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Collaborative Virtual Assembly Environment for Product Design

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***Abstract*—Collaborative virtual assembly environment is a vital computer-aided design tool in product design and can be used as a learning and training tool. It helps in supporting complex product design by enabling designers to collaborate and communicate with other designers involved in the product design. This paper proposes a collaborative virtual assembly environment built in two phases for the immersive and non-immersive environments. Phase one was developed in Unity 3D using Virtual Reality Toolkit (VRTK) and Steam VR. Whereas, phase two was built using Vizard and Vizible. This work aims to allow scientists and engineers to discuss the concept design in a real-time VR environment so that they can interact with the objects and review their work before it is deployed. This paper proposes the system architecture and describes the design and implementation of a collaborative virtual assembly environment. The outcome of this work is to be able to resolve communication and interaction problems that arise during the concept-design phase.**

Keywords—virtual reality, assembly system, collaborative virtual environment, computer-aided design, collaborative concept design.

I. Introduction

A collaborative virtual assembly environment allows designers and engineers to perform assembly tasks together in a shared environment. Companies and research organizations are involved in designing, assembling, and manufacturing that requires them to collaborate although their team may be geographically dispersed. Increased competition and the shortening of the product life cycle has made the product development cycle vital in companies and organizations. The product design stage is the most important phase in the product development life cycle. Firms usually build prototypes and verify the viability of different designs to determine the best possible design. Nevertheless, this is a time-consuming undertaking that increases the length of the product development cycle [1]. The assembly phase is crucial since it accounts for a significant proportion of the product manufacturing costs. Traditionally, automatic planning algorithms and physical prototypes determine the methods used in planning and assembly evaluation. The use of physical prototypes is very expensive and time-consuming. On the other hand, the use of automatic planning algorithms fails to use expert knowledge. Virtual reality (VR) technology helps in solving these problems. It helps in the development of virtual assembly (VA). VA technology helps in the development of assembly related processes, which include product assembly evaluation, assembly planning, assembly worker training, and learning without the need for developing physical prototypes [2]. Immersive VR environments such as Assembly VR [3] have been used for early concept design.

The virtual environment (VE) enables an organization to identify the potential problems without the use of physical prototypes, which helps in shortening the product development cycle. A ccollaborative virtual assembly environment is a vital computer-aided tool in product design. It helps in supporting complex product design by enabling designers to use their special advantages and communicate with other designers involved in product design. It facilitates communication with people who do not have an elaborate knowledge of 3D Computer-Aided Design (CAD) tools. Therefore, it may play a vital role in training assembly workers. Assembly learning and training can be undertaken in the virtual environment. Collaborative virtual assembly [4] technology helps in the development of a real-time experimental assembly environment that facilitates the activities of designers located in different geographical regions. It enables designers to share product data, identify and verify the assembly scheme developed to achieve the design scenario. Having a real-time synchronized collaborative virtual assembly helps in expressing the design idea in an easily understandable manner. It provides insights into how to improve the design quality and reduce the assembly evaluation time [5]. Nevertheless, it is vital to note that a collaborative virtual assembly environment does not meet the operational requirements of certain complicated products.

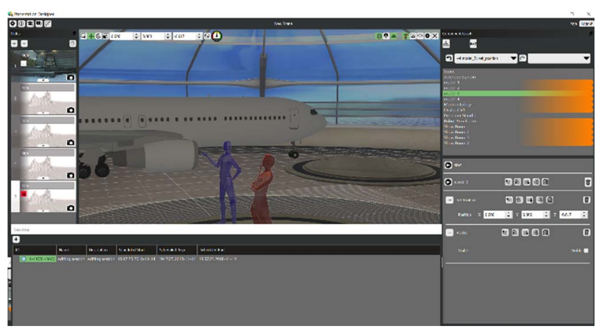

Fig. 1. Collaborative VR assembly of an aircraft using visible.

