engineering across the entire value chain [7]. Especially virtual prototyping [8, 9] and virtual training [10, 11] are gaining importance. Products and entire plants can be tested, validated, and improved in virtual space before the costly manufacturing process starts. Training on commissioning, plant operation, and maintenance can also be carried out virtually leading to fast and efficient implementations of new processes in production [10-13].

However, the full potential of VR and AR applications is not yet fully exploited in practice. Mixed reality technologies are mostly used to solve specific problems [15] and seldom reach into the general product development processes. This means that generated CAD data generated during the design process of a product can only be reused to a limited extent for new problems, which leads to a high implementation overhead, making the technology not viable for SMEs.

An example on an investigation of cross-process usage of AR and VR technologies is shown in the AVILUS project [16], where different research projects are conducted with the goal of creating a company-wide information source including various software tools. As result, an ontology is created to enable automatic extraction of CAD data (NX) and wiring information (EPLAN). However, the research only shows flagship projects conducted in different companies and facilities, thus no complete integration over a system lifecycle is demonstrated [16].

The presented work emphasizes the necessity to develop generic information models and concepts for effective CAD integration without the need of highly specialized and cost-intensive VR/AR authoring tools.

2. VR IN PRODUCT DEVELOPMENT

To achieve a pervasive deployment of VR technologies especially in SMEs, a deeper look into possible integration stages during the development of a new product and its production process is necessary. This should ensure a consistent use of available CAD data in the sense of integrated engineering throughout the entire product life cycle and over various technologies.

ISO/IEC 15288 [14] defines six lifecycle stages (concept, development, production, utilization, support and retirement stage). Additionally, a technical process consisting of 11 processes starting with the stakeholder requirements definition process and ending with the disposal process is determined. A typical product development process can be derived based on this standard (Fig. 1, black font). A similar process can be assumed for the design of operating equipment like for example a gripper for picking parts or tools.

For VR applications, the product development process is the most important part [15]. During this stage, virtual design reviews can take place in simulations [16], visualization of engineering data [17], and usability tests [18]. To include VR simulations, additional information is required (Fig. 1, red font).

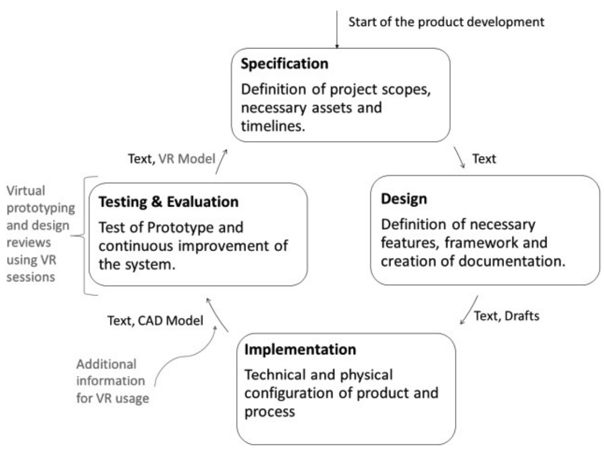

Fig. 1: Typical product development process

For a smooth integration of VR into the product development, different concepts were developed. Wolfartsberger *et al.* [17] show a multimodal VR-supported tool for design review. To integrate CAD models into 3D graphics software, they propose a three steps approach, converting a native CAD model (e.g. .ipt, .stp, etc.) to a 3D editable mesh (using 3DS Max, Blender etc.), and then importing this model into authoring tools (e.g. Unity3D) as interactive 3D models (typically .fbx). To integrate actions in Unity, an automatic creation of Colliders for the imported objects was implemented. Based on that, haptic feedback is provided to the user when a virtual object is touched. Their study showed that context-specific interaction processes, like pushing a button, are essential for an immersive user experience.
Berg *et al*. [19] state that a typical VR integration process consists of seven steps. First, VR sessions must be requested, and the relevant data are acquired. Next, the modelling process of the CAD data takes place, which lasts for hours to days. This step is considered as the most time-consuming part. Then, the virtual environment based on the application is created including object manipulations, physical properties, and animations. After finishing the VR scene, a proof-of-concept is conducted and then the VR session takes place. Finally, the outcomes are summarized.

