



EuroXR 2022

Proceedings of the EuroXR Conference

Kaj Helin | Arcadio Reyes-Lecuona |
Christoph Runde (eds.)

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EuroXR 2022: Stuttgart, Germany

The focus of EuroXR 2022 conference is on novel VR/AR/MR technologies, including software systems, display technology, interaction devices, and applications. Besides papers on the latest scientific results and highlights from many application fields, the EuroXR conference series aims at creating a unique human-dimension framework, interconnecting European and international XR communities, for knowledge cross-fertilisations between researchers, technology providers, and end-users.

14-16 September 2022

Stuttgart, Germany

Conference organizers



Preface

We are pleased to present these conference proceedings in the VTT Technology series, which contains the papers accepted for the Application and Exhibition & Demo Track of EuroXR 2022, the 19th annual EuroXR conference, being hosted by VDC from 14th to 16th September 2022 in Stuttgart, Germany. This publication is thus a collection of the application papers (talks, posters and demonstrations) presented at the conference. It provides an interesting perspective into current and future applications of VR/AR/MR.

In previous years, under the name EuroVR, the conference has been held in Bremen (2014), Lecco (2015), Athens (2016), Laval (2017), London (2018), Tallinn (2019), and Valencia (2020); and as EuroXR in Milan (2021) and Stuttgart (2022). The focus of the EuroXR conferences is to present, each year, novel Virtual Reality (VR), Mixed Reality (MR) and Augmented Reality (AR) technologies, including software systems, display technologies, interaction devices, and applications, to foster engagement between industry, academia, and the public sector, and to promote the development and deployment of VR/MR/AR technologies in new, emerging, and existing fields. This annual event of the EuroXR association (<https://www.euroxr-association.org/>) provides a unique platform for exchange between researchers, technology providers, and end users around commercial or research applications.

We would like to warmly thank the industrial committee chairs for their great support and commitment to the conference, and special thanks go to the local organizing committee for their great effort in making this event happen ☺.

On behalf of the organising committee,



Kaj Helin



EuroXR EC member, Principal Scientist at VTT Technical Research Centre of Finland Ltd, Finland



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Application track talks

Using 3D city models as an occlusion mask to overcome the hololens limited scanning range for outdoor AR-applications

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Keywords: Augmented Reality, Mixed Reality, Occlusion, Urban Planning, e-Participation, HoloLens, 3D City Model, CityGML.

Creating an immersive Augmented Reality (AR) experience requires aligning the digital content with the real environment so that the digital content appears and interacts in a similar way to a real object. For that, the virtual object must persist in its position across sessions and be occluded completely or partly, depending on whether a real-world object is in the line of sight. This research makes use of the cutting-edge technology available in the field of AR/MR, the Microsoft HoloLens 2.0, where the in-device Time of Flight (ToF) camera is used to scan the environment to create a Spatial Map. The CityGML LOD1 (OGC, 2012) model enriches the Spatial Map and, in addition, is used as an occlusion mask via a custom rendering pipeline to overcome the limited range of the HoloLens. The developed occlusion effect is used in urban planning scenarios to introduce a new area design featuring a car-free environment and enable public participation. The proposed method is evaluated based on performance indicators, including frames per second (FPS), since it is highly correlated to user comfort. The findings of the users' study demonstrate that the occlusion effect achieves its purpose since most of the participants reported enhancements in depth perception and overall experience by enabling the occlusion screening.

Introduction

Augmented Reality (AR) refers to the science and technology of overlaying digital content over the real environment. In other words, AR allows users to view materials and objects that they would otherwise be unable to see (Kasper et al., 2017). AR can be extended further to have a more interactive and immersive experience by introducing an interaction between digital content and the real-world environment to achieve a Mixed Reality (MR) and near-real experience. This necessitates a seamless transition between virtual and physical environments, as well as the ability for both to coexist and interact realistically. Simulating physical interactions like collisions, shadows, lighting, and occlusions is a difficult issue to overcome (Kasper et al., 2017, Fortin and Hebert, 2006). For that, the digital content should align with the real environment, including position, scale, and occlusion by other objects.

While building AR scenes, the purpose of occlusion is to maintain the laws of the line of sight. That is, any virtual item that is placed behind a real object should be occluded or hidden behind the actual object to provide the viewer with a realistic experience and improve the viewer's depth perception. When no occlusion effect is used, the digital content appears to float above the scene, as shown in Figure 1. When the occlusion effect is used and part of the object is hidden, the scene appears more realistic, and the digital content blends with the real environment. To achieve occlusion, knowledge of the real environment is required through the presence of a three-dimensional representation of it, which in turn will act as a mask to hide the virtual objects. This real-world representation can be obtained in real-time using various 3D sensing techniques or can be obtained by using a generalized model in the form of a city model, which can be obtained in advance.



Figure 1. Demonstration of the occlusion effect. (left) Occlusion disabled. Occlusion enabled (right).

Method

This research puts forward the idea of using the 3D building model as a custom shader to enrich the Spatial Map and create the occlusion effect. The geometry of the scanned spatial map, which was enriched further by the geometry of the 3D building model, was used as an occlusion mask as shown in Figure 2.

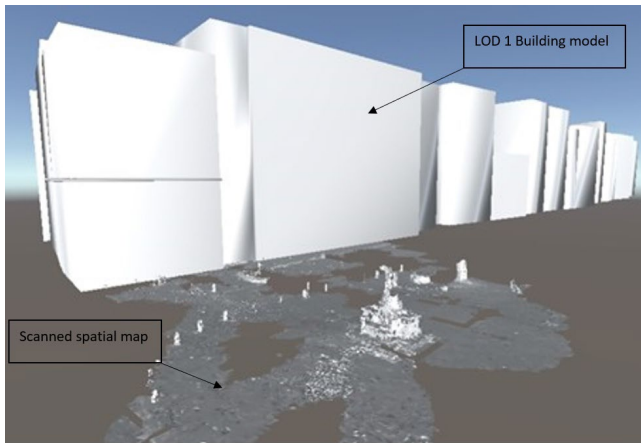


Figure 2. Occlusion mask based on the geometry of the scanned Spatial Map and 3D building model.

The occlusion shader calculates and determines how each pixel is rendered on the screen. The shader is wrapped in a material that can be assigned to the 3D building model to act as an occlusion mask. To render the occlusion mask before all other meshes in the scene, a queue value is set to one unit lower than the geometry value, where the geometry value is always 2000 and represents the priority to render solid objects. ZWrite is enabled to write the pixels from the occlusion mask to the depth buffer. The ZTest is set to render the geometry at the front and not draw any pixels behind it from other objects. In other words, all objects behind the occlusion mask will not be rendered. The ColorMask is also set to zero, which lets the shader change all three RGB values and the alpha channel, which stands for transparency.

To render the 3D content to its desired location, spatial anchors, which are defined as a keypoint in the environment where the system tracks over time, were used and automatically distributed in real-time. For that, World Locking Tools were added to the Unity scene and the main camera game object was stored in it. The World Locking Tools script initiates the World Locking Manager, which in turn takes control of placing the spatial anchors and performing the camera transformation needed.

Results & evaluation

The visual effect of the occlusion screening was shown via screenshots, and the occlusion effect's impact was evaluated through user feedback. Furthermore, the suggested method was assessed using a set of performance indicators since pixel-perfect occlusion is not necessary to acquire the intended occlusion effect (Kasper et al., 2017).

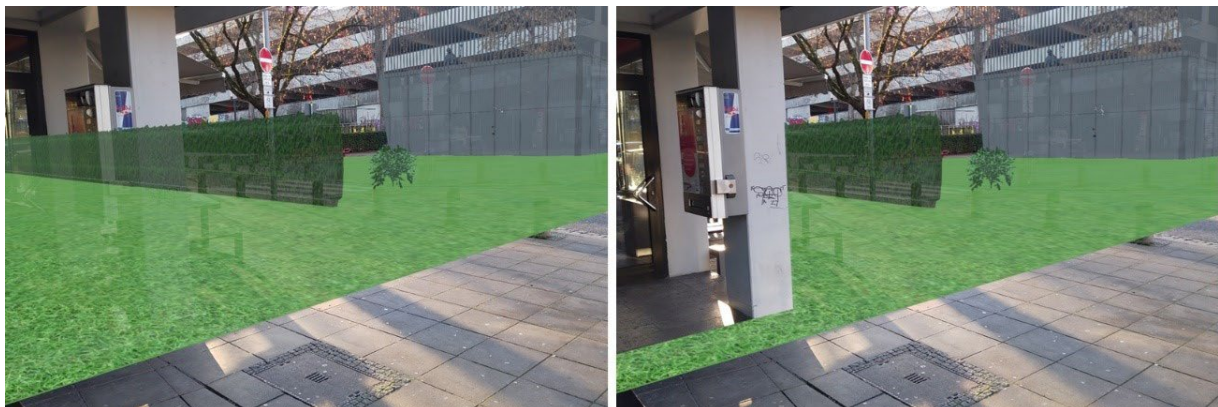


Figure 3. Occlusion screening based on the 3D building model. (left) Disabled. (right) Enabled.

The proposed method's performance was evaluated using the application's FPS. The greater the FPS, the less frequently the user blinks, which reduces stress (Tag et al., 2016). In low FPS rendering, judder can cause screen tearing when irregular frames are produced in the same view. During the test duration, the developed application was able to render at 60 FPS on average with 1-2 drop frames.

A live demo session as part of the mobility4iCity project was held in cloudy conditions to make up for the platform display's lack of brightness. After that, a questionnaire was used to obtain user opinions. The majority of respondents indicated they had adequate prior knowledge of AR in the first section of the survey. The participants were then asked about their impressions of the application as a whole. According to the majority of participants, the developed occlusion handler enhanced the immersion of the augmented reality experience.

Conclusion

This study proposed the use of a 3D city model to enrich the in-device scanned Spatial Map where the geometry of both was used as an occlusion mask. Achieving an immersive and representative experience by anchoring the digital objects to their true position in the real-world environment and hiding the augmented content when it is located behind a real object. The proposed method, wrapped in an application, is being used in the field of urban planning to enable the public to participate in the decision-making process, where feedback from the local community can be incorporated into the planning of future scenarios. Concerning assessing the proposed occlusion screening effect, a study was conducted on users from different backgrounds, where 14 users tested the application and evaluated the different occlusion options. Most of the participants reported that activating the occlusion option improved their depth perception and provided a more immersive experience.

References

- Open Geospatial Consortium. City Geography Markup Language (CityGML) Encoding Standard, version 2.0.0 (2012). <http://www.opengis.net/spec/citygml/2.0>.
- Fortin, P., & Hebert, P. (2006, June). Handling occlusions in real-time augmented reality: dealing with movable real and virtual objects. In *The 3rd Canadian Conference on Computer and Robot Vision (CRV'06)* (pp. 54-54). IEEE.
- Kasper, J., Edwardsson, M. P., & Romero, M. (2017, November). Occlusion in outdoor augmented reality using geospatial building data. In *Proceedings of the 23rd ACM symposium on virtual reality software and technology* (pp. 1-10).
- Tag, B., Shimizu, J., Zhang, C., Kunze, K., Ohta, N., & Sugiura, K. (2016, May). In the eye of the beholder: The impact of frame rate on human eye blink. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (pp. 2321-2327).

Immersive professional training for the textile industry

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Keywords: Immersive professional training, Virtual reality, Professional training

Introduction

Stäubli is a global supplier of mechatronic solutions, active in three distinct sectors: connection systems, robotics and textiles. Based on its experience, it wishes to continue to innovate its production processes by trying to integrate some of the new technologies of Industry 4.0. At the same time, Stäubli is focusing its efforts on training its operators in the assembly tasks of its industrial systems. In this context, Stäubli decided to redesign the training activity for the assembly of a doobby, which is a part of the weaving machines. The training is carried out in a practical way with an expert fitter who shows the 'right gestures' based on the job descriptions. Learning is done through a good practice approach. A completely new training course, using an immersive professional training (IPT), has therefore been designed. The aim of this article is to present this IPT.

State of the art

In the field of training and ergonomics, it has been accepted for many years that immersive technologies have a real interest (Arnaldi et al., 2018; Burkhardt, 2003). When applied to training, they allow for safe tasks, scenarios that cannot be reproduced in reality (accidents), simulation of rare scenarios and conditions (technical incidents, etc.), stressful situations, independence from time and other necessities (e.g. availability of facilities), and use of the same equipment for other training (Arnaldi et al., 2018). Expectations for the learner are, for example, to be able to experiment and evolve at their own pace, to self-assess and learn from their mistakes. The expectations for the trainer/teacher are to provide credible experiences, to record the learners'

activity (traces, performances), to be able to review / discuss / understand / replay the activity and to design his or her teaching application himself or herself (create virtual activities, choose scenarios or script the learning sessions). The potential applications are numerous, such as the acquisition of professional or technical gestures, training in complex systems and machines, training in safety procedures or professional activities through simulation, etc.

Presentation of the IPT for doobby assembly

Context

The training studied consists of learning how to make a part of the weaving machine called the doobby (see Figure 4). Its function is to drive the frames to form the shed (opening) and allow the interweaving of the threads as defined by the weave (weft weaving).



Figure 4. Doobby on the left and assembly station on the right.

The training is carried out in a companionship: an expert assembler will train a novice to make the doobby. The training lasts three weeks and deprives the production of resources such as a workstation and an expert assembler. During the first few days, the expert will show the trainee how to do the assembly. Afterwards, and until the end of the training, the trainee will carry out the assembly under the guidance of the assembler. The time required to assemble a machine is several hours, but at the beginning of the training course it takes about a day for the trainee to finish assembling a machine.

There are several issues related to training. The first is the cyclical demand for the textile sector: there are periods of low activity when there are few assemblers and then increases in activity which require qualified personnel to assemble the machines quickly. There is then a strong demand for hiring and therefore for training. As the training is not carried out by the same person, the training and its evaluation remain very subjective, which means that from one trainee to another, there is a risk of differences in the content or manner of carrying out the training.

Presentation of the IPT

The IPT was designed using a user-centred design process (Bisson et al., 2021). After an initial analysis of the needs of the sponsors of this training, we decided to spend only part of the training in virtual reality (VR) to avoid lengthy exercises. Thus, we decided that in parallel to the virtual training, there would always be the companionship with an expert assembler. To choose the most appropriate tasks to be carried out in immersive training, an analysis of the work and training was carried out through interviews and observations of the workstation. Two operations were selected: bevel gear assembly and synchronisation.

Exercise 1 consists of carrying out the adjustment of a bevel gear on the machine. A measurement between two parts is taken following the assembly. If this measurement is out of tolerance, then a component must be added or removed to adjust the clearance between the two parts. In general, the adjustment is good and does not require dismantling, so during a training course, a trainee will only dismantle the machine a few times to adjust the measurement (on average three times for about fifteen assembled machines). We propose to carry out this exercise in virtual reality so that trainees can practice the adjustment as many times as necessary until they know how to do it. There are several scenarios to vary the measurement between the two parts. Exercise 2 consists of synchronising the blades with a camshaft. The aim is to have the procedure repeated because most trainees do not understand the operation and therefore have difficulty remembering the actions to be performed.

In this IPT, the trainee will be able to find a work environment faithful to his workstation with his tools and a doobby being assembled. He will have to carry out approximately 150 interactions during the two exercises. The IPT also offers a mode incorporating multiple-choice questions (example of questions: Why should we use the tooling sprocket?). Two modes are possible for carrying out the exercises:

- A discovery mode: for each operation to be carried out, the trainee will be given assistance to indicate the tool to be used and its usefulness. A table will also indicate which action he must perform. This mode will help guide the trainee through the tasks they have to do and allow them to discover their "freedom" in the IPT (see figure 2).
- A training mode: once the operations and the IPT have been taken in hand, the trainee is no longer guided and must carry out the operations alone. They can ask for help if they get stuck.

What the trainee sees is transmitted to a computer for the trainer to observe. At the end of the exercise, the trainer will have access to the time taken by the trainee, the number of wrong answers (if the questions were activated), whether he has put on his protective equipment and adjusted the height of the virtual workstation.

The application runs on a computer coupled with an HTC Vive Pro headset. The user uses two joysticks to interact with the IPT. The main interaction is to be able to grab a tool with his virtual hand (see Figure 5). The trainee has to pick up a tool to bring it to the good location. Once the tool is in the good location, the associated operation is achieved automatically. Indeed, the objective is not to reproduce the gesture but to carry out the procedure in the right order. That is to say, if they don't do the right operation then they can't continue with the exercise. To finish the exercise, they must do the whole procedure. The scene is very close to their working environment to encourage immersion. The 3D model of the doobby comes from existing models in the company, in this case CAD models from the design studio.

The objective of the IPT, in addition to helping trainee in their learning, is to enable the company to rebalance the time spent mobilising the workstation and the trainer, formalise the knowledge to be passed on and its evaluation, raise awareness of the use of the tools made available, of good gestures and postures and of quality, and to evaluate the trainee and monitor his progress.



Figure 5. IPT on the left and user on the right.

Theoretical course of the training with the IPT

Theoretically, the training takes place over 3 weeks with alternating training sessions on the workstation with the expert assembler and sessions with the IPT. In the first week, the trainee spends all his time on the real workstation to give him time to familiarise himself with his working environment, the tools and the dobbie. In the second and third weeks, he alternates between companionship and virtual sessions on the model: a two-hour session every two days for two weeks, making six sessions in all. During the sessions, the trainee may perform the exercises once or several times. The first week the trainee will start in discovery mode and the second week he will do the exercises in training mode.

Conclusion

This paper presents an IPT for training operators in assembly tasks. It is currently being evaluated with trainees to assess its pedagogical relevance and usability.

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References

- Arnaldi, B., Guitton, P., & Moreau, G. (2018). *Réalité virtuelle et réalité augmentée: Mythes et réalités*. ISTE Group.
- Bisson, I., Mahdjoub, M., Zare, M., Bluntzer, J.-B., Goutaudier, F., Ravier, F., & Sagot, J.-C. (2021). *Cadre conceptuel appliqué à la conception de formation professionnelle immersive*, p. 17.
- Burkhardt, J. M. (2003). *Réalité virtuelle et ergonomie: quelques apports réciproques*. *Le travail humain*, 66(1), 65-91.

Full-body avatar representation for interior design evaluation experiences

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Keywords: Embodiment, Avatar, Sense of Presence, Animations, Design Evaluation, Human-Computer Interaction, Virtual Reality

Abstract

Virtual Reality systems can make users to feel fully immersed in virtual environments, with a high sense of presence (Slater, 2018; Sadowski et al. 2002; Singer et al. 1997). In VEs, they can only see virtual representations of their own body (avatars) yet having the sensation that each part of the virtual body corresponds to the parts of their real body (Slater et al. 2010). In general, the sensation to own a virtual body is commonly referred to as *sense of embodiment* (Kilteni. et al. 2012).

An immersive VR application has been developed by the VR Lab @ CIRA, the Italian Aerospace Research Centre, to carry out subjective tests of innovative design concepts for cabin interiors for both a business jet and a regional aircraft kinds of passenger aircrafts (Kaleja et al. 2017).

The users of the VR application were fully immersed in a highly realistic virtual environment which they could interact with through a scalable male/female avatar in order to evaluate in the most realistic way the prototypes to be tested (Guida et al. 2019, 2021).

Introduction

Many research works were carried out in order to demonstrate the applicability of the sensation of embodiment in different virtual reality field of application, such as health or entertainment. Anyway, it is still difficult to establish how the mechanisms of virtual embodiment could affect the effectiveness of these applications.

Embodiment describes the sensation, for the user of a Virtual Reality experience, that his/herself is placed inside a virtual body and he/she can control this body that belongs to him/her. More in detail, embodiment can be subdivided into three parts: the sense of presence,

the sense of agency, and the sense of body ownership. Presence, or self-location, describes the sensation of physically being in the virtual environment even if the user knows to not be really there (Schuemie et al. 2001). Agency refers to the sensation of managing the virtual body with one's own will (Clifton et al. 2020). Finally, body ownership offers the sensation that the virtual body represents the source of one's sensations (Argelaguet et al. 2016).

All these three aspects of embodiment have been considered for the realization of the Virtual Environment, developed within the CASTLE project framework (CAbin Systems design Toward passenger welLbEing), in which the subjective tests for the cabin interiors evaluation of innovative designs concepts of a future business jet and a regional aircraft have been carried out: the users, firstly, had to have the sensation to be really in the cabins of the aircrafts to be evaluated, secondly had to feel his body avatar respondent to his/her movements and finally had to interact and have feedback from his/her interaction during the execution of the assigned tasks.

The immersive VR application for subjective tests

The user assessment of comfort aspects of an aircraft passenger cabin requires the best lifelike rendering quality possible at immersive VR rates so the Virtual Interiors Immersive Simulator, was based on the game engine software Unreal Engine 4 (UE4), developed by Epic Games, that allowed to get a high-fidelity graphics experience achieved through the capabilities of setting all lighting parameters and materials characteristics and to manage fully rigged mannequins as well as most of commercial HMD and their controllers.

Thus, the Virtual Interiors Immersive Simulator offers a high-fidelity graphics experience considering real lighting parameters and materials characteristics. The immersive visualization, achieved through the new generation of head-mounted helmet (HMD), with high resolution displays and large Field of View ($120^{\circ} \div 180^{\circ}$ FOV), best fits to the immersive approach because it maximizes the sense of "being at the center of the virtual scene" for the user thanks to the whole coverage of its field of view by the graphic scene visualized.