This paper proposes a collaborative virtual assembly environment built in two phases. Phase one was developed in Unity 3D using Virtual Reality Toolkit (VRTK) and Steam VR. Whereas, phase two was built using Vizard and Vizible. Fig.1 shows the phase two collaborative virtual assembly environment of an aircraft in a virtual environment. The main purpose is to demonstrate both assembly and 3D presentation simultaneously for an aircraft. Vizible is a collaborative virtual reality tool to present 3D models in a collaborative environment and let the participants modify the 3D models in

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the shared space. Vizible gives the flexibility to view the virtual assembly environment in a range of VR headsets such as Oculus and HTC vive. There are two phases in Vizible application. One is to create VR content and another is to experience it. Vizible includes Vizible Presentation Designer and Vizible Presenter. Vizible Presentation Designer creates interactive VR presentations. Whereas, Vizible Presenter holds sessions, multi-user gatherings inside of the presentations for real time communication and collaboration in virtual reality. Presentation Designer is a 3D scene or a VR environment that can be populated with 3D models, videos, images, sounds, and documents.

A collaborative virtual assembly system should have the ability to handle a large number of components and products. For example, it should have the ability to have the pre-built components for an aircraft engine assembly. It should provide auditory, visual, tactile, and kinesthetic feedback. In so doing, it would provide different options for immersions, whether semi or fully. It should also provide haptic feedback, which includes tactile, kinesthetic, or both. It should perform efficiently in real-time. The system should enable the human operator in a collaborative virtual assembly to easily and intuitively assemble a section or component during the assembly process. The collaborative virtual assembly is used in the assembly of task simulation. It helps in the evaluation of the assembly alternatives and training assembly operators. Collision detection helps in evaluating product spatial relationships in real-time. This determines whether the assembly or disassembly procedure is undertaken in the best possible manner.

The rest of the paper is structured as follows: Section II briefly describes the work done previously; Section III describes the design and architecture of the two applications; Section IV describes the implementation; Section V highlights the simulation and research issues relevant to CVE; finally, Section VI lists results, conclusions and future work.

II. Related Work

Collaborative virtual environment (CVE) has been used as a training and educational tool for disaster response [6], military training [7], driving [8], and evacuation drills [9-11]. CVE allows multiple users to work together in a shared virtual space. CVE systems have been applied to military training, telepresence, collaborative design and engineering, distance training, entertainment, and industrial applications. Virtual Assembly Design Environment (VADE) [12] allows engineers to design, analyze, and plan the mechanical systems.

In a collaborative virtual assembly system, the human operator can disassemble a section or component of the assembly for maintenance. It requires CAD data to be imported into the virtual assembly environment in a systematic manner [13]. The importance of feedback in training cannot be understated. Different types of feedback may be obtained from a collaborative virtual assembly environment. These include cognitive and corrective feedback. Substantial feedback is provided during the beginning of the trainee's interaction with the system after which it is withdrawn gradually [14]. Collaborative virtual assembly should enable them to come together in real-time by providing an immersing environment [15]. Various system requirements should be integrated into the development of the collaborative virtual assembly system. The collaborative virtual assembly system enables to facilitate the collaboration between designers who are located in different geographical regions over the internet [16].

The collaborative virtual assembly system provides real-time interactive operations of the assembly line. It provides the designer with the ability to manipulate objects in the assembly line. For instance, the designers should have the ability to grasp, move, or constrain the motion navigation of objects in the assembly line. These actions should be depicted in the right manner in the virtual environment. Assembly tools are vital in the assembly process [17]. The collaborative virtual assembly system also includes synchronization control. Synchronization control helps in maintaining the consistency of the scenes of all system nodes. This implies that if the scene of a node changes due to object manipulation, the information related to the change should be transferred to all relevant nodes, which would update their scenes synchronously and automatically. The collaborative virtual assembly system has a large data set of the real-time process. As such, one personal computer may not have the capacity to render a complex scene especially of the scene requires the rendering of high-quality, 3D computer graphic image [18]. Therefore, the collaborative virtual assembly system needs to render scenes using a PC cluster.