Another approach for automatic integration of CAD models into VR environments is shown by Lorentz *et al.* [20]. Their work focuses on creating VR models out of CAD including previously defined animations (e.g. explosion views) and kinematic relationships. Their comparison on different 3D data exchange formats shows that VRML fulfills their requirements best. The presented conversion concept includes three main functionalities: 3D model reduction (using a special program like GPure from DeltaCAD [21]), animation transition (using VRML or capturing of motions on a time step basis), and interactive kinematics (use of CAD model for kinematics calculation, exchange information with VR system).

It can be concluded that the generation of VR applications for testing and evaluation is a time-consuming process. Typically, VR specialists are needed to create VR environments and to manage VR meetings due to their high complexities. Wolfartsberger *et al.* [17] show that the assignment of scripts in Unity is done using two ways: Automatic assigning of basic scripts (for example the generation of Colliders to all imported objects) and manual allocation of interactions to specific objects. However, no method is available for selecting the appropriate interactions that exist in the CAD programs. To solve this problem, an information model comprises basic interactions and physical properties, which are necessary to generate VR models automatically out of CAD models, is developed in our work.

Information model for VR interactions

The proposed information model consists of five main topics: physical properties, graphics, kinematic constraints, animations and interactions (Fig. 2). As the import process of kinematic constraints and animations is already covered in [17], the focus in this work lies on the interchange of physical properties and interactions. Additionally, graphical properties are considered. The naming and categories are based on the conventions used in Unity as it is widely adopted by the research community [6, 8, 17, 22]. For the same reason, Unity is adopted as the testing environment for the presented concept.

For every imported CAD object (GameObject), the physical properties must be selected. If a Rigidbody is attached, the physical behavior of the GameObject is enabled and the object will respond to gravity. If Colliders are added to an object, the object reacts to incoming collisions. Additionally, the specification of mass and air friction are essential for creating a realistic virtual environment [23].

The selection of the graphics parameters also has a significant influence on the realistic representation of objects. Thus, the definition of a mesh, a material (specification of the surface being rendered), a shader (script to calculate the color of pixels during rendering) and a texture (bitmap image applied over the mesh surface) must be presented in the CAD model [23].

Moreover, different kinds of user interactions are specified in the information model covering most typical use cases. To handle objects, four interactions are defined: selection, grabbing, placing, and mounting. Mounting is used if a tool is needed to interact with a virtual object, for example if a screwdriver is needed to tighten a screw. In this case, the interaction can only be finished if the right tool and the right object are selected.

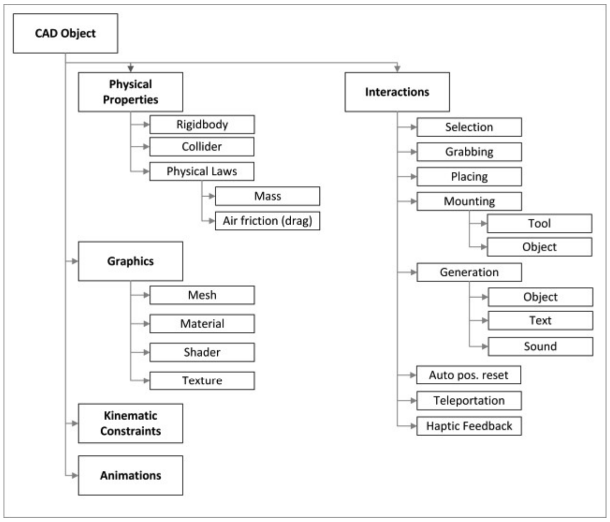

Fig. 2: Information model for VR interactions

Additionally, the option of generating new objects, text or sounds based on triggers, for instance a collision or pressing a button, is included. Furthermore, the option for an automatic position reset (for example if the object is released or if a specific button is pressed) is taken into account. As the virtual worlds may vary in size and to minimize motion sickness, a teleportation option should be available. Finally, the extensibility for haptic feedback like vibrations of a controller is added.