The VR runtime application, even if conceived for real-time rendering for keeping up with interactive frame rates, offers to the users a quite good rendering quality with a high number of complex lights and expensive rendering effects, such as per pixel lighting, smooth shadows, mirrors, reflective surfaces (Figure 6).

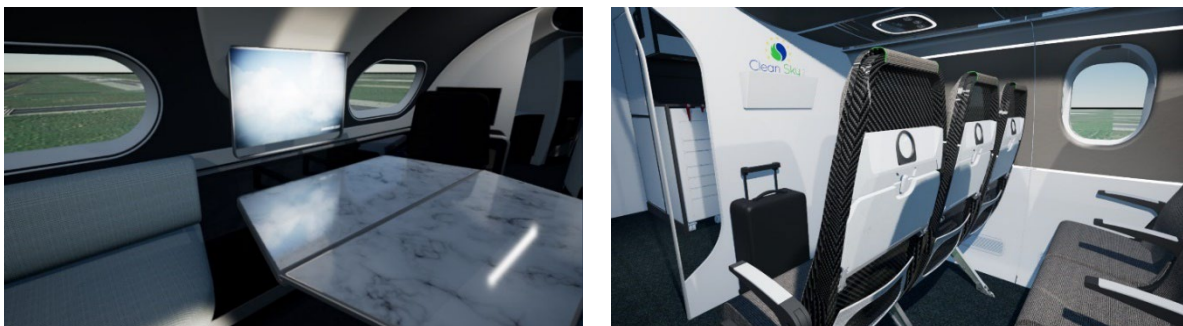


Figure 6. Examples of rendering quality of the Virtual Interiors immersive simulator.

The application employed CAD data supplied by the partners of CASTLE project. In particular, the models were sent to CIRA in STEP format for the 3D model part of the environment, while

images were passed aside as material textures along with a comprehensive document describing the mapping of materials to interiors surfaces.

The developed application allows a number of interactive mechanisms for switching between different material configurations, for manually interacting with objects in the environment by means of the hand controllers, for activating animations, and for quickly teleporting to other areas in the virtual cabin in order to freely moving within the whole cabin environment. The first contact force feedback gives to the virtual passenger the ability for testing reachability and usability of the features of the virtual objects to be tested all around him/her and the ability to perform habitability tests wrt. his/her own body size. (More et al. 2019; Mudliya et al. 2014).

Furthermore, an aircraft noise audio track was added into the virtual environment in order to increase the testers' sense of presence and the identification with the passenger role. For the regional aircraft, a seats row, kindly provided by the seat designer and manufacturer partner in the project (Figure 13, Figure 14), allows users to carry out the tasks in sitting position on a real aircraft seat corresponding to its virtual counterpart.

Full body avatar representation

An avatar for male and female people, sized at start-up with the user in standing position, allows the users to see their own body into the virtual environment (Figure 7). Other factors such as weight or skin color, that can increase the users' embodiment in that avatar, have not been considered since the user's attention would be mainly directed to the specific tasks to be performed.

The movement of the avatar's head, in terms of position and orientation (six degrees of freedom, 6-DoF) is connected to the virtual camera; the movement of the hands controls their virtual counterparts in the 3D scene. Furthermore, by only using head and hands HMD tracking data and the blending of predefined full body avatar animations, whole body movements are reproduced resembling user's actual ones with few tracking points (Figure 10).

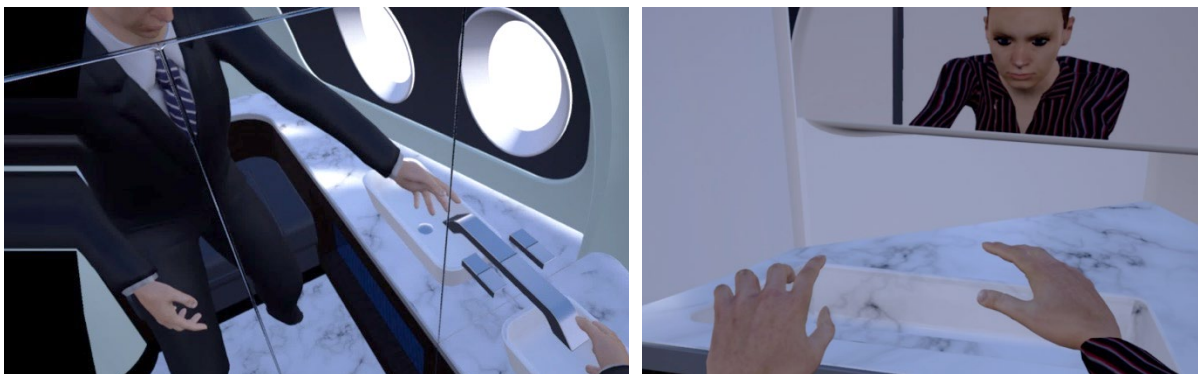


Figure 7. Lavatory mirrors reflecting male and female user's avatar mannequins.

Hand movements

The movement of the hands in the virtual space, including grasping and pointing the index, through the use of the two controllers supplied with the helmet, are transferred to their virtual counterparts in the 3D scene.

In particular, through the Blueprint scripting language provided by Unreal Engine, the two motion-controller trigger buttons are used to evaluate the amount of grasping of user's hands in order to set the blending value among the three grabbing poses of the virtual hand. In the same way, the two proximity sensors on the controllers are used to evaluate the extension of the user's indexes in order to set the blending value among the three pointing poses of the virtual hand (Figure 8).



Figure 8. Pointing and grabbing blended poses of the user's avatar mannequins.

A first-contact force feedback gives the passenger user the ability for testing reachability and usability of the features of the virtual objects to be tested all around him/her through a vibration that activates upon the contact between the parts of the body and the objects hit into the virtual environment.

Legs movements

The movements of the user's legs are not tracked so the position of their virtual counterparts is approximated through the height and the speed of the HMD reference system.

For each decrease of the height with respect to the user's tallness, there is an increasing amount of the squat pose towards the idle base pose. On the other hand, for each increase of speed, forward or backward, there is an increasing amount of the walking poses toward the idle base one. In this way, walking forward, backward or sideways, sitting, standing up and squatting are all movements that the virtual avatar can emulate and combine with the tracked movements of the virtual helmet (Figure 9).

Even if more complex movements of the legs, like go upstairs or elevate a single leg, are not included in the inference capabilities of the avatar, on the other hand it is possible to emulate a wide range of movements by using only the HMD reference position and nothing else with the undoubted advantage of not having to use more complex and invasive tracking systems to be worn by the user.

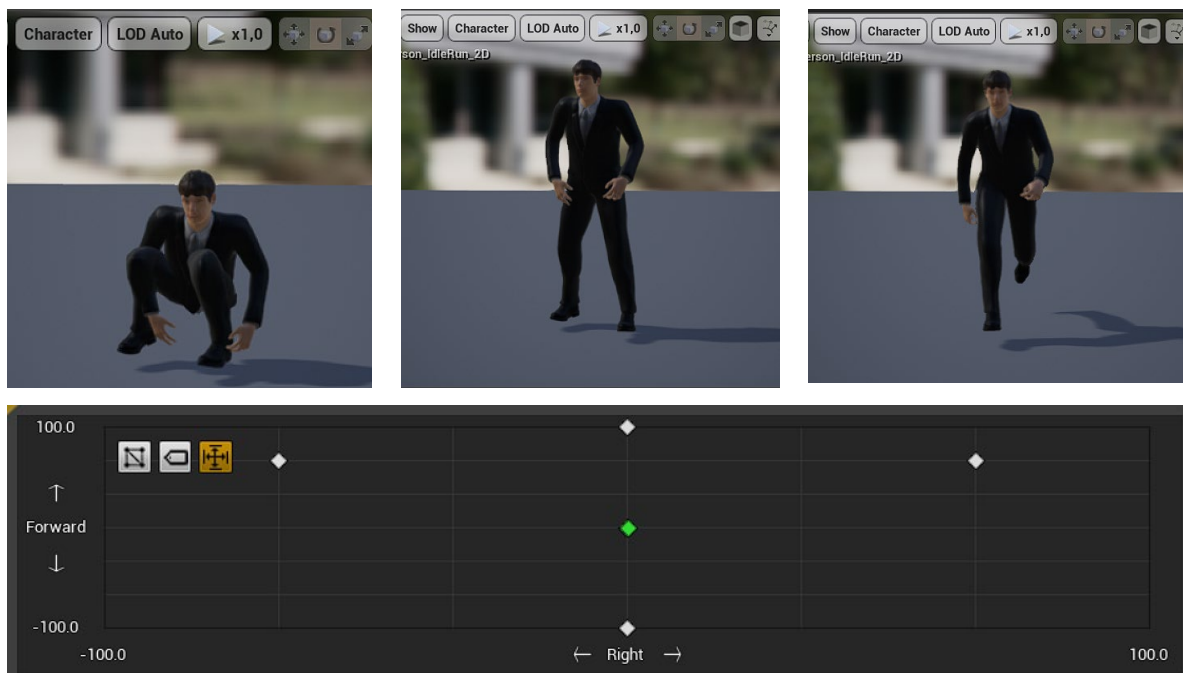


Figure 9. Walking forward/backward and left/right blended poses of the user's avatar mannequins.

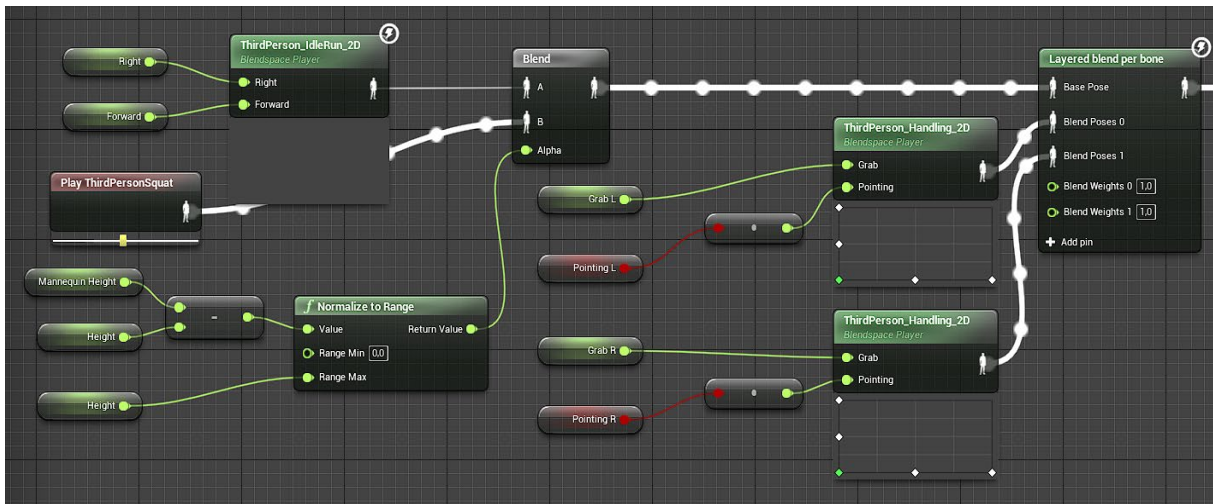


Figure 10. Blueprint scheme of the blending functions of the mannequin poses.

Physics-Based Manual Interaction

Physics simulations improves the immersion value of every virtual scene because it helps users believe that they are interacting with the simulation and that it is responding in a realistic way and thus empowers the virtual passenger to evaluate reachability and usability of the features of the virtual objects to be tested all around him/her.

All the movable object in the application are subjected to physics and are joined to the scene with realistic hinge mechanisms. The stowage bin, the cup holder and the tray table to be tested inside the regional aircraft as well as the notebooks, dishes, glasses, towels and cutlery to be tested in the relax zone of the business jet, all behave like their real counterparts.

Furthermore, even if there isn't any haptic response when the objects subject to physics are touched, a first contact force feedback, provided by the hand controllers vibration, gives to the users the capability to understand when the collision between his/her own hands and the virtual objects within the virtual world happen.

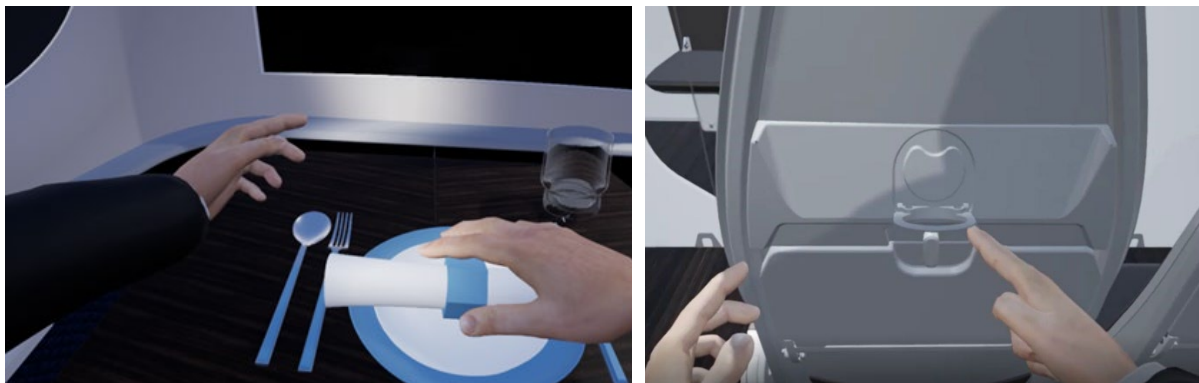


Figure 11. User interaction with physics based movable objects.

Testing Activity on the Concept Designs

The protocol followed for the human-in-the-loop subjective assessment of innovative design of business jet and regional aircraft interiors included two user questionnaires based on Likert five-points scales: the first one specific for the purposes of the core evaluation, the comfort aspects, the second one aiming at validating the user acceptance of VR, of the immersive approach, and of the VR application itself (Riva et al. 2007).

The two subjective test campaign made up of ~#25 testing subjects each involved people aged between 32 and 66 years with an average age of 47 years. The gender of participants was distributed between males and females with a prevalence of men. The heights were distributed from 160 cm to 195 cm with an average height of about 175 cm.

The questionnaires submitted after the test in immersive VR mainly concerned general design considerations on the proposed models as well as the ability to use arms and hands to do reachability tests, and to roughly measure spaciousness by relating to oneself avatar. In fact, the developed application allows the users to switch between different seat fabrics, turn on/off the internal lights (and adapt the intensity), move across a day range the sun light, but, above all, manually interact with a stowage bin, with a tray table and with a PSU (turning PSU light on/off) and manipulate physics objects.

In particular, the stowage bin can be opened by a lock/unlock system connected to his handle to be manipulated exactly as a real one (Figure 12) and more than 90% of the users agreed to consider it easy or very easy to reach/use.



Figure 12. Stowage Bin opening test (real/virtual user coupled view).

In the same way, the tray table can be overturned by rotating a pawl locking exactly as its real counterpart (Figure 13). Also in this case more than 90% of the users agreed to consider it easy to reach and to open/close. More than 75% at least agreed to consider the table adequate to eat/read/use the laptop even if more than 20% of them remained undecided.

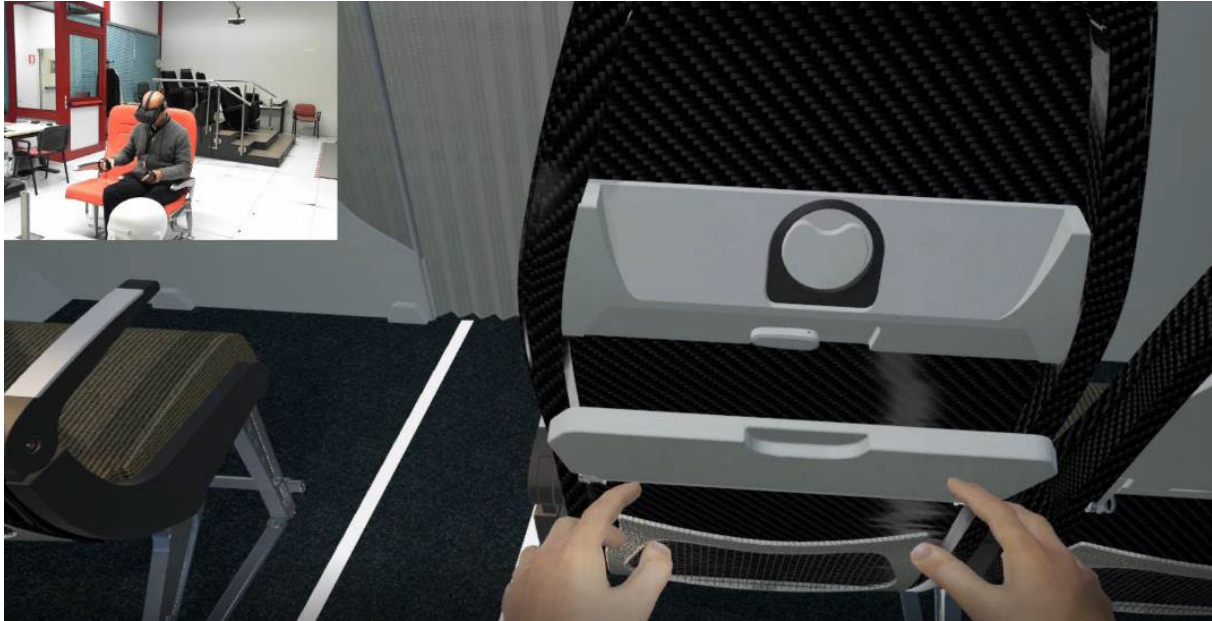


Figure 13. Tray Table opening test (real/virtual user coupled view).

As concern the evaluation of the accessibility and living space around the seats, a Blueprint automatic mechanism has been implemented in the application in order to lock the user's virtual body in sitting position when he has been asked to set on the real seat (Figure 14). Even if more than 80% agreed to consider sufficient the space for accessing the seat and the leg room, only 50% found the seat have enough space to stretch their own legs and almost 40%, especially taller people, remained undecided on the availability of space.



Figure 14. Accessibility and Living Space test (real/virtual user coupled view).

The manual interaction with unconstrained objects has been judged quite good by the users so that almost 80% of them have been able to simulate both simple dining operations and PC working tasks where required (Figure 15)

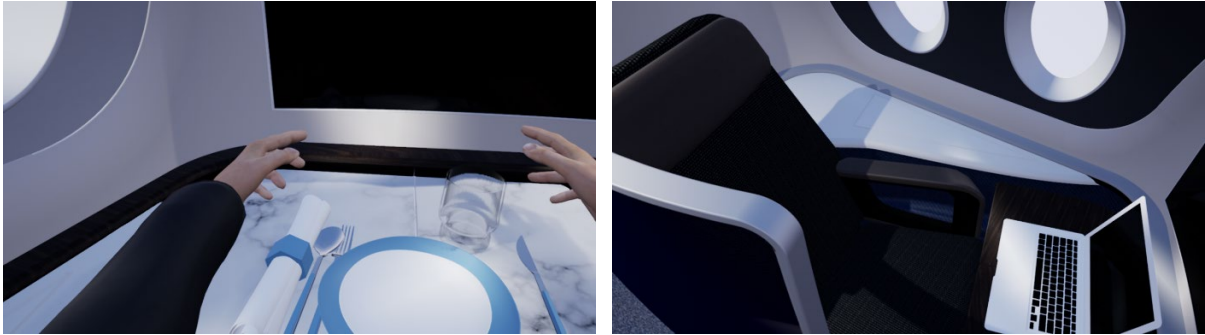


Figure 15. Physics based manual interaction with unconstrained object.

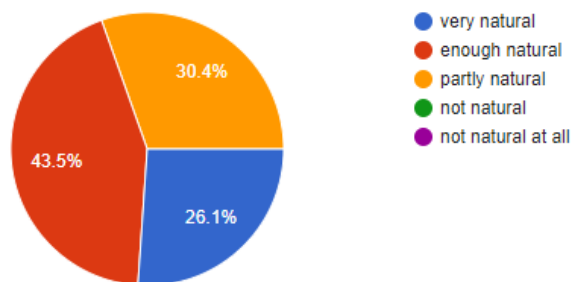
The Immersive VR Approach Evaluation

Subjective tests – i.e. tests done by humans by their senses as their own personal unchallengeable judgment, strongly depend on how each single tester actually perceive the submitted stimuli. In the case of comfort tests in an immersive virtual environment, test results are mostly dependent on how “good” is the virtual environment built to represent the design to give a rate. Stimuli are constituted by the 3D graphics rendered of the cabin environment to the HMD at interactive rate, by the interactions allowed to users within the cabin environment, and by the feedbacks the application has set up to alert the user.

The whole of the users, involved in the test campaign, were asked to evaluate the application used for the VR experience, and, in general, the immersive VR approach for the purposes of the tasks requested and finally they enjoyed, in general, the VR Experience.

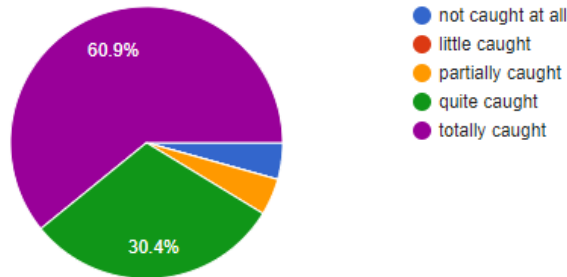
How natural the interactions with the environment seemed to you?