The use of a collaborative virtual assembly environment in learning and training faces several challenges. Simulation sickness is one of the challenges of using a collaborative virtual assembly environment in learning and training. How long an individual can be in a virtual environment is one of the challenges of collaborative virtual assembly environment. People may experience simulation sickness if they are in a virtual environment for too long. Also, it is vital to consider the individual characteristics of each user in virtual reality or virtual environments [19]. This creates the need to inform the participants beforehand and monitoring them during the review meeting. Accurate collision detection, realistic physical simulation, inter-part constraint detection, and management, and data transfer between CAD and virtual environment systems are also some of the challenges faced when using collaborative virtual assembly environment in learning and training [20].

Most organizations invest significant sums of money in developing their virtual environment systems, which are usually inefficiently used in the design process of the assembly lines [21]. There is also a need to endure that there is sufficient communication to ensure knowledge on the design defects and feedback is shared among different members of the organization. The major challenge is how organizations can adapt good practices, which is identified by extensive sharing of knowledge, in the processes [22]. Information from the VR assembly environment can be used in the development of the assembly sequence planning, robot path planning, and assembly training [23]. Virtual objections selection and manipulation is vital in assembly operations simulations [24]. It would involve various interactive devices that would provide interactive capabilities that would facilitate the selection and manipulation of virtual objects in the VR environment [25].

III. System Architecture

This proposed collaborative virtual assembly environment was built in two phases for the immersive and non-immersive environments. Phase one was developed in Unity 3D using

Virtual Reality Toolkit (VRTK) and Steam VR for an immersive environment. Whereas, phase two was built using Vizard and Vizible.

A. Phase First: Immersive VR Environment

The immersive collaborative VR application in the first phase one allowed users to collaborate in real-time. It was built for the HTC Vive HMD using Unity3D. The hand controllers in HTC vive were used to interact with the design objects in the application. The controllers use a virtual laser to guide the user in selecting and manipulating the objects. The left-hand controller was used for triggering the menus and the right-hand controller is used for selecting the objects from the menu as well as for navigation. The users interact with immersive collaborative VR application by using the HMD and hand controllers. Multiple users can modify and view designs while communicating with each other. The hand controller was used to enable the menu on the hand controller. The right-hand controller was used to grab the objects in the VR environment.

1) Menus: The user can trigger the menu by pressing a button on the HTC vive controller as shown in fig. 2. The menu contains objects such as a sphere, cube, cylinder as well as pre-developed CAD objects. The virtual parts were modeled from CAD files into a low-resolution and high-resolution version. Low-resolution models contained reduced polygons and contain fewer parts and were created so that collision detection can be included.

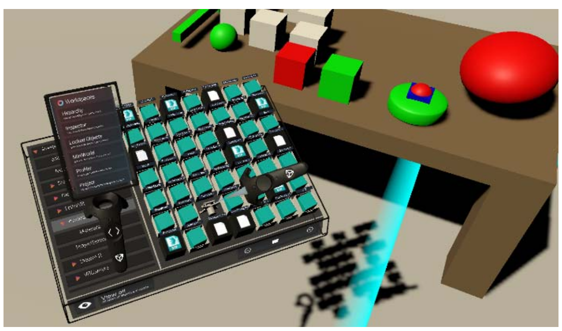

Fig. 2. Menus attached on the left controller

2) Grabbing: The HTC Vive allows users to grab the 3D objects using the two hand controllers. There will be several grab options that were implemented such as:

a) Fixed Joint Grab: Connected to the controller via a fixed joint

*b) Spring Joint Grab: T*he object is suspended by the controller as if it is connected to the controller using a spring coil

c) Axis Scale Grab: The user grabs an object using one controller and scales the object up or down

d) Child of Controller Grab: The grab makes the grabbed object a child of another object.

e) Track Object Grab: The object tracks the position and rotation of the hand controller rather than being attached to the controller.