A manual workstation of the Industry 4.0 model factory at FH Aachen is chosen (Fig. 3) as a physical platform for study in this work.

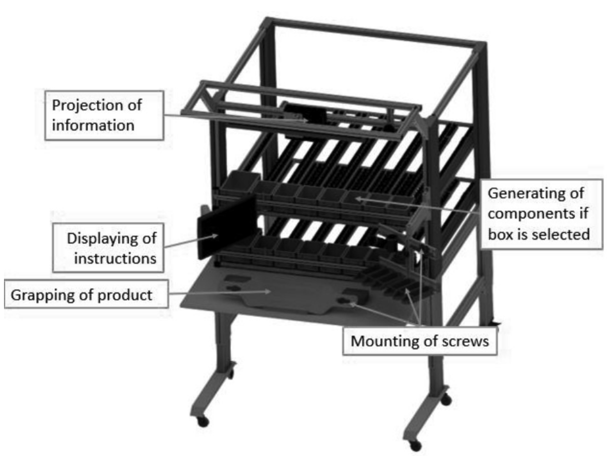

Fig. 3: Example for VR interactions (manual workstation at FH Aachen)

The station offers a variety of interaction possibilities to build virtual longboards. The projector in the upper part can be selected to project assembly information onto the desk. Besides, the status of the order can be reviewed at the monitor. When the user reaches a box in the storage area, a corresponding virtual component stored in the box is generated. All parts lying on the table can be grabbed and placed in the virtual working environment.

The in the information model (Fig. 2) specified properties and interactions of virtual objects can be allocated to CAD models in Unity manually. However, this is a time-consuming process and difficult to create synergy between the CAD designer and the VR modeler. Thus, an adapted workflow is proposed in Fig. 4.

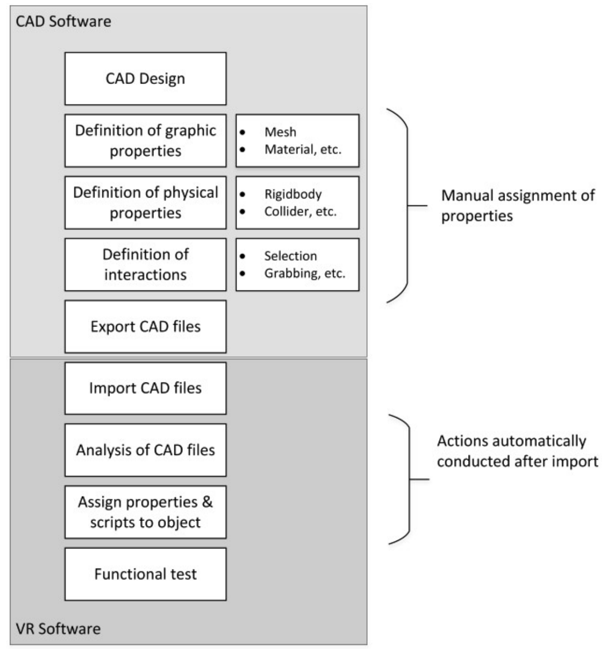

Fig. 4: Workflow for VR content generation

Adding properties & interactions to CAD files

To enable the workflow shown in Fig. 4, a process sequence using different environments (Inventor, 3ds Max, Unity) is suggested. The CAD model is expanded with additional properties in json format (Fig. 2, Fig. 5) to the objects, for instance in Inventor or 3ds Max (Fig. 6). As the export of files in Unity-readably formats is not fully supported in CAD programs (e.g. Inventor does not support the export of fbx-files), an intermediate step between Inventor and Unity using 3ds Max is utilized in the current design. However, solutions that support direct export of the appropriate formats from CAD programs like Inventor or SolidWorks will be explored in future projects.