23 responses



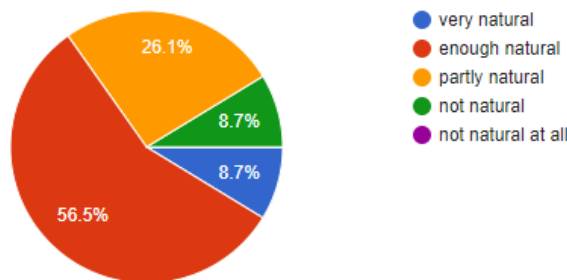
How much the visual aspects of the environment have caught your attention?

23 responses



How natural was the mechanism that controlled movements in the environment?

23 responses



How convincing was the feeling of the movement of objects in space?

23 responses

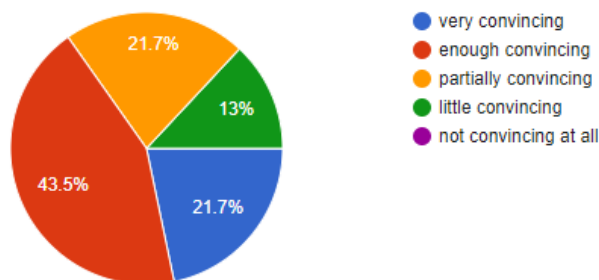


Figure 16. Some of the pie charts concerning the Virtual Reality users' experience assessment.

The Virtual Reality experience has been fascinating (charming), fine, good, and nice for all the participants, warm, active, predictable and funny for a large part of the audience, and almost not frightening or sad at all for all the users.

Almost 90% of the testers was able to control events. The environment responded to the actions nearly 95% of the testers have undertaken. Experiences done in the virtual environment have seemed quite conforming with those of the real world at least partly to whole of the users and enough to almost 90% of them.

About 90% of the users felt at least quite able to explore and actively inspect the environment with sight, as well as they felt the feeling of moving within the virtual environment very convincing, partially about 10% of them. More than 85% of them was very or quite able to carefully examine the objects in the virtual environment.

Three out of four testers adapted to the virtual environment experience at least quickly. 75% of the testers felt almost enough competent in moving and interacting with the virtual environment at the end of the experience and the percentage rises to over 95% if we consider also people who felt mediumly competent.

The quality of the head-mounted display interfered or distracted little three out of four testers during the performance of the assigned tasks or the activities required. Almost the whole of the users answered that the quality of the graphics rendering affected positively the execution of the assigned tasks or the required activities. On the other and, the interface devices (HMD, the connecting cable, hand controllers) have interfered little or very little with the execution of the assigned tasks or the required activities for 70% of the testers but much or very much for more than 10% of them.

The small tracked area limited, in more of 50% of the cases little or not at all and in the other cases partially or much, the performance of the required activities.

Three out of four testers have been able to concentrate much on the tasks assigned or on the tasks required rather than on the mechanisms used to perform these tasks or activities.

The users rated the Virtual Reality experience as a whole positive or very positive. Their performance in the Virtual Reality environment was satisfactory for more than 95% of the participants.

Among the sensory aspects of Virtual Reality that could be improved, most rated were:

- the perception of oneself
- the perception of touching objects
- sound/noise as manipulation feedback
- the congruence between the movement of objects and the sound associated with it

Practical aspects of Virtual Reality tested that could be most improved by the testers' opinion:

- the HMD comfort
- the hand controller comfort
- the tracked area
- the area where the VR experience has been held

Most of them could actually reproduce in real the operations performed in Virtual Reality.

Almost all of the testers could explore the environment by moving with their head, while a total of almost 80% could actually explore the environment by moving with their whole body. The large majority of them felt comfortable in the virtual environment.

During the Virtual Reality experience, as well as at the end of the Virtual Reality experience they felt:

- very little disoriented
- little or normally excited
- little or very little troubled
- very little indifferent
- much or normally happy
- very little embarrassed
- normally or much satisfied
- little or very little frustrated
- very little or normally relieved
- very little disappointed

During and at the end of the Virtual Reality experience, they have experienced very little of all these sensations: nausea, disgust, stress, dizziness, tension, anxiety, boredom (being annoyed), while at the end they zeroed almost all these negative sensations.

As to users' opinion, performance that can be obtained in Virtual Reality mostly depends on the functionality of a Virtual Reality application and on technological capabilities of Virtual Reality rather on individual skills or person's mood.

About 90% of the interviewed think it is possible to make a visual quality assessment in Virtual Reality and that it is possible to carry out an assessment of the reachability of commands and accessibility of objects.

Thus, by concluding, the comprehensive additional questionnaire has pointed out that both immersive VR and the specific VR application have largely passed the acceptability threshold to be considered reliable for the task of the subjective tests proposed.

Conclusion and future works

For our VR research lab, the presented application has been the first opportunity to test the use of ray tracing in a pre-production industrial application leveraging the newest NVIDIA GeForce RTX 3090 graphics card. The support of hardware-accelerated ray tracing from the 4.26 version of Unreal Engine allows us to generate virtual environments more and more realistic in which the user can feel always more immersed.

We look forward to evolve future projects of this kind to a multisensory VE, in which the testing passenger feels more and more immersed in a lifelike cabin environment. Additional sensory feedback to feed a user in order to contribute to identify oneself with the impersonating role may include temperature, humidity, and air flows, airline brand smells, more audio feedbacks for whatever happened in the cabin, tactile and grasping force feedback for ergonomics evaluations, rumble feedbacks to key parts of the user body bumping to environment (e.g. knees bumping into the front seat when seated and getting up), and populating the cabin with realistically moving autonomous virtual passengers.

Finally, whilst subjective, confronting their own sensations with the one of others in a collaborative virtual environment, thus actually helping each other in forming one's own opinion may surely improve the robustness of the process quality of the assessments, aside from definitely making the joint testing experience fun.

Acknowledgement

The work has been done within the AIRFRAME ITD. Grant Agreement n° CS2-AIR-GAM-2014-2015-01, aiming at delivering cabin interiors design of future regional aircraft that maximize the wellbeing of passengers, including Persons with Reduced Mobility (PRM) and crew, considering the travelling needs and requirements that are foreseen in the future of air transportation. The cabin configuration requirements, target and constraints have been provided by Leonardo – Aircraft Division in accordance with cabin layout of passenger accommodation (Leonardo proprietary) of the Clean Sky 2 Regional Aircraft Conventional Demonstration Platform.

References

- Argelaguet, F., Hoyet, L., Trico, M., & Lécuyer, A. (2016, March). The role of interaction in virtual embodiment: Effects of the virtual hand representation. In 2016 IEEE virtual reality (VR) (pp. 3-10). IEEE.
- Clifton, J., & Palmisano, S. (2020). Effects of steering locomotion and teleporting on cybersickness and presence in HMD-based virtual reality. *Virtual Reality*, 24, 453–468.
- Guida, M., & Leoncini, P. (2019). Comfort Assessment of Aircraft Interiors in an Immersive Virtual Environment. Italian Association of Aeronautics and Astronautics XXV International Congress, Rome, Italy
- Guida, M., & Leoncini, P. (2021). Regional Aircraft Interiors Evaluation in a Real Time Ray-Traced Immersive Virtual Environment. Salento AVR2021 International Congress, Otranto (LE), Italy. AVR 2021, LNCS 12980, pp. 483–498. https://doi.org/10.1007/978-3-030-87595-4_35
- Kaleja, P., & Kozlovská, M. (2017). Virtual Reality as Innovative Approach to the Interior Designing. *Journal of Civil Engineering*, 12, 109-116.
- Kilteni, K., Groten, R., & Slater, M. (2012). The sense of embodiment in virtual reality. *Presence* 21, 373–387.
- More, S., Wagh, T., & Suryawanshi, Y. (2019). Virtual Reality of Interior Architecture. *International Journal of Advanced Research, Ideas and Innovations in Technology*, 5, 1443-1445.
- Mudliyar, P., Ingale, Y., Bhalerao, S., & Jagtap, O. (2014). Virtual Reality for Interior Design. *International Journal of Research in Advent Technology*, 2, 260-263.
- Riva, G., Mantovani, F., Capideville, C. S., Preziosa, A., Morganti, F., Villani, D., ... & Alcañiz, M. (2007). Affective interactions using virtual reality: the link between presence and emotions. *Cyberpsychology & behavior*, 10(1), 45-56.
- Sadowski, W., & Stanney, K. (2002). Presence in virtual environments. In *Handbook of virtual environments*, CRC Press, 831-846.
- Schuemie, M. J., Van Der Straaten, P., Krijn, M., & Van Der Mast, C. A. (2001). Research on presence in virtual reality: a survey. *Cyberpsychol. Behav.* 4, 183–201.

- Singer, M.J., & Witmer B.G. (1997). Presence: where are we now? In M. Smith, G. Salvendy, R. Koubek (eds.), *Design of Computing Systems: Social and Ergonomic Considerations*, Elsevier, Amsterdam, 885-888.
- Slater, M. (2018). Immersion and the illusion of presence in virtual reality. *British Journal of Psychology* 109, 431–433. <https://doi.org/10.1111/bjop.12305>
- Slater, M., Spanlang, B., Sanchez-Vives, M. V., & Blanke, O. (2010). First person experience of body transfer in virtual reality. *PloS one*, 5(5), e10564-e10564. <https://doi.org/10.1371/journal.pone.0010564>

Development, Deployment and Evaluation of Augmented Reality Maintenance Support Applications

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Keywords: Augmented Reality, Maintenance, Service, Machine Control, Evaluation, Assessment

The development of Augmented Reality (AR) applications for maintenance support is most often limited to lab environments in research or in case of commercial developments, not published outside of press releases. Here, the development of two AR applications supporting maintenance in industrial production companies is described starting from the requirements analysis, over the applications development up to the results of the 14-month field evaluation period.

Introduction

One key application area of Augmented Reality (AR) is the support of maintenance activities through step-by-step instructions using superimposed 3D-models, texts, pictures, videos and even machine control data (Gattullo et al., 2020; Kollatsch et al., 2017; Lorenz et al., 2021). Further, AR remote support applications have been widely researched and applied in the context of maintenance (Palmarini et al., 2018). However, in the research domain, tasks for testing such AR support systems are almost entirely evaluated under lab conditions and the development of commercial solutions is not published asides from press releases.

In the Horizon2020 project PreCoM (Predictive Cognitive Maintenance Decision Support System) we developed two AR maintenance support application from scratch in collaboration with three industrial production companies. These applications were then deployed and evaluated on the shop floor during a 14-month period. The industrial use cases in the production companies consisted of a paper tissue machine, a largescale milling machine for wind power plant hubs and

grinding machines for high precision gears. In the following section, we will describe the initial requirement analysis, the capacities of the developed AR applications and the evaluation results.

Requirement Analysis

As described in more detail in Lorenz et al. (2018) we started the development process with on-site workshops where the workers and maintenance engineers were interviewed and observed whilst carrying out maintenance activities. Aside from technical and user requirements, we also focused on the environmental and regulative aspects on the shop floor, which is crucial but often neglected in other works. In the case of the three industrial manufacturers, the workers needed to wear protection gear, the air contained oil or tissue dust, electromagnetic fields were present and spilled liquids could occur. In terms of technical requirements, the most important requirements were battery capacity of at least 4 h as well as connectivity to live machine data and data storage systems. The most important user requirements were the need for step-by-step instructions consisting of superimposed 3D-models, texts, pictures and videos as well as the access to live-machine data and pdf documents. Further, documentation functionalities should be included for taking annotated pictures and videos. The need for an easy to handle authoring system for creating and maintaining the step-by-step instructions was emphasized. Lastly, a video conferencing system with annotation capabilities was requested.

AR Maintenance Support Applications

The environmental and regulative requirement alone demanded rugged tablets as hardware devices for running the AR applications, as other equipment is not robust enough or, in case of rugged projectors, too spacy and cumbersome to move. Software wise two applications were developed (see Figure 17): AR Guidance System including an authoring application; AR Remote Service System (Kim et al., 2020). The AR Guidance System was designed to provide step-by-step instructions using superimposed 3D-models, texts, pictures and videos as well as the access to live-machine data and pdf documents. An authoring system allows workers and maintenance engineers to create and maintain the instructions themselves, which includes the positioning of 3D-Models via a 3D-content editor containing more than 80 3D models Lorenz et al., 2020). The integration of live machine and sensor data was achieved by using middleware boxes (Savvy Data Systems S.L., San Sebastián, Spain) which were installed at all relevant machines of the industrial production companies. As the number of available parameters ranged from 791 to 1247 per machine, a selection and categorization process had to be undergone. This process and the technical implementation are described in detail in (Lorenz et al., 2021). The AR Remote Service System enables the workers to have video conferences with colleagues or staff from their machine suppliers. It allows superimposing 3D-Models and texts, exchanging documents as well as pausing and rewinding the last 20 seconds of the video stream. Both AR systems further have documentation functionalities integrated, allowing to capture the screen in form of pictures and videos. Those can be used in the step-by-step instructions or for other maintenance processes.

The user interface (UI) design for both AR maintenance support applications started with hand drawn wireframing tasks (Ramón et al., 2013) and ultimately led to complete mock-up prototypes created with Figma Design (www.figma.com). The UI designs were iteratively assessed by the workers of the companies, to ensure compliance with their demands. A more detailed description of the UI design process is provided in Kim et al (2020).

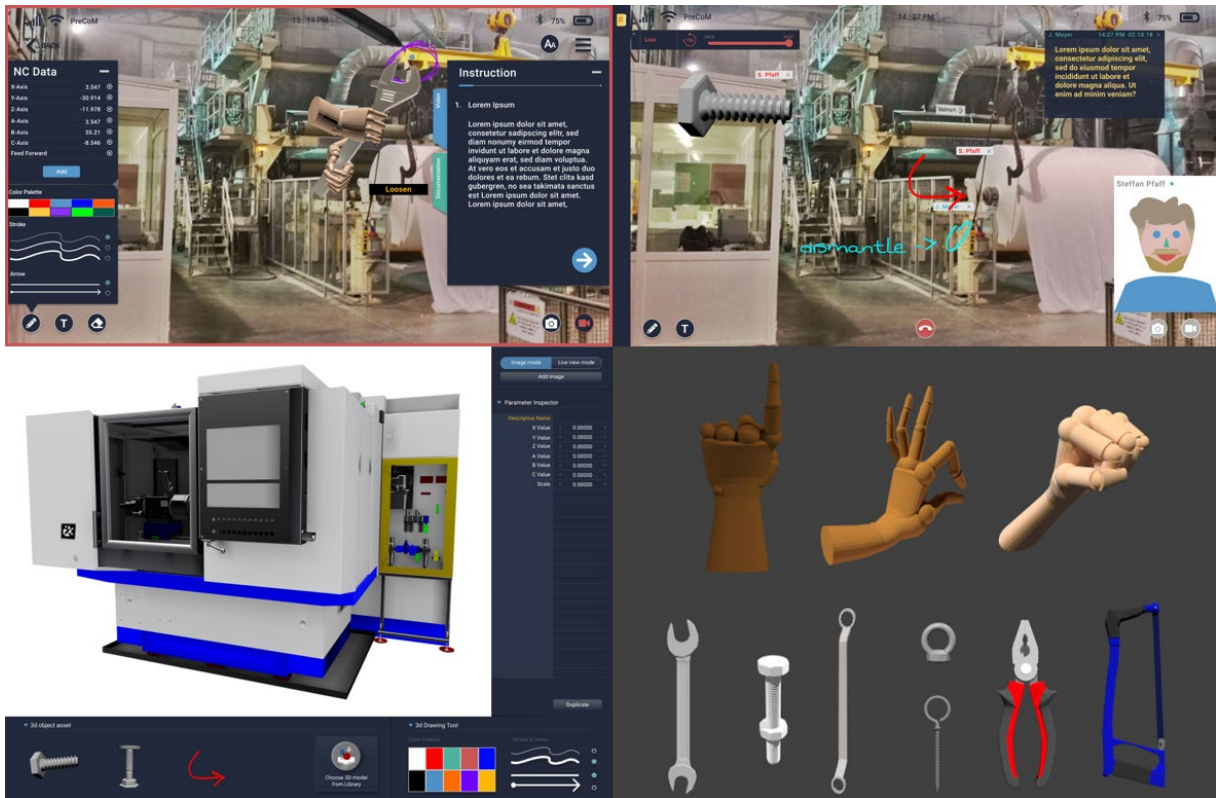


Figure 17: Top left: AR Guidance System demonstration (Kim et al., 2020); Top right: AR Remote Service System demonstration (Kim et al., 2020); Bottom left: AR Object Editor (Lorenz et al., 2020), Bottom right: Examples from 3D-model catalogue.

Deployment and Evaluation

Both AR applications were tested during a 14-month period at all three companies. For each company one or two step-by-step instructions were created for medium to high complex tasks that were carried out by their maintenance staff at least once during the evaluation period. Further, key users from the companies and their important machine suppliers were equipped with installations of the AR Remote Service System. The AR tools were deployed during 3-day on-site workshops at each companies' premises. Most of that time was needed for the technical setup whilst the worker training for both AR application only lasted 1-2 hours.

The assessment foresaw regular interviews with workers as well as answering of online questionnaires regarding the user experience of the AR applications. At the end of the evaluation period, we could prove improvements in task efficiency and reductions in errors due to the step-by-step instructions at all companies. The AR Remote Service System was not successful as the workers were already using WhatsApp or Skype as video conferencing tools. The user experience of our AR applications and its additional functionalities could not motivate the workers to change their used tools. The four most important insights we gained were however (1) that AR is not just another tool but rather triggered a changed in how the maintenance processes were organized. (2) Introduction of AR support must cover all task where it is meaningful, as it changes the work organization. A situation where some tasks are carried out with AR support and some without, leads to more stress for the workers. (3) AR support needs to be carefully introduced as many easy tasks, like oil level checking simply do not need such a sophisticated support. Further, there are workers who are so skilled that they also do not need guidance. (4) Introducing tablets to the shop floor let to collateral benefits totally unrelated to AR, as the workers were able to look up

information on-site and write Emails. A more detailed description of the assessment results are given in Lorenz et al. (2022).

Conclusion

We have shown that the usage of industrial AR must start with a rigorous requirements analysis that also considers environmental and regulative requirements aside from technical and user ones. However, defining for the successful deployment of AR support for maintenance applications is that AR is not considered as a further tool but rather as a change in the organization of maintenance processes. It must therefore be accompanied by an analysis of maintenance processes and be seen as a long-term activity.

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References

- Gattullo, M., Evangelista, A., Uva, A.E., Fiorentino, M. et al., 2020. What, How, and Why are Visual Assets used in Industrial Augmented Reality? A Systematic Review and Classification in Maintenance, Assembly, and Training (from 1997 to 2019). *IEEE Trans Vis Comput Graph*.
- Kim, J., Lorenz, M., Knopp, S., Klimant, P., 2020. Industrial Augmented Reality: Concepts and User Interface Designs for Augmented Reality Maintenance Worker Support Systems, in 2020 IEEE ISMAR, IEEE, p. 67.
- Kollatsch, C., Schumann, M., Klimant, P., Lorenz, M., 2017. [POSTER] Industrial Augmented Reality: Transferring a Numerical Control Connected Augmented Reality System from Marketing to Maintenance, in 2017 IEEE ISMAR, IEEE, p. 39.
- Lorenz, M., Knopp, S., Klimant, P., 2018. Industrial Augmented Reality: Requirements for an Augmented Reality Maintenance Worker Support System, in 2018 IEEE ISMAR, IEEE, p. 151.
- Lorenz, M., Knopp, S., Kim, J., Klimant, P., 2020. Industrial Augmented Reality: 3D-Content Editor for Augmented Reality Maintenance Worker Support System, in 2020 IEEE ISMAR, IEEE, p. 203.
- Lorenz, M., Shandilya, S., Knopp, S., Klimant, P., 2021. Industrial Augmented Reality: Connecting Machine-, NC- and Sensor-Data to an AR Maintenance Support System, in 2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), IEEE, p. 595.
- Lorenz, M., Knopp, S., Brade, J., Klimant, P., 2022. Industrial Augmented Reality: Lessons learned from a long-term On-site Assessment of Augmented Reality Maintenance Worker Support Systems. (under Review for ISMAR 22)
- Palmarini, R., Erkoyuncu, J.A., Roy, R., Torabmostaedi, H., 2018. A systematic review of augmented reality applications in maintenance 49, p. 215.
- Ramón, O.S., Molina, J.G., Cuadrado, J.S., Venderdonckt, J., 2013. GUI Generation from Wireframes, in 14th Int. Conference on Human-Computer Interaction Interaccion'2013.

User centered interaction & environment design for large scale virtual training environments (VTE)

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Keywords: Virtual training environments, VTE, virtual training, VR, XR, requirements, engineer training, UCD, interaction design, environment design, interaction fidelity, display fidelity, digital twin.

While virtual training environments (VTE) for engineering become more common, there is little in-depth discussion about challenges in VTE interaction and environment design, especially for large scale environments. We describe best practices for the design of large scale VTE for engineers on offshore wind turbines that we optimized in a user centered design (UCD) process over the course of three years. Additionally, we discuss criteria for usefulness in VTE design for engineer trainings, including interaction and display fidelity.