*f) Swap Controller Grab: A*llows objects to be swapped between the left and the right-hand controllers.

g) Snap Drop Grab: The user selects the desired object, drag that object and drop it over a region. That object then automatically snap into place.

h) Custom Joint Grab: Allows for a custom joint to be provided for the grab attach.

*i) Interact Controller Appearance: T*he controller should be visible on the display or not.

B. Phase Second: Collaborative VR Environment

The system architecture of VR assembly of an aircraft using vizible consists of four phases. i.e., starts from create, convert, assembly and present are shown in fig. 3.

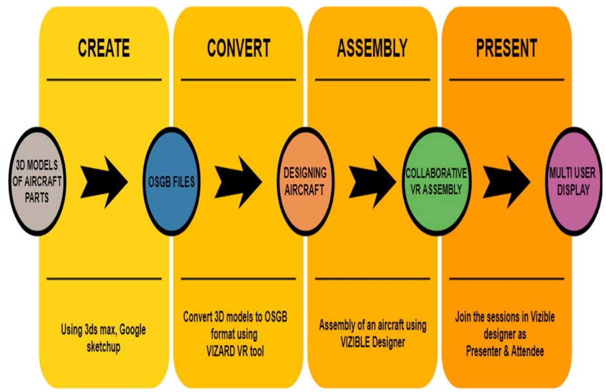

Fig. 3. System architecture of VR assembly of an aircraft using Vizible.

During the create phase, 3D models were created using 3ds max and google sketch up software. The models were then converted into OSGB files during the convert phase. During the aassembly phase, the 3D models are uploaded in assets folder in vizible and were used to assemble the aircraft in the VR environment. In the last phase, the assembled 3D models of an aircraft are presented to the multiple users in a collaborative VE assembly session.

IV. Implementation and Deployment

The implementation of the proposed collaborative virtual assembly environment was done in two phases.

A. Phase First: Immersive VR Environment

The immersive assembly VR environment application was built in Unity3D using the Virtual Reality Toolkit (VRTK) and SteamVR. The Virtual Reality Toolkit (VRTK) provides support for the implementation of grabbing options as well as the implementation of physics within the 3D space, 2D and 3D UI elements. Unity3D gaming engine was used doe the development and it allows developers to build VR applications. C# and JavaScript scripts were written to implement custom functionalities in Unity 3D for interaction in the immersive environment.

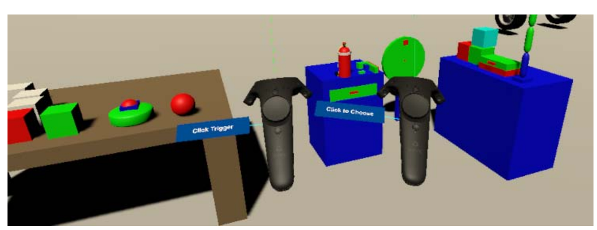

Fig. 4. Immersive VR environment showing grabbing and moving the objects

Scenes developed within the Unity gaming engine can also be played as a standalone executable (.exe) application. During this phase, the scenes were made into a VRTK prefab option which was then placed in front of the camera. Fig. 4 shows the scene being played within Unity. In this phase, menus were developed so that the user can interact in the environment using the two HTC vive controllers.

B. *Phase Second: Collaborative VR Environment*

Vizible is divided into three parts as designer, presenter, and attendee. Each part has different features in it. The Designer part allows the user to build the 3D objects according to the requirement. In designer, users don't need any external software to edit 3D objects as vizible supports in editing the object. If necessary user can run small 3D animation with pre-programed objects. The designer mode provides different rooms in the environment for incorporating different 3D objects. If necessary, the user can copy the objects from one room to another room. For each room user can prepare different slides, all those slides can be groped at the end in a sequential order to prepare a presentation. The vizible also gives access to connect to all other hardware devices like oculus, HTC vive.

Fig. 5. Vizible presentation designer.