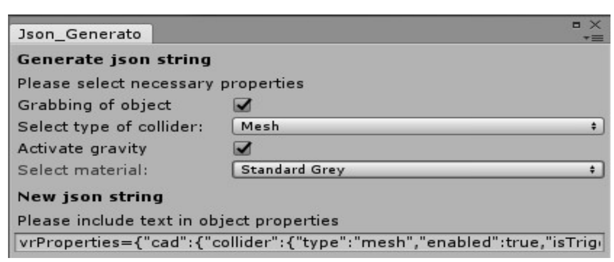

Fig. 5: User interface to generate json string

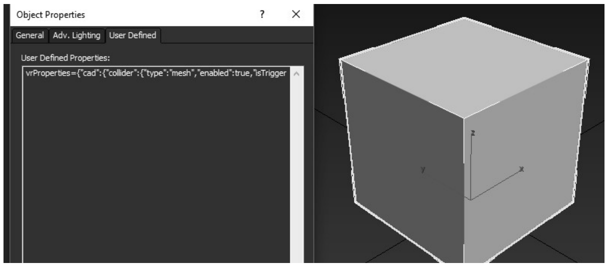

Fig. 6: Adding object properties in 3ds Max

Additionally, the property information must be included in the available file formats (i.e. .fbx, .dae (Collada), .3ds, .dxf, .obj, and .skp for Unity imports). According to our studies, the file format .fbx contains most previously added information and thus is selected as the file format in the tests in this work (Fig. 7).

```
Model: 2348822650400, "Model::Cube_1", "Mesh" {
    Version: 232
    Properties70:  {
        P: "PreRotation", "Vector3D", "Vector", "",-90,-0,0
        P: "RotationActive", "bool", "", "",1
        P: "InheritType", "enum", "", "",1
        P: "ScalingMax", "Vector3D", "Vector", "",0,0,0
        P: "DefaultAttributeIndex", "int", "Integer", "",0
        P: "Lcl Rotation", "Lcl Rotation", "", "A",90.0000093346676,-0,0
        P: "UDP3DSMAX", "KString", "", "U", "vrProperties={"cad":{"collider":

        P: "MaxHandle", "int", "Integer", "UH",1
    }
    Shading: T
    Culling: "CullingOff"
}
```

Fig. 7: Extract of the fbx-file including the property "mesh collider"

To generate the VR environment in Unity, the GameObjects must be added to the scene by drag and drop. Next, a parsing of the .fbx files of the present objects can be started via user interface. This results in an automatic allocation of properties and scripts to the corresponding GameObjects.

3. COMBINING PRODUCT AND EQUIPMENT DEVELOPMENT IN VR

Due to synchronous engineering processes, the development of new products as well as the corresponding equipment must be coordinated, and a well-defined information exchange standard must be available. Hence, the product and equipment development progress require a standardized connection (Fig. 8, upper part). Additionally, a generation of VR or AR training sessions by including extra information after the design process is possible (Fig. 8, lower part). The uniqueness lies in the reuse of CAD models for three different purposes (product/equipment evaluation, combined production analysis, and training sessions) by exploiting existing design information and adding further details.

For a combined VR analysis of the two models, three steps must be conducted: integration, testing and evaluation. The goal is to enable an automatic integration by mapping the CAD models of the product and the equipment with the corresponding process step. Typically, product assemblies are imported in VR for review processes [15]. Thus, the focus of the developed concept for VR analysis lies on compound products, which need different resources (machines, tools, etc.) to be assembled. As a basis for combined product and equipment VR reviews, a work schedule is taken. There are different concepts in the area of Computer Aided Process Planning (CAPP) available to generate automatically assembly sequences. [24, 25] Therefore, an ordered list of tasks is considered as given in this case. However, the assembly sequence must be enriched with all information necessary for VR integration (Fig. 9).

The expanded work schedule includes three main aspects: definition of the working area, specification of the final product, and determination of the necessary process steps. The working area defines the required space for operation as well as the area in which interactions can take place. In case of the manual work station, (Fig. 3) this would be the size of the room and the surface of the table. Additionally, the properties related to the final version of the product are included. For evaluation purposes, the position as well as the possible interactions (Fig. 2) must be considered. Using this information, a transparent view of the final product similar to the one in [17] can be generated automatically.