Introduction

For a long-term research project on the usability of virtual trainings for engineers on offshore wind turbines, we built three large scale VTE over the course of three years: a first contact scenario,

an emergency scenario, and a repair scenario. The VTE included several hundred interaction steps and numerous interaction zones, set on two different wind turbine types (see: Figure 1). During the ongoing, user centered design (UCD) process, questions of best practices and quality criteria for interaction and environment design became salient, as realism and high fidelity are time-consuming to build and need to be balanced against the rendering and financial budget. Additionally, we found that building VTE for practitioners such as engineers requires a specific mix of grounded “realness” of simulation and day-to-day usefulness of the application to increase user acceptance.

Research Context

Both Schwarz et al. and Lawson et al. state that process-related challenges in VTE design remain largely unexplored (Schwarz et al., 2020; Lawson et al., 2016). In their study on VTE for automotive assembly Schwarz et al. stress the need for a user centered design process (UCD) that involves engineers, trainers, and trainees, to build a system based on a comprehensive understanding of user requirements, and to increase user acceptance. They found that virtual trainings increase sequence learning of interaction steps. But after interviews with trainers, they concluded that simply clicking objects into position in a predefined order is not sufficient for learning a mechanical task, and that a virtual reproduction of detailed sub-steps with (pseudo)haptic simulation are needed (Schwarz et al., 2020).

Rogers et al. (2019) discuss general questions of interaction fidelity (IF) and display fidelity (DF) in virtual environments. They found that interaction fidelity increases task-oriented user experience (Rogers et al., 2019), while Nathanael et al. state that a VTE has to be as realistic as possible to be able to transfer trained skills from virtual to real interaction (Nathanael et al., 2016). Regarding visual fidelity, including surface detail and lighting realism, Rogers et al. observed that it increases immersion and presence (Rogers et al., 2019). These findings support earlier results by Yu et al. (2012), and Simeone et al. demonstrated that high surface and light fidelity increase material disambiguation and influences user trajectory (Simeone et al., 2017).

Methods: User Centered Design Process (UCD)

In the early pre-production phase for each scenario, we received descriptions and documents of training scenarios in different levels of detail, photos and partial CAD data or laser scan data. These were supplemented in constant communication with the engineers, mainly between one contact person each on the engineer side and on the VTE side. The communication continued until the end of the project. In irregular intervals, we conducted tests of the prototypes combined with qualitative interviews with users i.e., engineers, trainers, and trainees, to collect feedback that we implemented iteratively. Additionally, we conducted in-depth qualitative interviews with a larger trainer group, to learn more about didactic needs and requirements. We also conducted a context analysis at the training facility and collected behavioral observation data. A detailed analysis of the training scenarios, communications and interviews provided us with information about the types of training goals, mainly spatial orientation, sequence learning, or group cooperation (Meyer et al., 2021).

Results and discussion: Best Practices

Our interviews with engineers revealed their high degree of attention to the precision of the VTE of their daily workplace, and also their high degree of computer game affinity. Together, this resulted in their relatively high expectations for both interaction and environment fidelity, and realism. Our results support earlier findings about the usefulness of interaction and display fidelity for user acceptance and learning (Rogers et al., 2019; Nathanael et al., 2016; Yu et al., 2012; Simeone et al., 2017). For a discussion of the design of extradiegetic elements such as UI, gamifications, tutorials, and of venue design see Meyer et al. (2021).

Interaction fidelity

The foundation for a useful VTE is a detailed sequence analysis to identify the central interaction steps – which proved to be not an easy task, especially with large scale scenarios (Schwarz et al., 2020). We found that training documents are missing steps, and that engineers do not always remember repetitive movements correctly (“Do I turn the switch left or right?”). An in-depth analysis often showed that a single step consisted of several sub-steps, which bloated scenarios, in one case from ca. 30 to more than 120 interaction steps. Only after the complete chain of steps and sub-steps, including dependencies, was established, we could, in communication with the engineers, identify unnecessary steps and edit or simplify them. This process was central to avoid unrealistic “clicking-into-position” interactions, but also to balance time fidelity and interaction depth against cost. It could take up about 50% of the full production time. The edited step sequence formed the basis for all other design decisions, including degree of naturalness, object hierarchies, extension of static environments, movement types, and so on. Designing the scenarios and interaction objects from the interaction steps kept them scalable and adaptable to changes.

To increase spatial learning and muscle memory, and to allow easy adaption, we decided for a high degree of naturalism of hand interactions, including finger tracking, and for a hybrid movement system which combined physical movement with teleports over longer distances to avoid simulator sickness. For the same reason, we used natural feedback where possible e.g., forgetting to use a carabiner during a safety protocol resulted in falling. Due to their computer game affinity, the engineers demanded sound early on. We used spatial sound for orientation and feedback, and interaction sounds to simulate the missing force feedback of virtual objects.

Environment/display fidelity

We designed and edited the environments from the inside out i.e., from the interaction steps and interaction objects, which allowed us to build very precise object hierarchies for the interactions. That way we could also define dense interaction zones and build them with higher level of detail to simulate an overall higher display fidelity. As engineers know their wind turbine very well, and as spatial orientation tasks and body learning of movements in a narrow, packed environment were part of the training, a precise, digital twin-like environment became necessary (Slater, 2017). Finally, in such an environment with electricity, hydraulics and other potential danger zones, material disambiguation by way of high-fidelity materials for conductors and non-conductors, with real-time lighting and reflections was vital. Lighting, textures, and animations were also used to direct attention.

Conclusion

We discussed user requirements and best practices for designing large-scale VTE for engineers that we optimized over the course of a three-year research project with user centered design. Central for the perceived usefulness of the VTE was a precise sequence analysis and editing of interaction steps and dependencies, resulting in relatively high interaction fidelity and naturalness. The required degree of precision can be time consuming and needs constant communication between all participants to succeed, but results in high user acceptance. Due to their technological expertise and their computer game affinity, the engineers and trainees had high expectation on environment and display fidelity, including sound. Material disambiguation and movement training in high risk, confined spaces demanded relatively high environment, surface, and lighting fidelity.

Acknowledgment

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References

- Gavish, N., Gutiérrez, T., Webel, S., Rodríguez, J., Peveri, M., Bockholt, U., & Tecchia, F. (2015). Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks. *Interactive Learning Environments*, 23, 778–798.
- Górski, F., Zawadzki, P., Buń, P., & Starzyńska, B. (2018). Virtual Reality Training of Hard and Soft Skills in Production. *Proceedings of the 23rd International ACM Conference on 3D Web Technology* (pp. 33:1–33:2). New York, NY, USA: ACM. <https://doi.org/10.1145/3208806.3219787>
- Grabowski, A., & Jankowski, J. (2015). Virtual reality-based pilot training for underground coal miners. *Safety science*, 72, 310–314.
- Hafsia, M., Monacelli, E., & Martin, H. (2018). Virtual Reality Simulator for Construction Workers. *Proceedings of the Virtual Reality International Conference - Laval Virtual* (pp. 11:1–11:7). New York, NY, USA: ACM. <https://doi.org/10.1145/3234253.3234298>
- Lawson, G., Salanitri, D., & Waterfield, B. (2016). Future directions for the development of virtual reality within an automotive manufacturer. *Applied ergonomics*, 53, 323–330.
- Meyer, U., Becker, J., Mueller, T., Jeworutzki, A., Draheim, S., & von Luck, K. (2021). Asymmetrical Game Design Approaches Solve Didactic Problems in VR Engineer Trainings. *2021 7th International Conference of the Immersive Learning Research Network (iLRN)*, (pp. 1-5). <https://doi.org/10.23919/iLRN52045.2021.9459385>.
- Nathanael, D., Mosialos, S., & Vosniakos, G.-C. (2016). Development and evaluation of a virtual training environment for on-line robot programming. *International Journal of Industrial Ergonomics*, 53, 274–283.
- Petkov, E., & Angelov, V. (2020). Virtual Reality Training System for Specialists Who Operate on High-Voltage Switchgears in an Oil Plant in Russia. In *Proceedings of the 21st International Conference on Computer Systems and Technologies '20* (pp. 266–269). New York, NY, USA: Association for Computing Machinery. Retrieved from <https://doi.org/10.1145/3407982.3408003>

- Rogers, K., Funke, J., Frommel, J., Stamm, S., & Weber, M. (2019, May). Exploring Interaction Fidelity in Virtual Reality. Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. ACM. <https://doi.org/10.1145/3290605.3300644>
- Schwarz, S., Regal, G., Kempf, M., & Schatz, R. (2020). Learning Success in Immersive Virtual Reality Training Environments: Practical Evidence from Automotive Assembly. Proceedings of the 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society, pp. 1–11.
- Someone, A. L., Mavridou, I., & Powell, W. (2017, April). Altering User Movement Behaviour in Virtual Environments. IEEE Transactions on Visualization and Computer Graphics, 23, 1312–1321. <https://doi.org/10.1109/TVCG.2017.2657038>
- Slater, M. (2017). Implicit learning through embodiment in immersive virtual reality. In Virtual, augmented, and mixed realities in education. Springer, pp. 19–33.
- Yu, I., Mortensen, J., Khanna, P., Spanlang, B., & Slater, M. (2012, November). Visual Realism Enhances Realistic Response in an Immersive Virtual Environment - Part 2. IEEE Computer Graphics and Applications, 32, 36–45. <https://doi.org/10.1109/mcg.2012.121>

Daylighting simulation in virtual reality for architecture

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Keywords: Virtual Reality, HMD, natural lightning simulation, architecture, simulator

Introduction

Daylight in architecture can be studied in different ways: by in situ measurements inside a real building, by simulations on 3D digital data or by analyses and measurements under a physical daylight simulator on physical models. The National School of Architecture of Strasbourg (ENSAS) offers students a process of exploration and experimentation to study, predict and control lighting environments. For this purpose, it has set up the Light Laboratory¹, which includes two installations used to carry out simulations on architectural models: a "mirror box" for a quantitative approach and a mechanical sun-artificial sky simulator for a qualitative approach. We wanted to offer students a virtual reality tool that would allow them to carry out the same educational exercises carried out on digital models. To do this, we transposed all the functionalities implemented in the simulator onto physical models and set up all the parameters that would allow us to offer a comparable qualitative simulation.

¹ Light Laboratory: <https://www.strasbourg.archi.fr/en/school/strategy-and-development/espaces-de-travail/light-laboratory>

The sun-sky simulator on physical architectural models

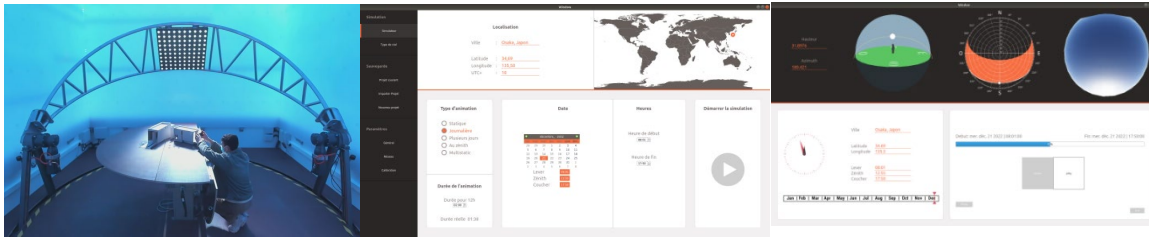


Figure 18: A student and his model in the sun-sky simulator and the simulation parameterization interfaces

The simulator is installed in a square base structure measuring 5m x 5m and 3.5m high². The sky is made up of 7000 controllable LED light sources distributed on the walls and ceiling behind diffusing panels (Blandet et al., 2019; Erbilgin et al., 2020). A mechanical sun that moves around the model reproduces the apparent path of the sun in the sky. As in the real world, the colour and intensity of the sun and the image of the sky change during a simulation that typically lasts 3 minutes. The students place their model on an experimental platform in the centre of the installation and define the parameters of the simulation: geographical location, day, duration of the experiment, sky model. During the simulation an interface shows the evolution of the image of the sky and the sun on a solar diagram (Figure 18). Cameras placed inside and outside the model record videos and images of the simulation.

From the physical model to the digital model

The digital models are made using SketchUp and then reworked in Blender, to correct any mesh problems. The models are used in the virtual reality environment we developed with Unreal Engine. We use version 5 of the game engine and its new dynamic global illumination engine: Lumen Unreal Engine 5³. We want to be able to produce simulations comparable to those on physical models. To do this, we need to work on the materials and their reaction to light in order to approach the real materials or those used for the physical models. In addition, virtual reality will allow us to carry out project reviews, visit the digital model, and produce indoor and outdoor daylighting simulations. For more realism in the simulations, we can add plants and avatars that will bring the models to life. Visualisation and interaction is done using HTC Vive or Oculus Quest virtual reality headsets.

Setting up the virtual model

In the virtual reality application, access to the various functionalities is via menus that appear generally on the back of the left hand. The main menu is a Ccube-type pop-up menu (Grosjean et al., 2002) which has three levels, each allowing entries to 9 (3x3) menus (Figure 19).

² Lighting simulators: https://igg.icube.unistra.fr/index.php/Simulateurs_d'%C3%A9clairage

³ Unreal Engine 5: <https://docs.unrealengine.com/5.0/en-US/lumen-technical-details-in-unreal-engine/>



Figure 19. The main Ccube-type menu

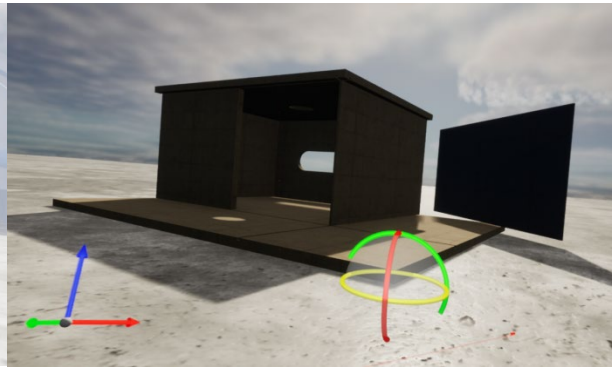


Figure 20. Placing elements with a gizmo.

Once the model is loaded, some modelling and modification functions using a "gizmo" allow the model to be adapted (Figure 20). Then a circular menu allows access to textures which can be applied to each element of the model (Figure 21).



Figure 21. The circular textures menu.

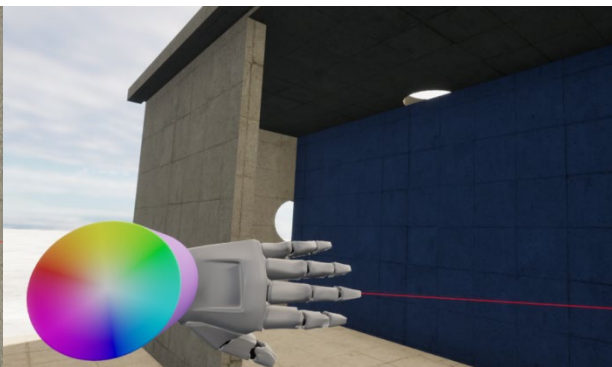


Figure 22. The colour picker.

The parameters of size, transparency, roughness, emitted colour or brightness make it possible to adapt the behaviour of the material to light. A colour picker is used to change the colour of an element or the colour parameters of a texture (Figure 22).

The parameters for the lighting simulation

Once the geometry and materials of the model have been defined, the parameters of the simulation must be specified. First of all, the geographical position of the model is located, for which several possibilities are offered: you can click on a globe and the city is chosen from a list of cities corresponding to the country on which you have clicked, you can also enter the name of the city using a virtual keyboard or the longitude and latitude of the place where you wish to carry out the simulation (Figure 23). Next, the orientation of the building must be specified. To do this, a smaller version of the model appears on the back of the hand, and it is then possible to turn the building in relation to a compass on which it is placed (Figure 24).



Figure 23. Geographical location of the model.



Figure 24. Orientation of the model.

As with the physical model simulator, the day, the start and end times and the duration of the simulation (by default 3 minutes) are specified. By default the simulation starts at sunrise and ends at sunset (Figure 25). Atmospheric parameters are also specified: clouds, fog in the scene or solar illumination.



Figure 25. The time parameters of the simulation.



Figure 26. Bookmarks and virtual photos.

During the simulation one can move around the virtual scene and take virtual pictures which, placed in a table, correspond both to images that are saved with all the parameters (camera position and lighting parameters) and to "bookmarks" that allow to return to a point of view with the lighting conditions at the time of the virtual shot (Figure 26).

The results of the lighting simulation exercises

We offered the students three exercises in which they had to experiment with physical models in the sky-sun simulator and their digital versions in virtual reality. A first experiment was carried out on a physical model of the Church of the Light by Tadao Andō. The students could see that the cardboard used for this model was not thick enough. Then we tried to reproduce the lighting conditions and the material parameters of the digital model to produce a result close to the photo of the real building (Figure 27).



Figure 27. Tadao Andō's Church of the Light in real life, in physical model under the sky-sun simulator and two images of lighting simulation in virtual reality.

Then the students worked with "lumboxes" which are wooden boxes that allow to quickly set up systems of openings and covers, to test hypotheses of light supply, light protection or to create luminous ambiances. They were able to experiment with different types of materials and installations to understand their impact on light transmission and distribution (Figure 28).



Figure 28. The principle of a "lumbox" and a "lumbox" under the sun-sky simulator.

They experimented with their physical models under the sun-sky simulator and then with the digital models in virtual reality. We tried to reproduce the lighting conditions and materials so that in the future they could use either technique (Figure 29).



Figure 29. Simulation images on a "lumbox" in virtual reality.

A free exercise then allowed the students to create a lighting design based on a hypothesis and to verify it both on a physical model and on the digital model (Figure 30).



Figure 30. A natural lighting ambiance project in a physical model and its digital versions in virtual reality.

Conclusion

The objective of the ENSAS Light Laboratory is to simulate natural light, to work on the quality of life and ecology, in particular to reduce the environmental impact with passive lighting. After observing the manipulations carried out by the student architects, it seems important to us to be able to offer both daylighting simulations on physical models under the sun-sky simulator and virtual reality simulations. The manipulation of the physical model allows immediate and comprehensible results to be observed. Illuminance measurements can also be performed. In the digital model, a virtual tour allows a good understanding of the spaces and how the building reacts to simulated daylight. We implemented a complete daylighting simulation system in virtual reality thanks to the new possibilities offered by Lumen, the lighting system of the latest version of Unreal Engine. We also implemented some materials to approximate both the results obtained on physical models and on real buildings. An advantage of the digital model is the possibility to easily modify the materials of the model. To enrich the tools we offer to students, we will create a database of materials that will allow us to improve the quality of simulations and to compare with real environments.

References

- Blandet, T., Erbilgin, E., Vergnes, N., Hoerter, N., Lehmann, O., 2019. Design of new daylight simulators on architectural scale models. 14th European Architecture Envisioning Conference (EAEA14 2019), Nantes, France, page 10, EDP Sciences, SHS Web of Conferences, Volume Volume 64, <https://doi.org/10.1051/shsconf/20196403010>
- Erbilgin, E., Blandet, T., Hoerter, N., Vergnes, N. (2020). A simulator based on LED technology to study daylight on architectural scale models, Proc. SPIE 11353, Optics, Photonics and Digital Technologies for Imaging Applications VI, 113531S (1 April 2020); <https://doi.org/10.1117/12.2555068>
- Grosjean, J., Burkhardt, J., Coquillart, S. & Richard, P. (2002). Evaluation of the Command and Control Cube, In Proceedings. Fourth IEEE International Conference on Multimodal Interfaces. ICMI'2002, 473–478.

Creating opera utilising augmented reality and virtual reality technologies

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Keywords: virtual reality, augmented reality, music, composition, opera, entertainment

This research project seeks to innovate opera by utilising novel technologies to create new opera experiences. The research outcomes include three iterations of the opera *Artemis* (Rose, 2020). The first version of my XR opera *Artemis* was created in *Unity3D* for viewing in the *Oculus Quest* headset. The second was created using *Tilt Brush* in conjunction with *Adobe Premiere Pro* and deployed via *YouTubeVR*. The third version of the opera was a live augmented reality version, developed to create a staging of the original augmented reality opera *Artemis* using the *EyeJack* AR app in conjunction with a handheld smartphone. I employed self-experiential prototyping to create the compositions and immersive environments for each opera version.

The research project employs a mixed-methods approach. Practice-based research and autoethnography methodology were employed. The research is situated at the intersection of science, technology, and art and draws upon underpinning theories of Human-Computer Interaction, immersive theatre, and interactive game composition methods.

Remote XR productions are becoming increasingly sought after; this project explores the operatic form in this context due to increasing technological advancements and the need for opera to reach a new diverse audience. No research has been conducted comparing augmented reality and virtual reality opera production creation. Self-experiential prototyping of the virtual reality opera *Artemis* and augmented reality opera *Artemis* was undertaken to collect new data to contribute to this emerging field.

The learnings I gleaned through the lens of composer as maker are that opera and extended reality are intricately interwoven. The audio-visual elements are constantly playing off one another. To realise the full potential of an XR production, the music and visuals must have a symbiotic relationship constructed through cyclic testing. Each musical element of being a composer-maker influences all the technological elements, as the word-painting of the libretto and the musical key must work intrinsically to bring across each cohesive season of *Artemis's* life story.