Fig. 5, shows that there are two virtual humans available in the scene, they are presenter and viewer. Vizible has a feature to have multiple presenters and viewers. Using the session ID from designer, presenter can log in to the account and see the slides available to present. When presenter logs in from the terminal, it enables the microphone and speaker to interact with the viewer. While the presenter is presenting, the presenter can move an object in the slide or scene. Also, the presenter can switch or transport from one place to other places in the work room. Presenter while giving the presentation can interact with the viewer or other presenter logged in as a presenter, using the microphone and speaker. The designer also has access to attend the presentation and thus allows to make changes if needed.

The presenter also has an option to pre-load the location to move in the workroom. The presenter can also load movements in a timeline manner so that the change is automatic according to the time loaded. The vizible has a feature to include as many attenders. Once the session ID from the presenter or designer is assigned, the attendee can log in from the terminal. The viewer can see only what presenter shows in the presentation using regular tools, but in the vizible the attender can move around in the room and explore the room by itself. But attendee cannot edit or move the object in the scene. The presenter can set proximity sensors for the attender, so that when the attender reaches a certain location, he gets information about a certain object in that location. The information can be in terms of opening a text window or voice clip or a description of the object in the scene. A head-mounted display (HMD) could also be integrated into the assembly environment. A video see-though HMD could be used in the assembly environment since the real image and the virtual image would be overlaid in a video stream.

V. Simulation and Results

Limited testing was performed for the two developed VR assembly applications. The first one involved immersive assembling the parts of the car using HTC vive as shown in fig. 6. This task involved the user interacting with the menus and choosing the write option to grab the objects. Initially, the parts and objects were dragged and dropped in the scene and then, placed into groups located at different parts of the scene. Using the HTC vive controllers, the object parts were grabbed and moved, to assemble the car. Once the session was finished, the scene was saved into a file so that it can be opened up again later for further modifications.

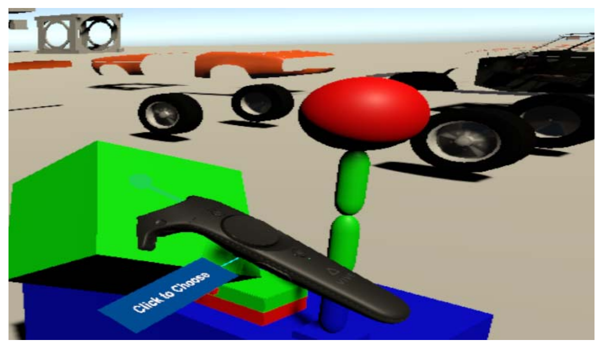

Fig. 6. VR assembly of a car using HTC vive.

The VR assembly of an aircraft can provide answers to various questions. It could help in determining the parts that should be incorporated in the real prototypes. It could also help in determining how much manipulation of the virtual parts is required. The final decisions on VR assembly of an aircraft would depend on the design strategy, assembly operations, component properties, and prototyping costs.

Fig. 7. Collaborative VR assembly of an aircraft using vizible.

Fig. 7 shows the collaborative VR assembly environment for an aircraft using visible where two attenders, can collaborate successfully. The purpose of building better communication in a collaborative virtual assembly environment for the concept design stage is to rapidly share concepts and reach a common consensus during product design. The objective of this work is to:

- Apply VR technology for building a visualized collaborative concept communication environment with hardware integration.
- Deliver the system analysis and design results for developing a collaborative concept design system.

Vizible lets the user to present their 3D model and to modify the 3D model during the collaborative session. As mentioned earlier, there are two parts to Vizible, one to create VR content and another to experience it. With Vizible presentation designer, one can create interactive VR presentations. Then, with Vizible presenter, one can hold sessions, multi-user gatherings inside the session for real-time communication and collaboration in virtual reality.

VI. Conclusions and Future Work

In conclusion, a collaborative virtual assembly environment is a vital computer-aided tool that helps in supporting complex product design. It enables each product designer to exert their special advantages, communicate with other designers and workers using an intuitionistic manner, which helps in identifying and solving design problems collaboratively. Real-time collaboration and can be used in learning and training in a virtual assembly environment. However, a collaborative virtual assembly environment has several challenges that should be addressed to improve its efficiency.