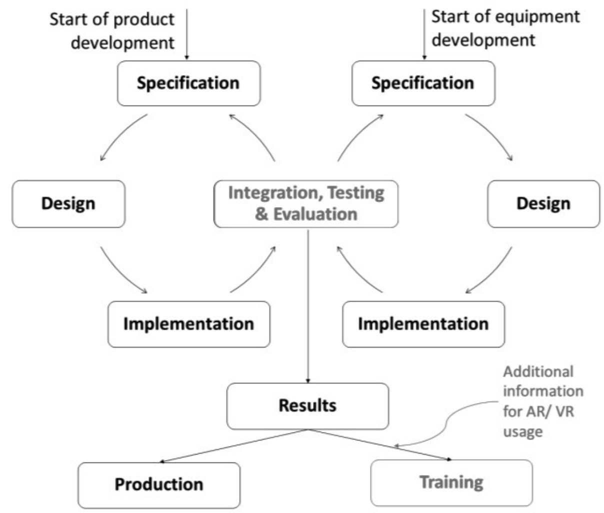

Fig. 8: Combination of product and equipment lifecycles (VR and AR integration highlighted in red)

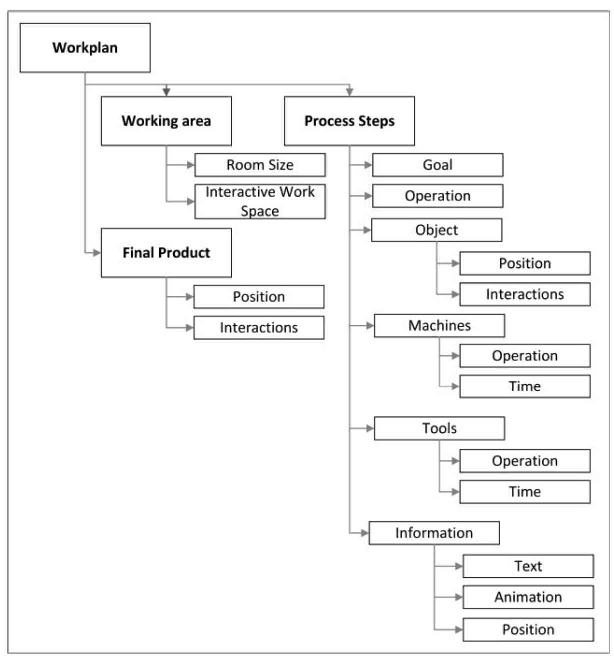

Fig. 9: Required information in the work plan for VR integration

The following process information is needed for the realized of a process step in VR. First, the goal and the corresponding required operations are assigned. In the example of the manual workstation, this would be the mounting of screws (Fig. 10). Additionally, the necessary tools (Fig. 10, green box) and/or the machines (Fig. 10, blue box) are defined.

To enable a process-oriented simulation in VR, operation times of machines and tools can be added. The objects required for the process step (Fig. 10, red boxes) including their positions in the workspace and the possible interactions are defined. Furthermore, the CAD designer should be able to display supplementary information during VR sessions (Fig. 10, yellow box) at designated areas.

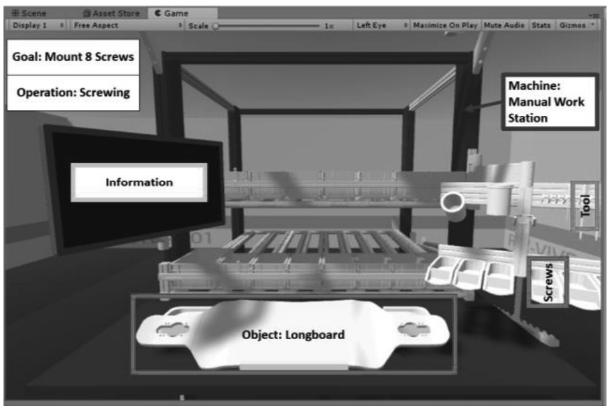

Fig. 10: Example for essential information for the realization of one process step in VR