Opera and extended reality influence each other throughout the creative process in multiple ways. Firstly, the score must cohesively mesh with the extended reality environment through a similar natural theme reflected in both the libretto and the visualisation of the mythological story;

otherwise, the experience feels disjointed. Secondly, the instrumentation and visual elements must be symbiotic; one aspect must not take away from the other. Instead, they must work in harmony to create an experience of wonder. Thirdly, the journey of coming to this understanding is that the creative audio-visual process is continually interwoven in prototyping workflows; trying out different audio spatialisations alongside the visuals is key to creating a Gesamtkunstwerk that does not make the user nauseous.

For example, the film paths the composer-maker selects in rendering the *Tilt Brush* sketches for the *YouTubeVR* version must flow with the music; the maker must listen to the musical composition while rendering the film paths to ensure cohesiveness. These prototyping workflows are transferable to others, as the new digital 'Gesamtkunstwerk' requires constant reflection on how opera and extended reality elements talk to each other. For the third iteration of the *YouTubeVR* version, I used the metaphor of symphonic orchestration composition, which refocuses the same melody with the colour change, timbral change, the addition of instruments, and by playing the same leitmotif. How you develop that additive way to the experience, by adding dynamically, by adding composition layers, changing harmonic rhythm, and using additive orchestration, this metaphor can be transferred and applied to performance design and media work. As a 20-minute *YouTubeVR* experience, I thought about what visuals I needed to vary and at what times there should be visual changes to keep the experience engaging; these changes include colour changes, environmental changes, and wide shot to narrow shot zooms. While making the 20-minute version, I thought about how I, the maker, could shift the focus. Using the same visual environment to change the audience's focus while using the same 6-minute render from *Tilt Brush* as the simple frame, while repeating this source material's 6-minute loop, I thought about shifting focus through colour changes in the source material.

My journey entailed comparing the iterative processes of creating an extended reality opera using different technological mediums. The various processes are seen in Figure 31, highlighting the different prototyping processes in creating an Oculus opera, an augmented reality opera, and a *YouTubeVR* opera. A Venn diagram helps the maker see the overlaps between making and disseminating new extended reality productions. The processes and overlaps are compared in Figure 1; these processes for developing extended reality operas for different platforms help other creators structure their journey. Other creators can use this figure and explanation to expand their horizons and create new works as solo creators, testers, and distributors of extended reality opera productions. This is valuable to me as I have grown as a composer to become a maker of extended reality productions, wearing the hats of the developer, designer, composer, and director in extended reality mediums that I had not explored before undertaking this research.

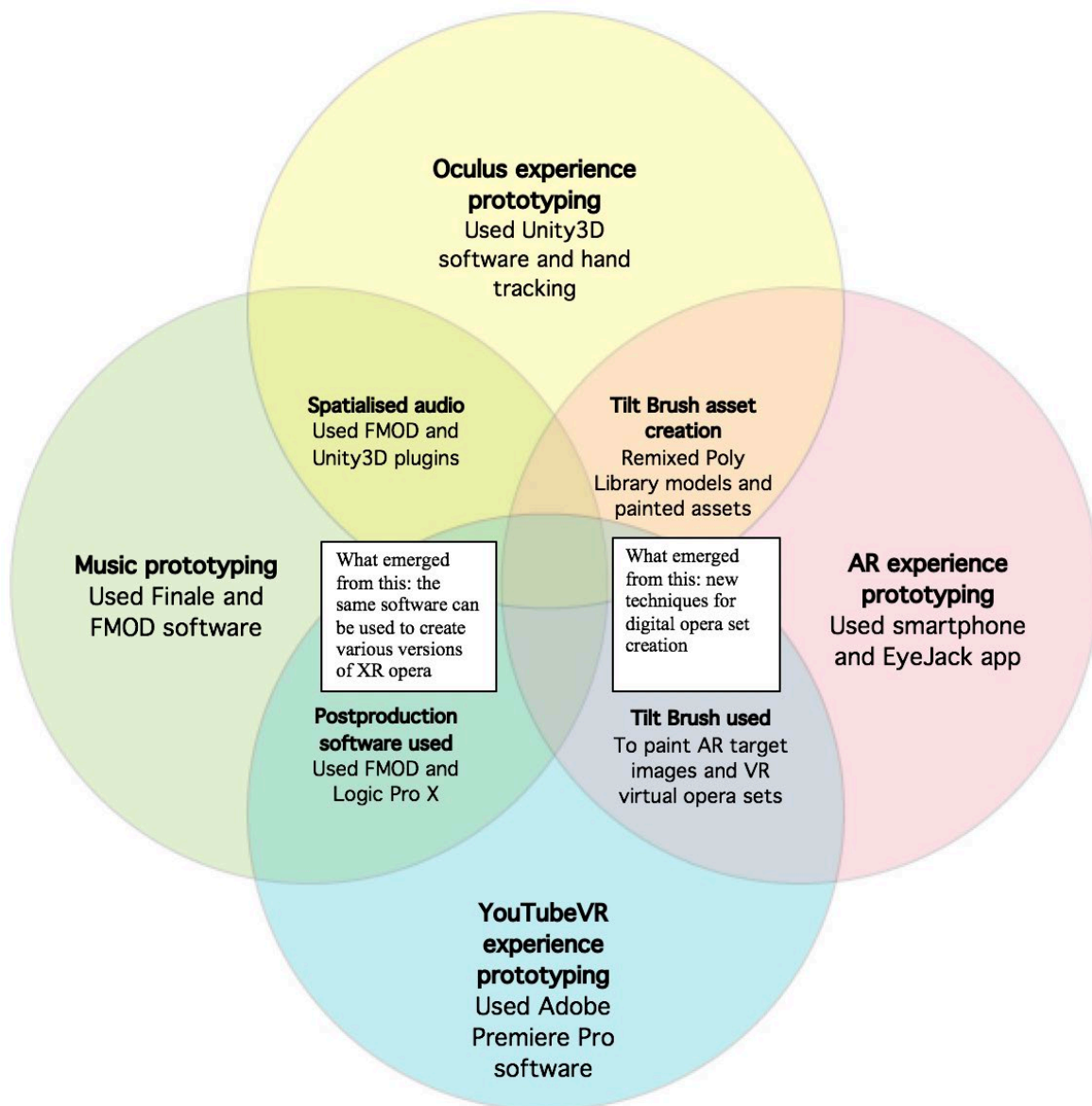


Figure 31. A Venn diagram highlighting how the making process has overlaps.

References

Rose, T. (2022). Figure 31 A Venn diagram highlighting how the making process has overlaps

Emera, a virtual reality radiation protection training platform

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Keywords: Virtual Reality, HMD, radiation protection, serious games, edutainment

Introduction

Radiation protection defines all the measures taken to ensure the protection of humans and their environment against the harmful effects of ionising radiation. It applies in many fields such as the control of nuclear installations, medical applications for imaging and therapy or the management of radioactive waste. Whatever the field concerned, the initial and ongoing training of personnel in radiation protection is a fundamental element for the safety of the public and workers.

In this context, the EMERA project (Experimental Platform for Radioactivity Measurements), carried out in collaboration between the Physics & Engineering Faculty of the University of Strasbourg and the IGG team (Computer Graphics and Geometry) of the Icube laboratory, aims to develop a virtual reality training tool for radiation protection. This tool should enable users to better understand the various situations of exposure to ionising radiation that they may encounter within the course of their professional activity in order to improve their practices. The tool is also intended to be used in the context of the "Nuclear Techniques and Radiation Protection" degree offered at the University of Strasbourg, in order to provide students with a risk-free means of training in the various radiation protection professions. Several scenarios have been implemented in the medical field (interventional radiology) and the industrial field (control of radioactive contamination). For each scenario, the user has to carry out several missions in a radiation exposure situation, while limiting the dose received as much as possible (ALARA principle). The user is provided with protective equipment and measurement systems that can be selected according to the situations encountered. The missions can be carried out with several levels of difficulty, based on the possibility of visualising or not the radiation field (dose rate) in 3

dimensions. The development of this tool was thus an opportunity to study different options for representing a radiation field in virtual reality, with the aim of seeking the visualisation solution best suited to the perception of risk in radiation protection. Our software was developed using the Unreal Engine game engine for use with Oculus Quest 2 virtual reality headsets.

Two areas: interventional radiology and radioactive contamination control



A first set of scenarios takes place in an interventional radiology room (use of radiology to enable diagnostic and therapeutic procedures). Radiation is emitted by an X-ray generator placed in the centre of the room, which can be moved in space by rotating the mechanical C-arm (Figure 32). A series of exercises, mainly based on the positioning of the staff in the room during the procedure, are proposed with different visualisation methods.

Figure 32. Arm rotation in the interventional radiology scenario.

These exercises allow the user to better visualise the spatial distribution of radiation in the room as a function of several adjustable parameters such as beam energy or intensity. By becoming familiar with this radiation environment, the user should be able to optimise their positioning and movements in order to reduce the total dose received during the procedure. The tool allows the user to know at the end of the exercise the dose received by the different parts of his body (head, trunk, arms, hands, legs), and to visualise the evolution of the doses received over time.



The second set of scenarios takes place in an industrial environment. Radiations are emitted by one or more sources of radioactive contamination hidden in the room (point sources, liquid contamination residues). Using a dose rate measurement system (different types of detectors are proposed to the user, more or less relevant according to the type of contamination) and a spray paint can, the user has to delimit a safety perimeter around each identified contamination zone (Figure 33).

Figure 33. Example of perimeter delimitation in the industrial scenario.

Once the perimeter(s) have been delimited, the radiation field is displayed and the user is evaluated according to the dose received by the different parts of his body and the precision of the delimited zone. This exercise allows users to be trained and evaluated in contamination control procedures (choice of measurement system, zone delimitation, risk taking, etc.). The exercises to be carried out allow to choose different types of gamma and/or beta emitting radionuclides (^{137}Cs , ^{60}Co , ^{241}Am , ^{18}F , ^{131}I , etc.) and different activity levels (in Becquerel).

3D dose rate mapping

3D dose rate maps ($\mu\text{Sv/h}$ or equivalent) have been pre-calculated from a Monte Carlo modelling of the different scenarios. The modelling is carried out using the GATE software (Sarrut et al., 2014), based on the Geant4 radiation-matter interaction calculation code developed by CERN. The rooms in which the exercises take place are subdivided into voxels of varying resolution (currently $10\times 10\times 10\text{ cm}^3$), and the dose rate value corresponding to each voxel is calculated according to the various scenarios. By setting the adjustable parameters (energy, intensity, radionuclides, activity ...) at the beginning or during the exercise, the corresponding dose rate map is selected from the database. The user's movement (position, time) then allows the calculation of the integrated dose received by each body part. In interventional radiology, this database contains, for example, maps calculated for several beam intensities, radiation energies (between 50 and 150 kV), positions of the C-arm and for certain specific cases such as the use of a lead shield at the level of the legs or the presence of a doctor in the radiation field (shielding).

Radiation field display methods

In order to display the pre-calculated 3D radiation field mapping, several visualisation methods have been developed and evaluated. The visualisation of the radiation field (and the relative perception of the user) is a very important element for a tool intended for radiation protection training. A first method, inspired by the work of Takeshi Takata et al. (2014), consists of discretising the 3D space and displaying coloured transparent spheres for each portion of the space (Figure 34). A second method uses the surface nets algorithm (Gibson, 1999) to construct transparent iso-surfaces at different radiation field intensity thresholds (Figure 35).

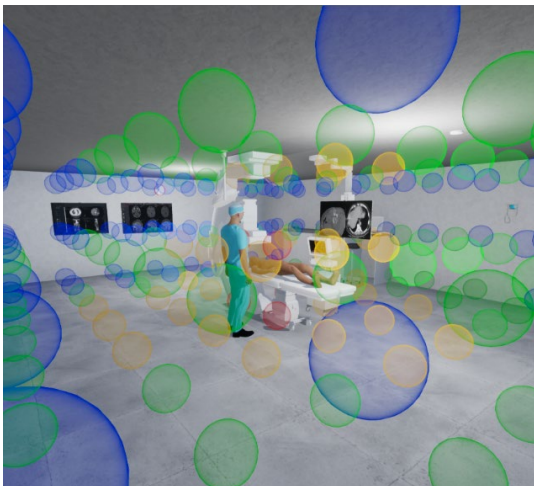


Figure 34. Visualisation by transparent spheres.

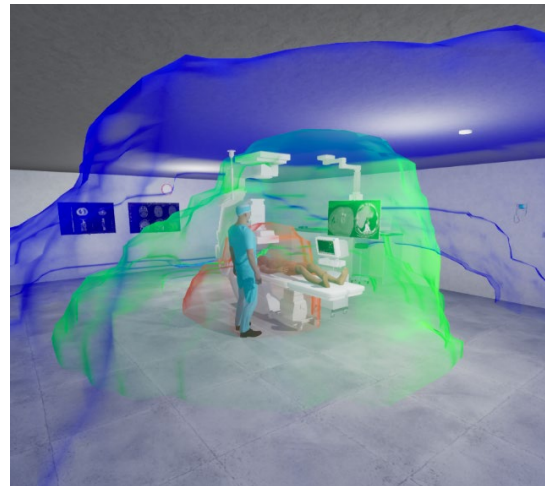


Figure 35. Visualisation by iso-surfaces

A third method, inspired by the work of Michael N. Louka (2010) displays a histogram on the ground where the height of a stick represents the average intensity in the column of that stick, a variant of this method has been developed by replacing the histogram with a mesh (Figure 36). Finally, a fourth method, inspired by Tessa E. Klunder (2018) displays a large number of particles whose random position is weighted by the intensity of the radiation field, the density of particles in a given space thus representing the intensity of the field (Figure 37).

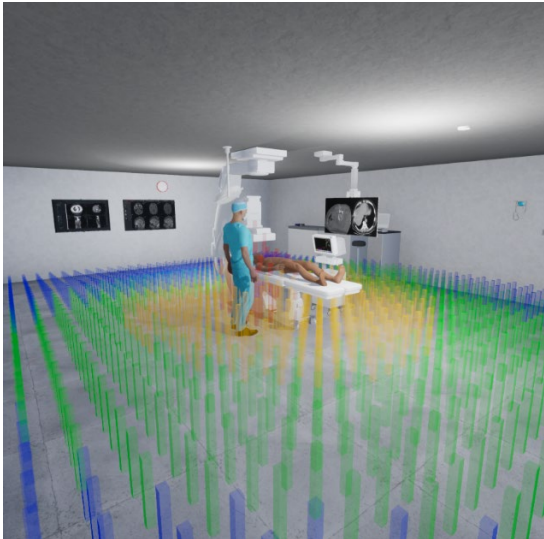


Figure 36. Dynamic particle visualization



Figure 37. Visualisation by histogram.

Dose calculations

In the different scenarios, the user has one or more missions to accomplish, and his behaviour can be observed by a teacher in multi-user mode. An avatar reproduces his movements in the virtual environment by inverse kinematics. His path, dose rates and cumulative dose received are recorded and can then be analysed. To calculate the doses received by the different parts of the body, an approximation of their geometry is considered in relation to the 3D dose rate map (intersection between the limb or organ and the voxel(s) of the map). A miniature representation of the user's avatar can also be displayed on his wrist (Figure 38). It shows for each part of the body the real time dose rate and the cumulative dose received since the beginning of the sequence.



Figure 38. Dose received by the different parts of the body.

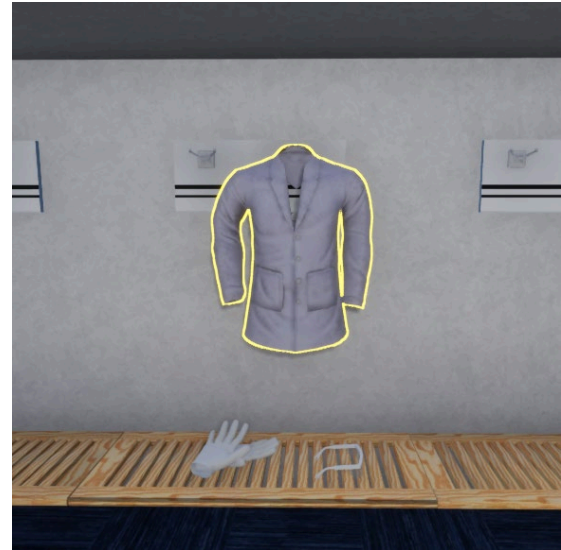


Figure 39. Protective equipment.

Some scenarios also allow the user to select the protective equipment to be worn in the preparation room (Figure 39). This equipment is taken into account in the calculation of the dose received in the form of a reduction coefficient. The user will thus be able to see the reduction in the dose received with and without the use of the appropriate equipment.

Conclusion

The EMERA virtual reality radiation protection training platform offers users (staff, students) the possibility of experimenting different exposure situations, and thus optimising their practices, without taking any risks. This platform will be used for the next academic year in the framework of two training courses on radiation protection in initial and continuing education. The users will be students/staff in the medical field (doctors, technicians, nurses) for interventional radiology, and students/workers in radioactive contamination control organisations for the industrial field. The first user tests carried out have validated both the field visualisation methods and the different scenarios proposed in the current version of the tool. We are waiting for the feedback from the next training sessions to improve the user experience and to propose new scenarios or even for new fields of application.

A video of the application can be accessed here: <https://igg.icube.unistra.fr/index.php/Emera>

References

- Sarrut, D., Bardiès, M., Bousson, N., Freud, N., Jan, S., Létang, J. M., ... & Buvat, I. (2014). A review of the use and potential of the GATE Monte Carlo simulation code for radiation therapy and dosimetry applications. *Medical physics*, 41(6Part1), 064301.
- Takata, T., Kondo, H., Yamamoto, M., Shiraishi, K., Kobayashi, T., Furui, S., ... & Kotoku, J. I. (2020). Immersive radiation experience for interventional radiology with virtual reality radiation dose visualization using fast Monte Carlo dose estimation. *Interventional Radiology*, 5(2), 58-66.

- Gibson, S. F. F. (1999). Constrained elastic surfacenets: Generating smooth models from binary segmented data. TR99, 24.
- Louka, M. N., & Rindahl, G. (2010). A comparative study of radiation visualization techniques for interactive 3d software applications. Proceedings of NPIC&HMIT, 7-11.
- Klunder, T.E., Houtkamp, J.M., 2018. Visualizing X-ray radiation levels with the Microsoft HoloLens. Missä julkaistu

Special session

XR Based GUI
Concept and its
application for BIM
Digital Twin Data
Visualization

BIM digital twin visualization in XR – Novel GUI concept

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Keywords: BIM, Digital Twin, GUI, eXtended Reality

Introduction

This extended abstract introduces the novel graphical user interface (GUI) concept for the visualization of Digital Twin Model in eXtended Reality (XR). The first version of the GUI concept has been introduced earlier (Helin et al., 2021). Based on the user evaluation of the BIMprove XR systems, the novel GUI has been updated. The abstract also describes BIM@Categories, which includes six (6) different GUIs to access Digital Twin Model. Work has been done in a European Commission funded H2020 project called “BIMprove - Improving Building Information Modelling by Realtime Tracing of Construction Processes” (BIMprove, 2022).

The novel XR based graphical user interface concept

The construction Digital Twin Model has various layers and users with different needs and requests for information. There is no ‘one-fit-for-all’ GUI for all user roles and needs. The BIMprove’s general GUI concept can be seen in Figure 40. The GUI concept has four modes:

- 1) Digital Twin mode
- 2) Immersive Digital Twin mode
- 3) Mobile mode
- 4) Notification and Warnings mode

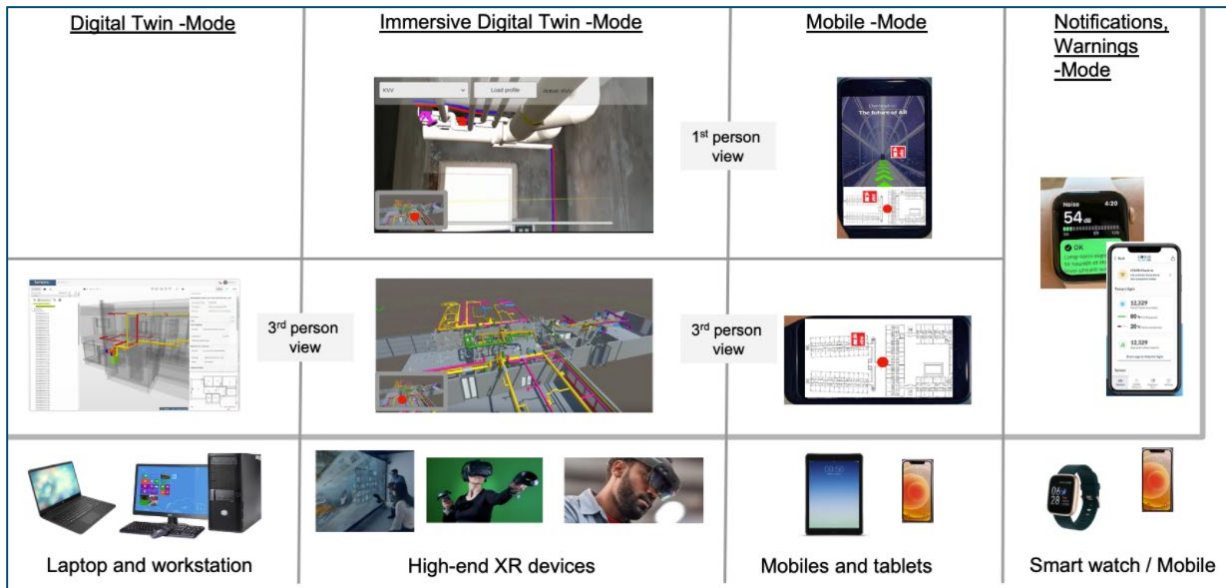


Figure 40. BIMprove's general-level UI concept, to be used in various devices.