This paper presents a collaborative virtual assembly environment for product design, which can build a collaborative virtual assembly system allowing geographically located engineers to perform an assembly task together. This paper aimed at introducing two phases and their corresponding interaction metaphors to allow a design engineer to intervene in a collaborative design session supported by a CVE. Phase one (immersive VR environment) was developed in Unity 3D using Virtual Reality Toolkit (VRTK) and Steam VR. Whereas, phase two (collaborative VR environment) was built using Vizard and Vizible. The immersive VR application that gives engineers and scientists a platform to view and modify concept product designs in a collaborative environment. It was developed for HTC Vive using Unity, VRTK, and SteamVR. The users can interact and navigate the environment using HTC vive hand controllers.

Future research would be undertaken to determine how to tackle the shortcomings of a collaborative virtual assembly environment to improve the operating efficiency of the system and improve its application in learning and training.

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References

[1] Y. Hu, D. L. Wu, X. Fan, and X. J. Zhen, "Grid-enabled collaborative virtual assembly environment," Assembly Automation, vol. 30, no., 4, pp. 352-364, 2010.

[2] G. Caruso, S. Polistina, and M. Bordegoni, "Collaborative mixed reality environment to support the industrial product development," In Proceedings of the 2011 ASME World Conference on Innovative Virtual Reality, pp. 207-215. American Society of Mechanical Engineers, 2011.

[3] J. Stigall, R. Baskar, S. Sharma, "Assembly VR: An Immersive Virtual Reality Environment for Concept Design", Proceedings of ISCA 27th International Conference on Software Engineering and Data Engineering (SEDE 2018), New Orleans, Louisiana, USA, pp. 57-62, October 8-10, 2018.

[4] D. Wu, X. Zhen, X. Fan, Y. Hu, and H. Zhu, "A virtual environment for complex products collaborative assembly operation simulation," Journal of Intelligent Manufacturing, vol. 23, no. 3, pp.821-833, 2012.

[5] G. Gonzalez-Badillo, H. Medellin-Castillo, T. Lim, J. Ritchie, and S. Garbaya, "The development of a physics and constraint-based haptic virtual assembly system," Assembly Automation, vol. 34, no. 1, pp.41-55, 2014.

[6] Sharma, S, Frempong, I.A., Scribner, D., Grynovicki, J., Grazaitis, P "Collaborative Virtual Reality Environment for a Real-time Emergency Evacuation of a Nightclub Disaster", IS&T International Symposium on Electronic Imaging (EI 2019), in the Engineering Reality of Virtual Reality, Hyatt Regency San Francisco Airport, Burlingame, California, pp. 181-1-181-10(10), 13 January- 17 January 2019.

[7] Sharma, S., Devreaux,P., Scribner, P., Grynovicki, J., Grazaitis, P.,"Megacity: A Collaborative Virtual Reality Environment for Emergency Response, Training, and Decision Making, IS&T International Symposium on Electronic Imaging (EI 2017), in the Visualization and Data Analysis, Proceedings Papers, Burlingame, California, pp. 70-77(8), DOI: https://doi.org/10.2352/ISSN.2470-1173.2017.1.VDA-390, 29 January- 2 February 2017.

[8] Sharma, S, "A Collaborative Virtual Environment for Safe Driving in a Virtual City by Obeying Traffic Laws", Journal of Traffic and Logistics Engineering (JTLE, ISSN: 2301-3680), doi:10.18178/jtle.5.2.84-91, pp. 84-91, Volume 5, No. 2, 2017.

[9] Sharma, S, Jerripothula, S., Devreaux, P., "An Immersive Collaborative Virtual Environment of a University Campus for performing Virtual Campus Evacuation drills and Tours for Campus Safety", Proceedings of IEEE/ACM International Conference on Collaboration Technologies and Systems (CTS 2015), Atlanta, Georgia, USA, ISBN: 978-1-4673-7646-4, page 84-89, DOI: 10.1109/CTS.2015.7210404, June 01-05, 2015.