The required process to generate the VR environment shown in Fig. 10 starts with two CAD models (Fig. 11). Next, all required information is added in the CAD program for the product and the equipment designs. Additionally, a work plan is generated out of the product CAD files. Then, both CAD models are exported into a .fbx file and imported in Unity. In Unity, automated processes are started using the information provided in the .fbx file. First, all CAD models are transformed into GameObjects. Second, the scripts enabling user interactions are added to the GameObjects. After finishing the scene according to the work plan, the VR application can be used for design reviews.

4. DISCUSSION AND LIMITATIONS

The use of the presented information models to generate a VR manual work station showed that the process to include user defined information in .fbx files via user interfaces can be seamlessly integrated in already existing CAD design processes. Following, the designer only has to put the CAD models into the VR environment and maybe adjust them in size, position or orientation. The VR properties are added automatically via scripts.

However, limitations occur for the automatic allocation process. First, a standardized and consistent naming through all programs is the basis for the whole process to match the defined properties in the .fbx file with GameObjects in Unity. Second, only objects which are important for the functionality of the whole system should be enhanced with additional information. Less important parts or for example frames, screws, etc. must often not be part of the physical simulation, which reduces the work effort and the required computing power. It must also be conducted that only general properties like physical behavior or the property "grabbing" can be added in the CAD system. Specific requirements like for example the grabbing of tools only on the handle must be adjusted manually in Unity.

5. CONCLUSION AND FUTURE WORK

VR based review sessions in development of new products as well as VR trainings are mostly used for highly complex and costly products like those in the automotive and aerospace industries [19]. However, due to the availability of low-cost VR devices, potential applications for SMEs are emerging. To support smaller companies, concepts and applications, which enable the use of VR by lowering its technical entry barrier.

The concepts and information models proposed in this work enable a consistent usage of the already available CAD models in VR by including additional information. This process can minimize the time and personnel expenditure to use VR reviews along value chains [17, 19, 26]. Using the presented approach, the CAD models generated during the design process can be reused three times (product/ equipment review, combined review, training) in the same environment. As all information are already included in the CAD programming environment, the CAD designer can directly import models into VR.

The proposed concept was tested using different scripts for interactions (grabbing, placing and object generation). Additionally, an automatic assignment of physical properties to imported object is included. This results in time and complexity reductions as manual allocation is not needed in Unity. The specification of the room creates the floor, walls, and a roof of the virtual space. The collection of scripts can be further expanded to incorporate other specified interactions.

In our future work, the connection between product and equipment will be implemented using Inventor and Unity. Supplementary user studies are scheduled to identify additional required information and interactions.

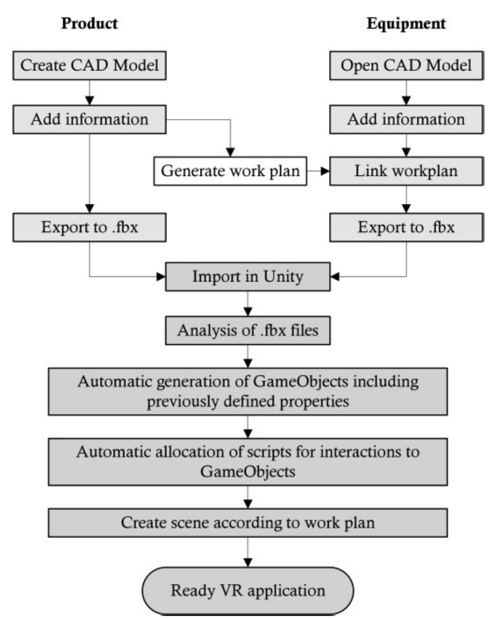

Fig. 11: Complete process to model the VR environment (blue: CAD software; red: VR software; white: assembly plan generator)

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