User is able to change modes based on device features and user-profile-based access rights. User can have the 1st person or 3rd person view in Immersive Digital Twin and Mobile modes. Digital Twin mode allows user to exploit only the 3rd person view. In the 1st person view, user will see information from the digital twin in real scale, i.e., can feel as if being located in a real room in Virtual Reality. In the 3rd person view, user can see information from digital twin in free distance, e.g., zoom in and out in a 2D map. There are mini maps on the 1st person or 3rd person views, which support user's orientation on the BIMprove Digital Twin model and elicit better situation awareness. The most urgent and relevant information will be given to user via Notification and Warning mode.

BIM@Categories

The BIMprove System, with the digital twin of the construction at its core, will have many different GUIs to be used by a very diverse group of users in different contexts. Therefore these UIs are divided by their context of use into the following six categories.

BIM@Construction



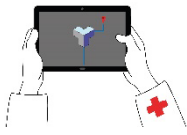
First functional prototypes of BIM@Construction UIs are already implemented. They support immersive and mobile AR features on the construction site, for example to make installations visible, be it a future installation or an installation "hidden" inside a wall (see Figure 41).

BIM@Vehicle



This category covers the use of BIMprove from a vehicle. The first functional prototypes of BIM@Vehicle are produced, but due to COVID-19 it has been tested only in a laboratory environment with a fork-lift simulator (see Figure 41).

BIM@Emergency



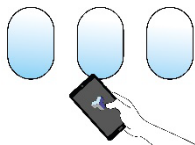
One of the BIMprove project's major goals is to improve both the avoidance of and the reaction to emergency situations. The BIM@Emergency category encompasses GUIs to support both these goals.

BIM@OffSiteOffice



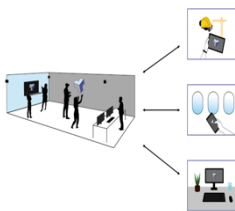
To maintain the digital twin of the construction as the single source of truth throughout the construction process, the BIMprove System needs to enable planner engineers to make changes to their plans when requested. The first functional prototypes of BIM@OffSiteOffice are produced.

BIM@Anywhere



BIMprove will be a cloud-based system. This UI category facilitates accessing it from anywhere via a mobile device. Here, the differences to other UI categories are the user roles and the tasks. The expected main devices will be smartphones and tablets.

BIM@SiteOffice



In Aust et al. (2021), we introduced “Multi-User-XR for Digital Twin Data in Construction”. This system comprises both the context of using the BIMprove System from the construction site office and joining a multi-user-session from another office, or from the construction site itself, or from anywhere via a mobile device. Already the second version of prototypes are produced (see Figure 2).



Figure 41. Example views of various BIM@-Categories tools. From left to right BIM@Construction, BIM@SiteOffice and BIM@Vehicle.

Conclusion and next steps

Based on the first functional prototype testing, the developed XR based GUI has been updated pertaining to four out of six BIM@Categories. In next phase, BIMprove System will be tested in a real construction site and more detailed end-user feedback will be collected. Also, the last two BIM@-Categories tools will be developed based on user needs.

Acknowledgment

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References

- Aust, M., Kvrjic, J-F., Frohnmayer, J., Otto, M., Helin, K. (2021). Multi-User-XR for Digital Twin Data in Construction. In K. Helin, J. Perret, & S. Arlati (eds.), EuroXR 2021: Proceedings of the Virtual EuroXR Conference, pp. 27-30. VTT Technical Research Centre of Finland. VTT Technology No. 395.
- Helin, K., Goriachev, V., Karjalainen, J., Kuula, T., Liinasuo, M., & Aust, M. (2021). XR Based GUI Concept for BIM Digital Twin Data Visualization. In K. Helin, J. Perret, & S. Arlati (eds.), EuroXR 2021: Proceedings of the Virtual EuroXR Conference, pp. 27-30. VTT Technical Research Centre of Finland. VTT Technology No. 395.
- BIMprove, CORDIS, <https://cordis.europa.eu/project/id/958450>, last accessed 2022/06/28.

Storing, Maintaining & Updating the Digital Twin

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Keywords: BIM, Digital Twin, Robot, Drone

Update, save and visualize Digital Twin data: a recurring process

A core characteristic of the Digital Twin - as an extension to a pure model or simulation – is that it is updated and extended in different "life phases" with data from the real-life world (Jiang et al 2021). In this context, BIMprove deals with the construction phase and maintains data from the construction process itself into the Digital Twin. The system considers the construction phase from the beginning earthworks until handover to the client. This data is used for various purposes:

- Documentation of the different construction phases
- Recording the progress of the construction
- Early detection of geometric errors
- Supporting safety on the construction site

Furthermore, an important motivation for this project is that it bridges the model from the planning to the operational phase. In both phases, the great advantages of digital twins could be experienced in practice in the past years, while the construction phase itself has been slow to embrace digitization.

This article focuses on data acquisition, further processing and storage of the data. BIMprove aims to work exclusively with open data standards and not to produce isolated solutions for the subareas of data acquisition, processing and visualization. Instead, the entire process of request for data → acquisition of the data → processing → visualization and the feedback to the original request is to take place in a clear workflow. This may involve the use of existing established standards. In particular, the concept of BCF-issues should be mentioned here to handle this transition consistently across different disciplines and users.

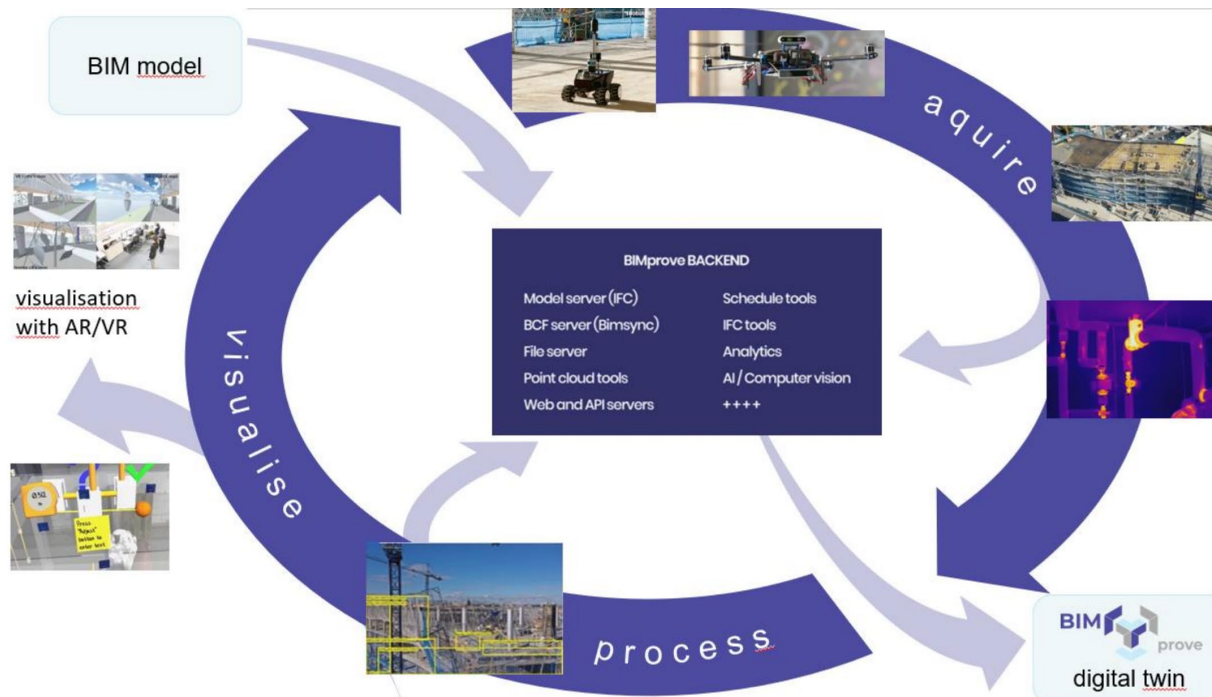


Figure 42. The BIMprove data capturing, processing and representation of captured data.

Figure 42 shows the whole process schematically. The cycle shown can represent a daily cycle, but also, for example, the entire creation of a specific floor. The project manager or the foreman receive timely direct feedback on what is happening on the construction site. It can be compared with the planning - where do delays exist, where are things going according to plan, where are fundamental geometric deviations?

Automated Data capturing

BIMprove has several sources of data. In principle, it is possible to supply the system with manually recorded data. A strong focus on automated or automatable processes is to perform the often-recurring activities with consistent quality. Furthermore, data collection should typically take place after core working hours and should not interfere with the usual processes and activities on the construction site.

Geometric data is collected with drones indoors and outdoors, they typically capture photos which are processed in a photogrammetry software to create point clouds. Besides that, the drone's onboard sensors (like depth cameras) deliver additional data to get an overview about conditions on site. Indoor wheeled robots are also available. These are equipped with a Leica BLK360 laser scanner for geometric data capture. Again, onboard sensors (2D laser scanners) can give additional information. Both systems can be equipped with IR cameras to detect thermal hazards. Beside these UxV other data acquisition systems for people and machines are present – they are not considered here.



Figure 43. Example of captured data with wheeled robot on BIMprove pilot site in Madrid. Captured data can be shown together with the 3D model.

Backend Digital Twin

A core concept in BIMprove is the so-called Backend. It has its own server running in the cloud. It uses Bimsync® as a model and BCF server, but provides both an application and an API server. The backend as a running service can be seen as a living digital twin. It contains “original data” including a series of versioned IFC-files, schedules, point clouds, BCF-issues, photos, sensor data, mission plans, and device/worker position logs. These are typically created/provided by satellites surrounding it – e.g., the data capturing systems, visualization systems etc.

The Backend also contains derived data, for example the result when comparing the asbuilt plan with the point cloud from the captured data. The result in this case can be a colored heatmap, showing the L2-norm of the difference of the specific IFC-object and the scan. From those results a BCF-issue would be created presenting the results and link enabling manual inspection so that a human can make a final decision - which would also be stored. In addition to being a “living” digital twin, the contents of the backend can also be serialized in – as far as possible – open standard formats. Models as IFC, point clouds as .las or .e57, images as jpeg/png, issues as BCF etc.

4D BIM data

A very important functionality of BIMprove is the ability to link a detailed construction schedule with the actual status on the construction site on a daily basis and thus detect deviations at an early stage. This requires model data that, in addition to geometry, also includes the fourth

dimension "time". Since the data comes from various sources, it is very challenging to provide and maintain it on one platform in .IFC standard.

In this way, however, it is possible to narrow down relevant data in the fourth dimension in addition to the spatial dimensions (for example: "Activities on the 3rd floor in the past week"). Based on the described database, various further services can now be performed: Visualization on the construction site itself to plan next work steps, discuss errors etc. But also to better plan new data scans and to create a new data base. The presentation of scan results and the model can be done on different devices, for the foreman on a tablet but also with VR systems that are installed at the construction site or somewhere and allow to discuss things collaboratively in a VR environment very intuitively (Aust et al. 2021).

Conclusion

Digital Twin technologies are making their way onto the construction site. In BIMprove, automated data collection systems are developed, the data processed and fed to Digital Twin in a clearly defined process. Next steps are to test, adapted and optimize the developed functionalities on 3 pilot construction sites. Clearly, adjustments will be necessary in the transition from the laboratory environment to the very specific conditions on construction sites.

Acknowledgment

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958450.

References

- Jiang, F., Ma, L., Broyd, T., & Chen, K. (2021). Digital twin and its implementations in the civil engineering sector. *Automation in Construction*, 130, 103838.
- Aust, M., Kvrjic, J-F., Frohnmayer, J., Otto, M., & Helin, K. (2021). Multi-User-XR for Digital Twin Data in Construction. In K. Helin, J. Perret, & S. Arlati (eds.), *EuroXR 2021: Proceedings of the Virtual EuroXR Conference* (pp. 27-30). VTT Technical Research Centre of Finland. VTT Technology No. 395.

BIM@SiteOffice: Comparing IFC and point clouds in Multiuser VR – Workflows and Tools

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Keywords: VR, XR, Points clouds, Digital Twin, BIM, Collaboration

Using point clouds in virtual reality (VR) to make processes more accurate

The BIMprove (BIMprove 2022) system's goal is to enable Digital Twins in the construction phase by addressing two main challenges. The first challenge is combining information from the physical object with building information modeling (BIM) models in a precise overlay of as planned data versus as built data. Doing this requires combining BIM planning information with as-built data collected during the construction and switching from a georeferenced position to a local position to visualize this information in the BIM. As-built data is obtained with laser scans from robots and photogrammetry from day-ahead planned drone flights and is stored as point clouds inside the BIMprove system's backend. To create a reliable overlay, BIMprove's partners have come up with a marker-based solution in which physical markers on site and virtual ones in the BIM model are automatically detected and aligned.

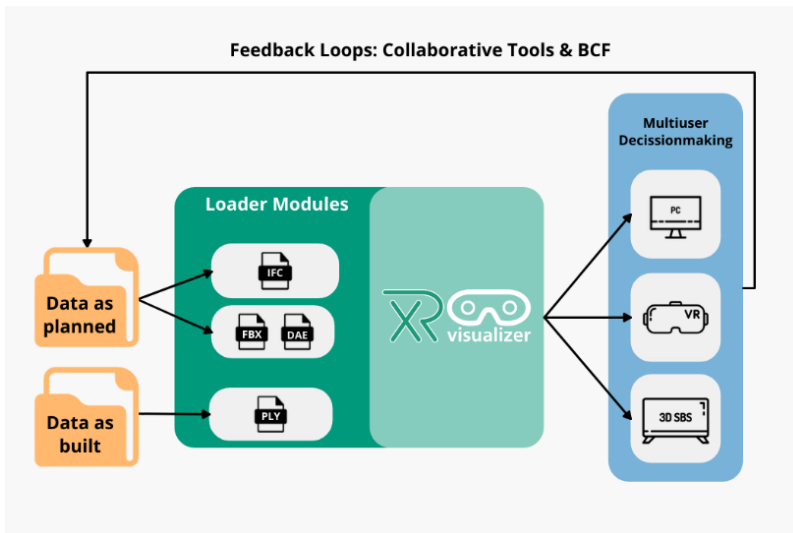


Figure 44. XRvisualizer Feedback loops.

The second challenge BIMprove tackles is the need for tools that ensure that the digital twin always contains relevant and up to date information so it can continue to live on in the operation phase of the building. BIMprove's system uses open standards (BuildingSmart) file formats like IFC, BCF, e57 or PLY to enable workers to make continuous updates and accurate decisions within short time during the construction phase. The XRvisualizer (Aust et al. 2021), a visualization tool, developed at Fraunhofer IAO and University of Stuttgart IAT, is used to support precise decision-making by enabling quick team reviews of as-planned and as-scanned data within a session on different devices. The automated user interface (UI) gives all participants the possibility to hide and show parts of the virtual dataset to only highlight the data of interest. Finally, the issue manager enables the users to create feedback loops into the BIMprove system where issues can be visualized or created as BCF and integrated into the BIM process (Figure 44).

Workflow for bringing point clouds into VR

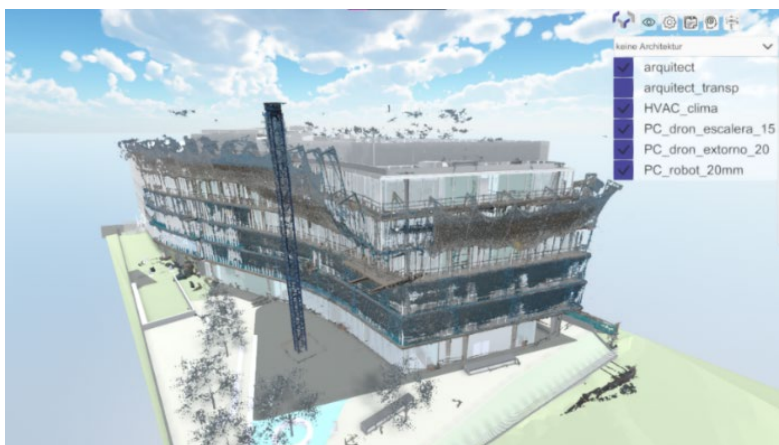


Figure 45. Overlay of point cloud and BIM model.

In the BIMprove system, point clouds are visualized in context with complex BIM models (Figure 45). A fully automated workflow was created to do this based on the following steps. To begin, it's important to optimize how the point cloud is imported to ensure an overall satisfying view and smooth render of the combined information sources. In this process, the amount of rendered points and shader techniques used are the most critical factors. Optimizing the import process starts by reducing the number of points in the point cloud. The best way to do this is to reduce the extension of the point cloud to get rid of unnecessary data. Subsequently, the density of the

point cloud needs to be reduced by, e.g., using the Opensource software “CloudCompare” to create subsamples with a defined density of 1 or 2 cm. This software can import the most used point cloud formats such as E57, LAS, PTX and some ASCII formats like PTS.

The next step is to choose the rendering method. Here selecting simple point cloud-shaders may be tempting based on their high performance (because they render each point as a single pixel), but the limited resolution of head mounted displays may cause problems. For example, when users navigate in the point clouds, the point clouds vanish because the resolution of the actual display is too low to show the single points. The approach chosen in BIMprove to remedy this issue has been to reduce the density of point clouds and render the points as small discs, the size of which is decided by the density of the respective point cloud. Best practice is to use a size of 1 or 2 cm. This facilitates rendering low density point clouds in virtual reality using head mounted displays and allows getting very close to the rendered points thanks to the size of the discs. Users can also easily locate the single discs in 3d space precisely because of the advantages of stereo projection in virtual reality. Once the point cloud size and rendering has been optimized, the final step of this fully automated workflow in the BIMprove system is to create “Unity Asset Bundles”. These can be loaded extremely quickly during runtime in the XRvisualizer because they are based on Unity’s own binary graphics format.

Implementation and using the XRvisualizer

Using the XRvisualizer allows users to visualize their data in VR with the option to connect with alternative devices if no VR-Headset is available (Helin et al. 2021). The tool should be easy to use and accessible and provide meaningful features that support decision making and analysis for a single user or as a part of a group discussion. The tool is developed with Unity 3D and uses different assets to directly visualize models in different file formats. The users can copy IFC, FBX, DAE or Unity streaming assets (point clouds) into a specific folder and then use the XRvisualizer to load them and automatically generate a menu out of the files loaded. The UI can then show and hide all models that are separately loaded, and the names displayed correlate with the names of the loaded data. The process of loading the data leads to a loss of performance but makes the workflow much more convenient as one would otherwise have to create a new Unity build for each session.

A specific issue tab in the UI has been developed to allow participants in the scene to create feedback loops into the BIM model. When this tab is activated, participants can see all available issues and interact with them. Each issue is represented by a question mark (Figure 46). Additionally, participants can create novel issues and send them to an operating person.

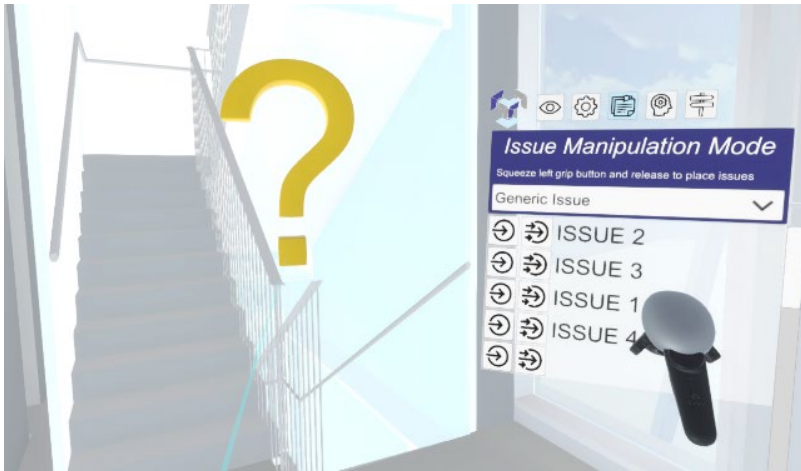


Figure 46. View of the UI where issues in the XRvisualizer are shown with question marks.

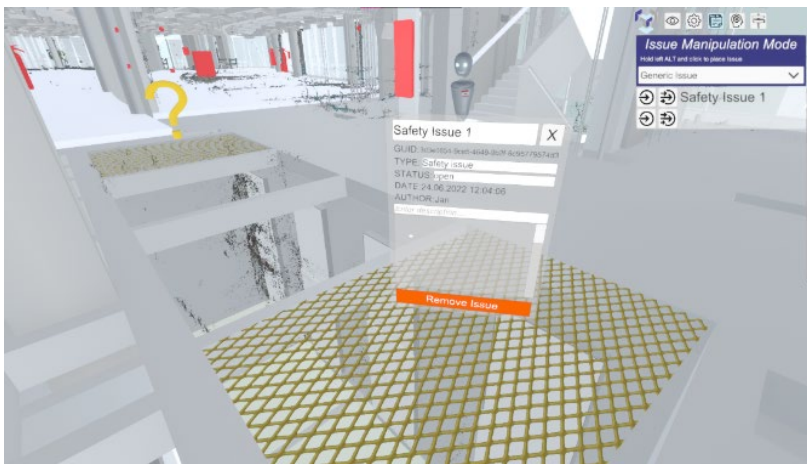


Figure 47. Illustration of a safety issue in the UI with placement of a safety net.