[10] Sharma, S, Jerripothula,S., Mackey, S. and Soumare, O, "Immersive Virtual Reality Environment of a Subway Evacuation on a Cloud for Disaster Preparedness and Response Training", Proceedings of IEEE Symposium Series on Computational Intelligence (IEEE SSCI 2014), Orlando, Florida, USA, page 1-6,DOI:10.1109/CIHLI.2014.7013380, Dec. 9-12, 2014.

[11] Sharma, S., Otunba,S.,"Collaborative Virtual Environment to Study Aircraft Evacuation for Training and Education", Proceedings of IEEE, International Workshop on Collaboration in Virtual Environments (CoVE -2012), as part of The 2012 International Conference on Collaboration Technologies and Systems (CTS 2012), Denver, Colorado, USA, page 569-574, May 21-25, 2012.

[12] S. Jayaram, J. Yong Wang, , U., Lyons, K., Hart, P., "A Virtual Assembly Design Environment", Proc. IEEE Virtual Reality 99 Conf., IEEE CS Press, Los Alamitos, Calif., 1999, 172-179.

[13] C. Greenhalgh, Large scale collaborative virtual environments, New York, NY: Springer Science & Business media, 2012.

[14] M. Behandish and H. T. Ilies, "Haptic assembly using skeletal densities and Fourier transforms," Journal of Computing and Information Science in Engineering (JCISE), vol. 16, no. 2, pp. 1–11, 2016.

[15] J. Bender, K. Erleben, and J. Trinkle, "Interactive simulation of rigid body dynamics in computer graphics," Computer Graphics Forum, vol. 33, no. 1, pp. 246–270, 2014.

[16] M. Bordegoni, U. Cugini, and F. Ferrise, "Requirements for an enactive tool to support skilled designers in aesthetic surfaces definition," International Journal on Interactive Design and Manufacturing (IJIDeM), vol. 6, no. 2, pp. 83–91, 2012.

[17] G. Caruso, S. Polistina, M. Bordegoni, and M. Aliverti. Collaborative mixed-reality platform for the design assessment of cars interior. In R. Shumaker, editor, Virtual and Mixed Reality - Systems and Applications, volume 6774 of Lecture Notes in Computer Science, pp. 299–308. Springer Berlin Heidelberg, 2011.

[18] C. Cheng-Jun, W. Yun-feng, and L. Niu. Research on interaction for virtual assembly system with force feedback. In Proceedings of the

2010 International Conference on Information and Computing (ICIC'2010), volume 2, pp. 147–150, 2010.
[19] B. Christiand, "Assembly simulations in virtual environments with optimized haptic path and sequence," Robotics and Computer Integrated Manufacturing, vol. 27, no. 2, pp. 306–317, 2011.
[20] J. Whyte and D. Nikolić, Virtual reality and the built environment, Routledge, 2018.
[21] H. Liu & L. Wang, An AR-based worker support system for human-robot collaboration, *Procedia Manufacturing*, 11, pp.22-30, 2017.
[22] A. Kunz, M. Zank, M. Fjeld, and T. Nescher, "Real walking in virtual environments for factory planning and evaluation," *Procedia Cirp*, vol. 44, pp.257-262, 2016.
[23] A. Marzano, I. Friel, J. Erkoyuncu, and S. Court, "Design of a Virtual Reality framework for maintainability and assemblability test of complex systems," Procedia Cirp, vol. 37, pp.242-247, 2015.
[24] V. Bharath and P. Rajashekar, "Virtual manufacturing: A review," In National Conference Emerging Research Areas Mechanical Engineering Conference Proceedings (pp. 355-364), 2015.
[25] A. Al-Ahmari, M. Abidi, A. Ahmad, and S. Darmoul, "Development of a virtual manufacturing assembly simulation system," Advances in Mechanical Engineering, vol. 8, no. 3, pp.1687814016639824, 2016.