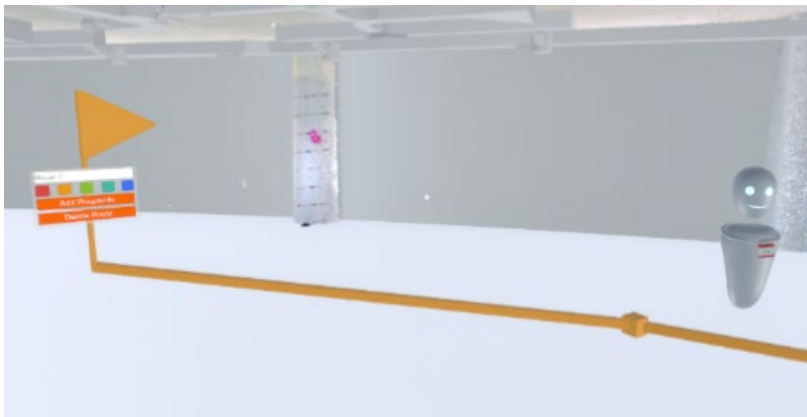


Figure 48. Waypoint manager illustration.

The issue manager also features a special issue interaction for placing missing safety nets and a spatial interaction feature was developed to intuitively place missing nets (Figure 47). When creating a safety issue, the first click defines the first edge of the net and the second click will place a line. Then the safety net will scale automatically according to whether the user is moving horizontally or vertically. In addition to the previously described issue tab, a waypoint manager was also developed (Figure 48). This feature is not fully implemented yet, but will support fire exit visualization, planning, and drone scheduling. Currently, the UI and the user experience are fully functional but not connected to the drone scheduling or the fire exit planning from the BIM tools.

Using the XRvisualizer to collaborate on different devices

The XRvisualizer implements Normcore 2.0 as a multiuser asset in which the visibility of all layers is synchronized for all users. The main idea is that every participant has a local copy of the data on his or her hard drive and only the input and position data of the avatars and geometries are distributed over the internet. To log in, simply type your name and a room name on the login screen. If the room already exists, you will automatically join the room and a check if all data is equal is executed. If you are the first one to log in, the room will be created for you.

The participants can collaborate in the virtual environment with different synchronized assets. The base set up displays a head that shows the line of sight of the user while a user in full VR setup will also have hand icons visible. Users can point to objects (Figure 49) they'd like to discuss using a virtual ray and can communicate using a basic voice chat functionality. If you discuss in close quarters the avatars can be turned transparent (Figure 50). On the menu you can group teleport every participant to a certain issue or waypoint.

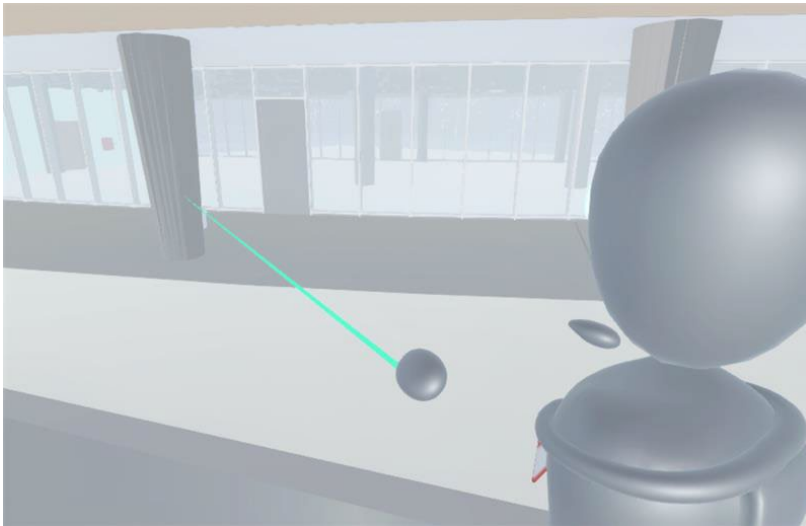


Figure 49. Laser pointer.

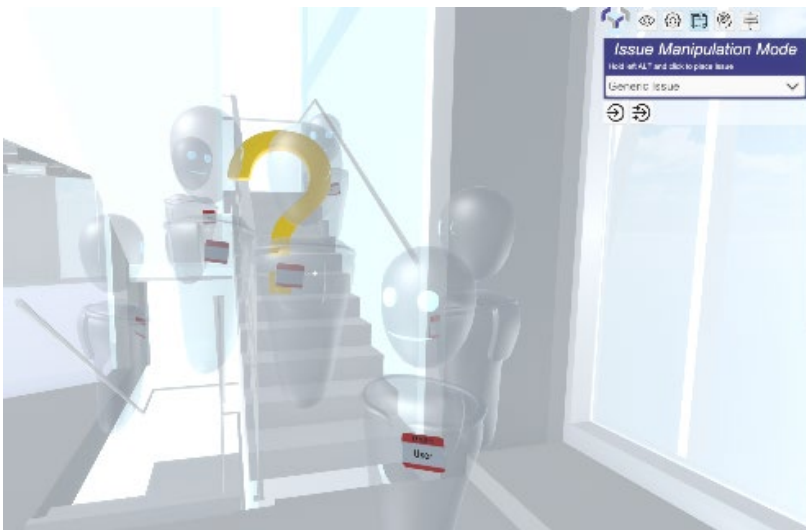


Figure 50. Transparent avatars.

Tools in the XRvisualizer and back loops into the BIMprove system

To make the feedback loops from a multiuser session in the XRvisualizer more convenient, the issue tab as well as the waypoint tab were set up to match the BCF standard. This means the parameters a BCF needs to provide are automatically generated when an issue is created in the XRvisualizer. The issue represented by a question mark will reveal its information when interacted with in the form of a world space UI. Additionally, all BCF information about issues is readable and editable directly in the BIMprove system. The next step we are currently working on is to provide a BIMprove backend and connect it to the XRvisualizer. All these developments are designed to be in the form of an open standard with a consistent workflow throughout all systems.

References

BIMprove, CORDIS, <https://cordis.europa.eu/project/id/958450>, last accessed 2022/06/28.

BuildingSmart, <https://www.buildingsmart.org/about/openbim/openbim-definition/>, last accessed 2022/07/27.

Aust, M., Kvrjic, J-F., Frohnmayer, J., Otto, M., & Helin, K. (2021). Multi-User-XR for digital twin data in construction. In: Helin, K., Perret, J., Arlati, S. (Eds) EuroXR 2021 Proceedings of the Virtual EuroXR Conference, ISBN 978-951-38-8756-8, 27-30.

Helin, K., Goriachev, V., Karjalainen, J., Kuula, T., Liinasuo, M., & Aust, M. (2021). XR Based GUI Concept for BIM Digital Twin Data Visualization. In: Helin, K., Perret, J., Arlati, S. (Eds) EuroXR 2021 Proceedings of the Virtual EuroXR Conference, ISBN 978-951-38-8756-8, 31-35.

Evaluation of BIMprove XR User Interfaces

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Keywords: Usability Testing, eXtended Reality, Multi-User-Virtual-Reality (MUVR), Augmented Reality (AR), Building Information Modeling (BIM)

Introduction and Motivation

This work documents the evaluation of the XR user interfaces introduced in Aust et al. 2021 and Helin et al. 2021 in the BIMprove project (BIMprove, 2022). It describes the procedures followed in the different tests with their results and suggests a pragmatic and cheap way to estimate the readiness of a collaborative software system for a specific context of use.

Usability testing of the BIMprove XR applications

Three usability tests were conducted to evaluate the performance of two of the BIMprove XR applications. The first application tested is the BIM@Construction AR application (see Helin et al., 2021) which was evaluated on two different devices in a lab environment. The second and third tests focused on the BIM@SiteOffice multi-user-VR-system (see Aust et al. 2021). This application was first evaluated in a lab environment and then in a “field test” in a construction site office. The general structure of the testing procedure was the same for all three tests: after receiving an *introduction* to the systems and the testing procedure, the test persons were asked to perform several *tasks* with the respective system, during which they were required to think aloud. *Questionnaire(s)* were to be filled out afterwards (in all three tests the System Usability Scale (SUS, Brooke 2013,) was used), and *interviews* were conducted to close out the tests.

Evaluation of the BIM@Construction AR application (lab test)

BIM@Construction provides an AR application that can be run on an Android tablet or on the Microsoft HoloLens 2 (Helin et al. 2021). The application superimposes 3D Building Information Models (BIM) of a construction project onto the image of reality and offers several interaction options. The tests used both the above-mentioned devices and four test users. Only two of them had prior experience with the HoloLens 2. The *introduction* was done via prerecorded videos. With each device, the test users were asked to perform the following *tasks*: a) Initialize the device, b) modify the view (rotate, zoom) in 3rd person view, c) view the Menu panel (tools, floor plan, options), d) choose options: hide and show models, adjust opacity, interact with the floor plan, e) change to 1st person view, f) check wires on the building structure in 1st person view, g) (HoloLens only) use measuring and annotation tools. After completing the tasks, the test situation was reviewed with the participant. In the after-test interview, users were asked about the usability and user experience of the user interfaces and then fill out the SUS questionnaire.

The overall feedback of the test users to the HoloLens application was positive. Users commented that they found it useful, impressive, and simple to use. The menus were found to be self-explanatory and easy to use except for some interaction techniques that were difficult to perform (e.g., closing menus, using sliders, and dragging and dropping). The resolution of the HoloLens display was too low, and the field of view too small. In general, testers familiar with HoloLens had no difficulties using it, while those who were not, needed more support. The tablet was both easy to use and interact with. Rotating and zooming the building worked well, and pictures and resolution were found to be clearer and crisper than in HoloLens. On the downside, the tablet's screen was found to be too small to scrutinize the building model, and so were the buttons. The tablet was better at giving a clear overview of the building (3rd person view), while HoloLens' strength was to provide an immersive experience (1st person view). The SUS questionnaire was used to evaluate the HoloLens application. The results show that all participants evaluated the system usability as acceptable, with an average score of 77/100. With the lowest score being 70, the overall usability will not be a major concern going forward and is expected to be improved thanks to the comments collected in the testing.

First Evaluation of the BIM@SiteOffice MUVR-system (lab test)

BIM@SiteOffice follows the idea of making the whole BIMprove System and its digital twin of the construction site available in the construction site offices. One of its main user interfaces is a multi-user-VR-system, where Head Mounted Displays (HMD) are used to view BIModels of the planned building and point clouds from scans of the construction site. There were four users for these tests, two of which were experienced VR-users but had only little background in constructional engineering, while the other two were civil engineers with little VR experience. None of them had prior knowledge of the specific BIModels. The *introduction* to the test was done via a slide presentation. When needed, participants received assistance and explanations for the HMD. The *tasks* were divided into two sessions: a single-user and a two-user session. Tasks in the single-user session included learning the interaction techniques for navigation (travel), using the hand-UI, using the Issue-Manipulation-Mode with which annotations can be created and shared, and closely inspecting a specific discipline BIModel (either electrics or HVAC (heating, ventilation, air conditioning)). The Simulator Sickness (SSQ, Kennedy et al., 1993) and Igroup Presence (IPQ, Igroup) *questionnaires* were deployed after the single-user sessions, followed by a short *interview*. *Tasks* in the two-user session were to apply the techniques learned in the first session and

communicate with the other participant about the BIModels, find issues and try to solve them. Afterwards, two more *questionnaires* were used: the SUS and the social presence module of the Game Experience Questionnaire (GEQ-SP, IJsselsteijn et al., 2013). A final *interview* followed.

The results showed that all participants were pleased with the software. The learning curve was reasonable, with some interaction techniques taking more getting used to and sometimes requiring reminders. No one complained about any interaction techniques being unfit or counterintuitive. The average SUS score was 76/100, with the lowest being 65 and the highest being 88. A score of 65 is rated as marginally acceptable. It came from the least experienced VR user. The SUS rating is as expected and not worrying. The average result for the IPQ was 4.9 which can be considered fairly high (Likert scale range: 1 to 7, where 7 is best). The GEQ-SP consists of three components. The scores for each were: 1) Psychological Involvement – Empathy 2.7, 2) Psychological Involvement – Negative Feelings 0.8, and 3) Behavioral Involvement 2.4 (Likert scale range: 0 to 4, where 4 is best). This is a good result.

Evaluation of the BIM@SiteOffice MUVR in a construction site office (field test)

The second BIM@SiteOffice MUVR-tests followed roughly the same procedure as the lab tests reported above. The main difference was that these were conducted in a real construction site office with domain experts from the construction site. Participants were a site manager, a production manager, a technical office manager, a BIM manager, a safety manager, and a foreman. After learning the system in single sessions on day one of the test, they inspected the BIModels of “their” building, together with scanned point clouds of one storey of the construction, in two-user sessions, on day two.

In addition to the think-aloud analysis, interviews, and questionnaires, we developed a quick and pragmatic heuristic method to estimate the readiness of collaborative multi-user systems (Table 1). This heuristic scale is based on the notion that the more time users spend communicating about domain problems and possible solutions, instead of talking and worrying about functionalities and interaction techniques of the software, the closer the system is to being “ready for use” in the specific context of use. For the two-user sessions, we rated each point of conversation between the test users on the following scale:

Table 1. Heuristic scale to rate readiness of a collaborative MUVR system.

Topic of conversation	Rating	Comment	Example
Solutions for domain-related issues	9	Construction-related issues, in this case	“We’ll use XY-machine to build this!”
Identification of domain-related issues	7	Construction-related issues, in this case	“What tools will we use to build this?”
Visualisation	5	In this case BIModels or point clouds	“This looks better than in software XY”
Software features	3	Expressions of (new) software requirements.	“I cannot draw, here, can I?”
Interaction techniques	1	Questions on <i>how</i> features can be used.	“How do I mark this as an issue?”
Anything else, relevant	0		
Off-topic / irrelevant	-1		

Shown in Figure 51 are diagrams of the conversations in each of the three two-user sessions. Each pair of dots connected by a horizontal line depicts the start and end points of a conversation topic.

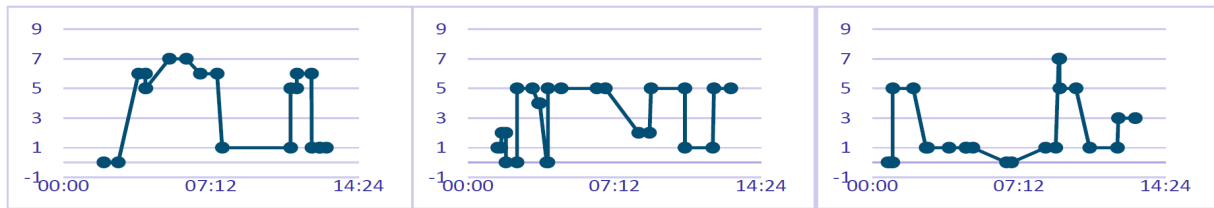


Figure 51. a) Production Manager & Forman, b) Technical Office & BIM Manager, c) Safety & Site Manager

These diagrams turn categorized time stamps into a graphical representation of the conversation, that we find helpful in the analyses. One can see how, for example, in session a), after a slow start, the topic of conversation went to the models and concrete construction issues, before requiring an extensive reminder of a specific interaction technique, just after the halftime point of the session. This, again, shows the learning curve on some of these interaction techniques. In other results, the average SUS score was 83/100 (lowest 65, highest 95). We had reduced the other questionnaires to three items after each session: One on sickness and two on presence – general sense of presence after the single user and on social presence after the two-user session, all rated on a 1-5 Likert scale. Sickness was not an issue (all scores 2 or below, avg. 1.4). Presence scores were very high, as they often are with novel users: 4.4 overall average.

Conclusions

As an overall result, we can state that the usability of the tested systems is not an issue. They are usable and useful. However, it should be noted that none of the quantitative results provide statistical significance due to the low number of test participants. A general problem with usability testing in projects, where there are few chances and not much time to test with real end users is that the main factor influencing the results seems to be the learnability of the tested system. This, unfortunately, is also a problem with our newly developed heuristic scale. It mainly rates the users' familiarity with the system and therefore its learnability. We find it very useful and worth of further testing and development, nonetheless.

References

BIMprove, CORDIS, <https://cordis.europa.eu/project/id/958450>, last accessed 2022/06/28.

Aust, M., Kvrjic, J-F., Frohnmayer, J., Otto, M., & Helin, K. (2021). Multi-User-XR for digital twin data in construction. In: Helin, K., Perret, J., Arlati, S. (Eds) EuroXR 2021 Proceedings of the Virtual EuroXR Conference, ISBN 978-951-38-8756-8, 27-30.

Helin, K., Goriachev, V., Karjalainen, J., Kuula, T., Liinasuo, & M., Aust, M. (2021). XR Based GUI Concept for BIM Digital Twin Data Visualization. In: Helin, K., Perret, J., Arlati, S. (Eds) EuroXR 2021 Proceedings of the Virtual EuroXR Conference, ISBN 978-951-38-8756-8, 31-35.

Brooke, J. (2013). SUS: A Retrospective. *Journal of Usability Studies*, 8(2), 29-40.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. *International Journal of Aviation Psychology*, 3(3), 203-220.

Igroup, igroup presence questionnaire, <http://www.igroup.org>, last accessed 01.07.2022.

IJsselsteijn, W. A., de Kort, Y. A. W., Poels, K. (2013). *The Game Experience Questionnaire*. Technische Universiteit Eindhoven.

Application posters

Reproduction of Multiple Mirror-Based Arbitrary Lighting Environment

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Keywords: Spatial Augmented Reality· Light Field Projection· Lighting Reproduction

Introduction

Appearance manipulation with reproducing lighting environment from precisely designing light field projection is potentially hacked our perceptions and creates fictional objects. It is helpful for programmable room lighting, SFX for motion pictures and photography, theater effects, and lighting for amusement parks, museums, etc. We propose a virtual lighting environment reproduction method using multiple ray casting in this work. Our system employs mirror-based light field projection for multiple-ray projection using four projectors and nine mirrors. With a precise design of incident light ray distribution, we successfully created a light field that reproduced lighting environments such as multiple point light sources, parallel light sources, and diffuse ambient lighting.

Related Works

Light field projection is required to reproduce the direction of the incident light. Oya et al. proposed an image-based re-lighting with 5-DoF incident light fields wherein 4 DoF position and 1 DoF color (Oya et al., 2017). However, the system aims to perform re-lighting in the synthesized image, and the system does not produce a light field in the real world because multiple ray projection is not capable in the system. Zhou et al. proposed a 4 DoF light field projection in the real world by projecting lighting images onto a lens array. In their system, the lens array converts the projected images into a controlled anisotropic point light source array (Zhou et al., 2015). Recently, Takeuchi et al. proposed a prototype implementation for an integral illumination device (Takeuchi et al., 2022). They built the device using a combination of an LED array, a high-resolution LCD panel, and a custom-designed lenticular lens sheet. These approaches realized the re-

creation of a 4 DoF light field in the real world. Therefore, they enable the correct creation of cast shadows, reflected incident light rays, and attached shadows on the surface. However, the lens array or sheet size limited the capable angular range of the incident light rays. Hence, multiple units are required to expand the angular range, making cost expensive. Therefore, we propose a wide angular-range light field reproduction that employs multiple projections with multiple mirrors.

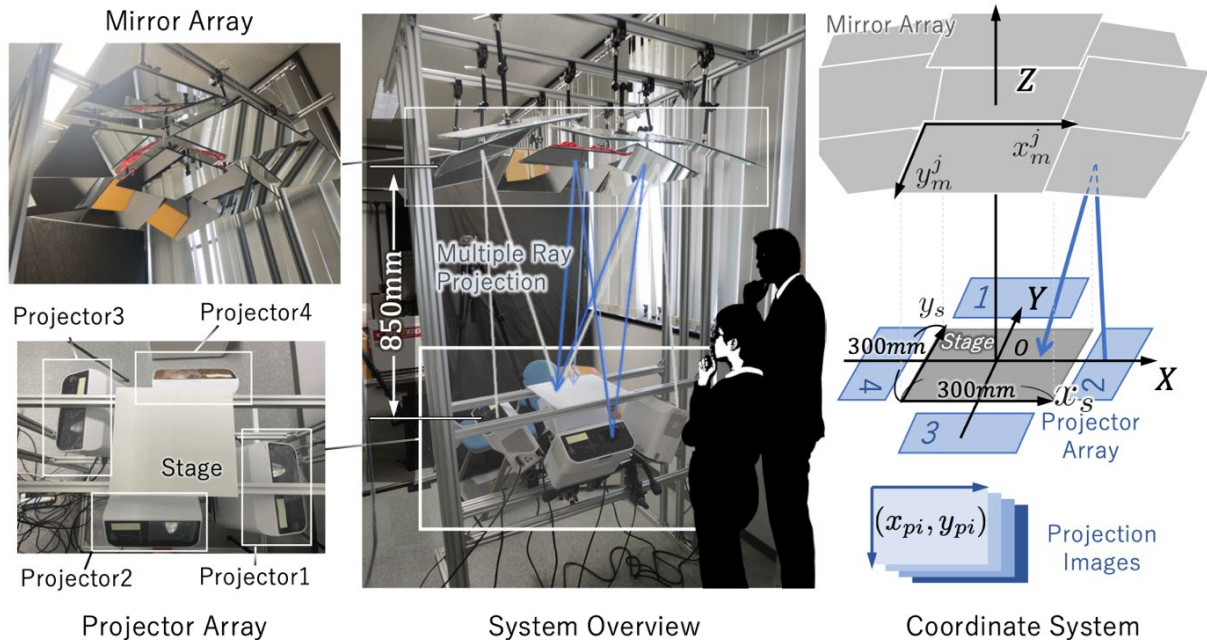


Figure 52. Overview of the proposed mirror-based light field projection system.

Mirror-based Projection System

System Design

We built a mirror-based light field projection system, as shown in Figure 52. The system consists of nine mirrors and four projectors. The system employed four ultra-short slow projectors (RICOH PJ WX4125, 3,000lm) with a 1280×800 pixels resolution to realize a wide angular range light ray projection and a 3×3 mirror array (size of $300\text{mm} \times 300\text{mm}$.) placed above 850mm from the projectors. Each projector casts a light ray on the stage ($300\text{mm} \times 300\text{mm}$) using mirror reflection, and the maximum zenith angle is as high as 40 degrees (depending on the projection location on the stage). Based on the location, the number of casting rays is 3 to 15 in each $1\text{mm} \times 1\text{mm}$ projection area on the stage (stage local region). We calibrated the pixels corresponding to the projection images (x_p^i, y_p^i) , local coordinates on the mirrors (x_m^j, y_m^j) , and a stage (X, Y) for each projection image i . These relations are described with Homographies.

Light Ray Synthesis

First, we identified the reachable casting light rays I_n where $n = 1, 2, \dots, N$ in each local region ($1\text{mm} \times 1\text{mm}$, in this paper, we divided 300×300 local regions on the stage.) from all the projection pixels. Then, we reproduced the desired incident light rays at each stage local region

by synthesizing these light rays. To perform this synthesis, we considered the light ray angular distribution on the surface as the normal distribution and modeled it as follows:

$$I_n(\omega_x, \omega_y) = k_n \exp \left\{ -\frac{(\omega_x - \omega_{x0})^2 + (\omega_y - \omega_{y0})^2}{\sigma^2} \right\}$$

where ω_x and ω_y denote the normal gradients toward X and Y coordinates, ω_{x0} and ω_{y0} denote the casting light ray directions. The light ray intensity k is calibrated using image measurement as follows:

1. Place a white sheet assuming Lambert reflection on the stage.
2. Cast uniform illumination to the mirror j from the projector i .
3. Acquire the surface radiance with an industrial camera and determine k_n .

Light field Generation

We designed the light field based on the incident light ray distribution on the stage created by the desired lighting environment. For instance, when we reproduce the point light source located at $(X, Y, Z) = (0, 0, h)$, the incident light direction at each stage of the local region can be expressed by

$$\begin{cases} \tilde{\omega}_{x0}(X, Y) = X/\sqrt{X^2 + Y^2 + h^2}, \\ \tilde{\omega}_{y0}(X, Y) = Y/\sqrt{X^2 + Y^2 + h^2} \end{cases}$$

and the intensity of the casting of each light ray is

$$\tilde{I}_0(x_s, y_s) = gh^2/(X^2 + Y^2 + h^2),$$

where g denotes the illumination gain. With this modeling, we solve the non-negative optimization problem

$$\min_{\{\alpha_n, n=1,2,\dots,N\}} \int_{-\pi/2}^{\pi/2} \int_{-\pi/2}^{\pi/2} \left(\tilde{I}_0 \exp \left\{ -\frac{(\omega_x - \omega_{x0})^2 + (\omega_y - \omega_{y0})^2}{\sigma^2} \right\} - \sum_{n=1}^N \alpha_n I_n \right)^2 d\omega_x d\omega_y,$$

subject to: $\forall \alpha_n \geq 0$.

Here α_n denotes proportional to the projection pixel value. We obtain projection images from it with a proper illumination gain. For the colored illumination, we separately calculated the pixel value using this procedure for each channel.

Results

The most significant advantage of light environment reproduction is that it enables a rapidly changing illumination situation without mechanical equipment and creates correct shadows and

reflections without geometric information and registration. For a good example, we reproduced the lighting condition in which the three point-light sources move independently, as shown in Figure 53. We used a plaster statue that assumed Lambert's reflection in this experiment. Figure 54 shows a comparison of shading between physical illumination and our lighting environment reproduction. For this evaluation, an LED Maglite is used to attach a pinhole on the lens and placed at $(X[mm], Y[mm], Z[mm]) = (-150, 0, 400)$ and $(-150, 150, 400)$ for positions #1 and #2, respectively. We then calculated the projection images to reproduce these lighting environments. Since our reproduction synthesizes the desired lighting environment with a combination of discrete casting rays, we can observe penumbras in reproduced cast shadows, as shown on the left. Furthermore, these sparsely cast rays produce gradation in the cast shadow at the nose area, as shown in the intensity profile on the right. However, the direction of the cast shadow and intensity gradients of the attached shadow are well-reproduced.

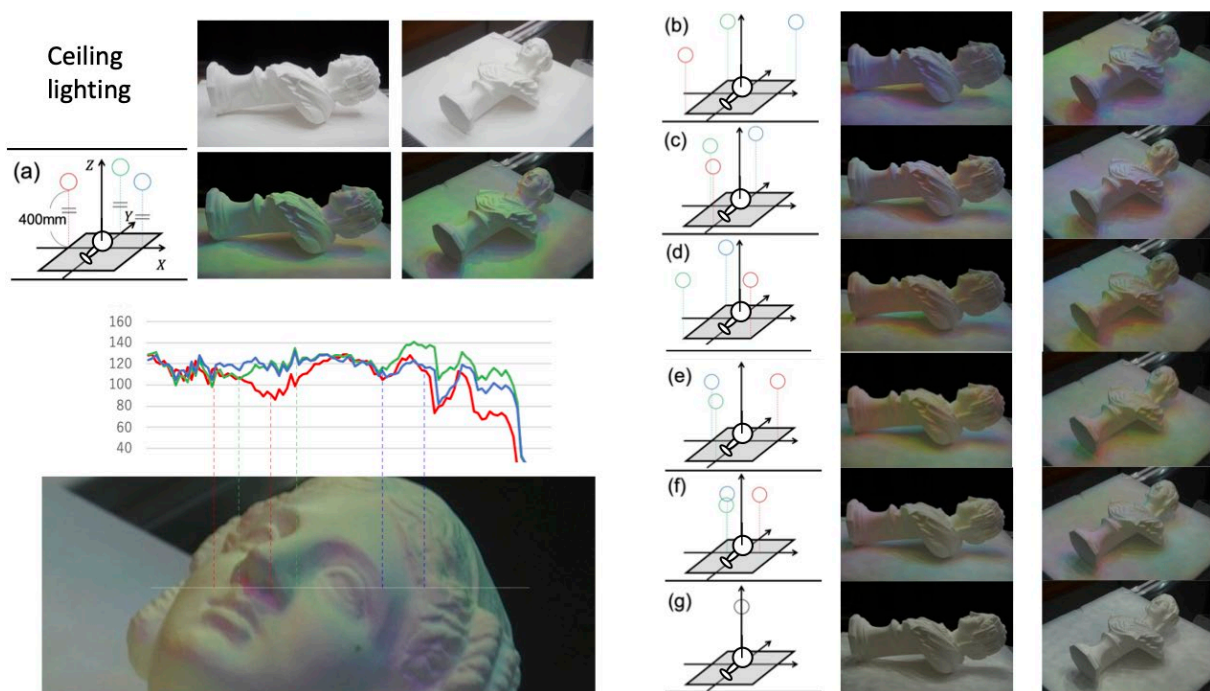


Figure 53. Result of the illumination reproduction by dynamically moving three colored point light sources.

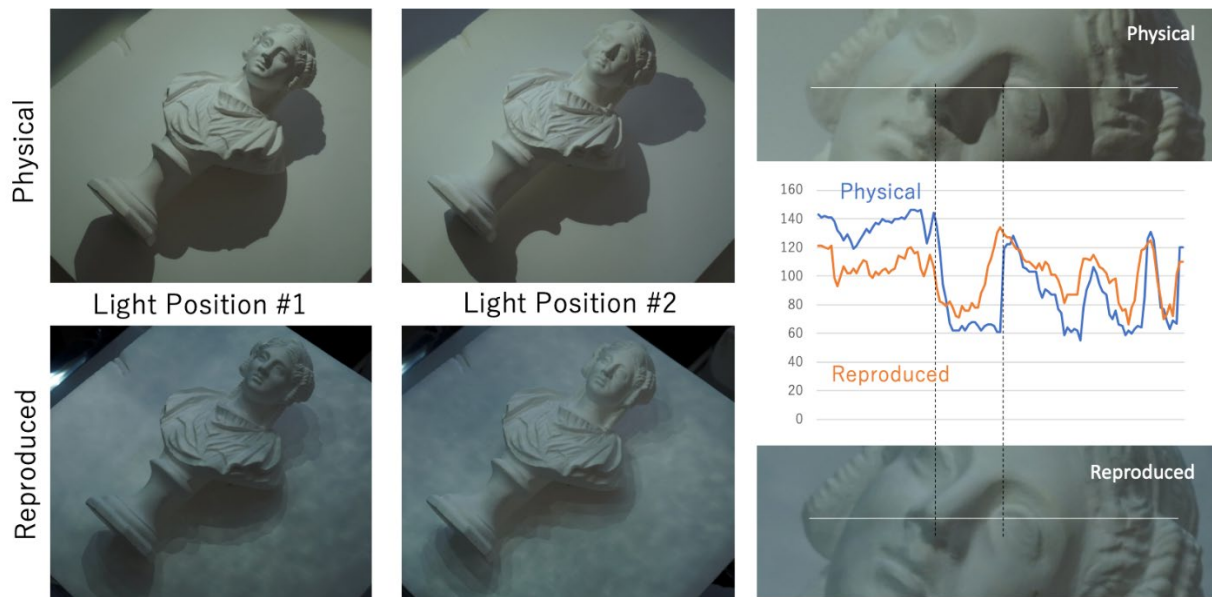


Figure 54. Comparison between physical illumination and lighting environment reproduction.

Conclusion

We proposed an alternative approach for arbitrary lighting environment reproduction using multiple mirror reflections. Our approach expands the angular range of incident light rays and efficiently reproduces a lighting environment that drastically moves the light sources. Additionally, we successfully reproduced the attached shadows on Lambert surfaces and directional reflections on mirror surfaces. However, our system produced penumbras in the cast shadow for the sparse angular resolution of the casting light rays. More projectors and mirrors will be employed to solve this problem in our future works.

Acknowledgements

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References

- Oya, S., & Okabe, T. (2017). Image-based relighting with 5-d incident light fields. In Proceedings of the IEEE International Conference on Computer Vision Workshops (pp. 3031-3038).
- Takeuchi, Y., & Nagamine, K. (2021). Theory and Implementation of Integral Illumination. *IEEE Access*, 10, 939-950.
- Zhou, Z., Yu, T., Qiu, X., Yang, R., & Zhao, Q. (2015, March). Light field projection for lighting reproduction. In 2015 IEEE Virtual Reality (VR) (pp. 135-142). IEEE.

A storyliving virtual museum: EPANASTASIS-1821

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Keywords: Virtual museum, serious game, storyliving, cultural heritage, virtual reality.

Introduction

The scope of this contribution is the presentation and the demonstration of an innovative virtual museum that embeds the theory and the practice from the field of Serious Games, in a cultural heritage context. The EPANASTASIS-1821 virtual museum hosts a set of cultural exhibitions that narrate the history of the Hellenic Struggle against the Ottomans. This virtual museum does not represent a brick-and-mortar cultural heritage organization. In the same virtual space tangible and intangible evidence in digital form, currently dispersed geographically and in different cultural heritage sites are being exposed.

The purpose of the virtual museum *EPANASTASIS-1821* was to communicate important events of the Greek Revolution and to highlight aspects of the Nation's revolution war, as depicted in archival material, books and artistic representations in Greece and abroad. The project is addressed to the general public and aims, through the use of innovative educational tools of high-immersion virtual reality (full-immersive), to enhance the user's experience and to create a more effective understanding of the impact these events had on our people, the evolution of the Greek state and its influence in the European world.

For this purpose, a consolidated exhibition program was made to support the virtual museum of *EPANASTASIS-1821*, which with semantic flow and relevance, narrates aspects of the Greek Revolution through the compilation of a collection of digitized material, which is related to the events and the personalities of the liberation. The main objective of this research is the utilization in the field of museum practice of the modern digital possibilities offered by virtual reality technology and serious games.

Methodology

The cardinal research goal was the study and identification of the possibilities and challenges that raised by the development of digital museological productions that embody VR applications and serious games. In this context, the project *EPANASTASIS-1821* explored the interpretive, communicative and educational dynamics of VR applications and gamification in a virtual museum environment, which make this experience experiential, participatory and entertaining. In achieving the main objective, we have set out the following objectives:

- *Obj.1 – Generalization*: Identify needs in terms of functional and user requirements.
- *Obj.2 – Representation of stories*: Communication of historical events to revive them and enhance memory.
- *Obj.3 – Story Interaction*: Use VR for user immersion and emotional engagement.
- *Obj.4 – Testing*: Pilot testing and evaluation.
- *Obj.5 – Promotion*: Dissemination and exploitation.

Implementation

The starting point for the *EPANASTASIS-1821* is the virtual museum, where the digital 3D reconstructed exhibits are exposed. Some selected paintings trigger additional experiences in VR (Anastasovitis et al., 2020). Since accepting the mission, the player will be transferred back in time (Figure 55, Figure 56, Figure 57) and will try to gather all the necessary information through adventure games designed in *Unity* game-engine and interacting with *Oculus Rift S* head mounted display with the touch controllers (Georgiou et al., 2021).



Figure 55. Storyliving in *Captain's Cabin* level of *EPANASTASIS-1821* virtual museum.



Figure 56. Interacting with archives and objects in the full-immersive cosmos of EPANASTASIS-1821.



Figure 57. Still image from the mission of Need more warships stage in EPANASTASIS-1821.

Results and discussion

As part of the dissemination and evaluation of the EPANASTASIS-1821 research project, tests of the virtual museum were carried out on users from the general public (Fig.4). According to the results of the evaluation, the design of the virtual museum EPANASTASIS-1821 responds to a completely satisfactory degree to the factors of usability, easy orientation, understanding of the content, easy handling of the device that were raised on the principle of the programmatic museological design and development of the virtual environment. The high level of photorealism and immersion that users enjoy from their virtual museum experience was reflected in the highly positive impressions recorded by users. The interdisciplinary research project EPANASTASIS-1821

successfully combined the virtual museum and serious games and is expected to be a guide for the next generation of experiential virtual museum development.



Figure 58. Testing the innovative virtual museum EPANASTASIS-1821.

Conclusion

The research project *EPANASTASIS-1821* provides the general public with access to the virtual museum of the Greek Revolution War, where the user/ visitor is able to view digital representations of historical exhibits of that period, accompanied by scientific documentation and multi-sensory educational experiences, based on virtual reality and serious games.

Acknowledgements

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References

- Anastasovitis, E., Georgiou, G., Nikolopoulos, S., & Kompatsiaris, I. (2020). EPANASTASIS-1821: Reviving the naval history of the Revolution through full-immersive Virtual Reality. In: Helin, K., de Antonio, A., & Reyes-Lecuona, A. (eds.). Proc. Virtual EuroVR Conf. VTT Technology No. 381, pp.65-70. Valencia, Spain, 25-27 November 2020. <https://doi.org/10.32040/2242-122X.2020.T381>.
- Georgiou, G., Anastasovitis, E., Nikolopoulos, S., Kompatsiaris, I. (2021). EPANASTASIS-1821: Designing an Immersive Virtual Museum for the Revival of Historical Events of the Greek Revolution. In: Ioannides M., Fink E., Cantoni L., Champion E. (eds) Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection. EuroMed 2020. Lecture Notes in Computer Science, 12642, 334-345, Cyprus, 02-05 November 2020. Springer, Cham. https://doi.org/10.1007/978-3-030-73043-7_28.

ECHOES from the past through immersive technologies and creative industry

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Keywords: Virtual reality, augmented reality, serious game, gamification, cultural heritage, storytelling, storyliving.

Introduction

The excavations of the Metropolitan Railway in Thessaloniki brought to light 250000 movable finds, 55181497 m² of excavation space as well as the two ancient cemeteries of the city with approximately 4500 burials. The findings bear witness to the multicultural character of the city as well as to the long history that has continued for 23 centuries. This important archaeological treasure is undoubtedly a field of important scientific research, but it can also be an innovative cultural product with applications and services offered by cultural institutions and individuals to the general public and the ever-growing touristic element of the city.

The main goal of the *ECHOES* research project is the access of visitors to the history of the city through a pioneering prism of study and innovative presentation of the biography of its inhabitants. However, to present the story of a city's people in an interactive way so that the visitor can participate and experience it more intensely, advanced visualizations and storytelling methods are required. These will be developed during the project and will be implemented for these purposes.

This contribution presents the immersive technologies and the tools from the sector of creative industries that will be used for the design and the development of the digital cultural products in our effort to fulfill the cardinal objective of the *ECHOES* research project.

Creative industry and immersive technologies

The digital documentation and presentation of archaeological finds and skeletal remains is used both at the museological and research level. Among the emerging technological applications in the field of museology is the establishment of virtual and augmented reality. In virtual reality the user is immersed in another space and in a past time using a head mounted display, while in augmented reality the existing material of the physical exhibition is enriched with multimedia content displayed on a portable device (smart-phone, tablet).

Based on gained expertise from previous projects (Anastasovitis et al., 2017-2021), the research team defined a scenario regarding the VR application. The selection, the collection, and the documentation of the archaeo-anthropological will feed the artistic team in creating 3D digital representations of objects and places from scratch with top level of photorealism. In addition, through photogrammetry and decimation some special artifacts will be digitized for further use in *Unity3D* game-engine. 3D characters will be made through the *Make-human* software and they will get some predefined animations in *Mixamo*.

The player of the VR application will use the *Oculus Quest II* HMD. The starting, as well as the anchor point of the full-immersive experiences will be a subway wagon. Through the five selected metro-stops (Table 2) the VR user have the opportunity to explore and gain the knowledge for the history of the city. The gamified missions and the storyliving will offer an edutaining perspective in the whole experience.

In a similar way, the visitor of the city will have the opportunity to learn the history of Thessaloniki through the AR application, during the cultural walks in downtown.

Table 2. Knowledge transfer for each thematic area of the SG for the virtual reality production.

Thematic	Knowledge transfer	Means of communication
Nutrition	mortality, habits	VR experiential, 3D-animation, storytelling, storyliving
Professions	scripter's office	VR experiential, 3D-animation, storytelling, storyliving
Trade	the life at the port area	VR experiential, 3D-animation, storytelling, storyliving
Burial customs	tomb architecture, funeral pyre, artifacts	VR experiential, 3D-animation, storytelling, storyliving
Breastfeeding	infant nutrition	VR experiential, 3D-animation, storytelling, storyliving

Conclusion and future work

In this contribution the combination of creative industry and immersive technologies for better communication and understanding of cultural heritage was presented. The use of gamification in augmented reality application during the cultural walk in Thessaloniki, as well as the development of full-immersive serious game in virtual reality that promotes the story of the city under the perspective of archaeo-anthropology is the core of this presentation. Both of the initial versions of XR digital cultural productions will be tested by the experts and the evaluation will feed the final edition of the AR and VR applications.

Acknowledgements

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References

- Anastasovitis, E., Ververidis, D., Nikolopoulos, S., & Kompatsiaris, I. (2017). Digiart: Building new 3D cultural heritage worlds. In 2017 3DTV Conference: The True Vision-Capture, Transmission and Display of 3D Video (3DTV-CON), 7-9 June 2017, Copenhagen, Denmark, (pp. 1-4). IEEE. <https://doi.org/10.1109/3dtv.2017.8280406>.
- Anastasovitis, E., Ververidis, D., Nikolopoulos, S., Kompatsiaris, I., Abrams, G., Modica, K.D., Bonjean, D., Groote, I.D., Bezombes, F. & Strecha, C. (2017). DigiArt: Exploring the Scladina cave. Demonstration presented at EuroVR 2017 International Conference, Laval, France, 12-14 December 2017, pp.10-11. https://www.researchgate.net/publication/340594796_DigiArt_Exploring_the_Scladina_cave
- Anastasovitis, E., & Roumeliotis, M. (2018). Virtual Museum for the Antikythera Mechanism: Designing an immersive cultural exhibition. In 2018 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct), Munich, Germany, 16-20 October 2018, pp. 310-313, <https://doi.org/10.1109/ismar-adjunct.2018.00092>. IEEE.
- Anastasovitis, E. & Roumeliotis, M. (2019). Designing an edutainment serious game for the Antikythera Mechanism in virtual reality. In Helin, K., Perret, J., & Kuts, V. (eds.) The application track, posters and demos of EuroVR: Proceedings of the 16th Annual EuroVR Conference. VTT Technology No. 357, 94-97. Tallinn, Estonia, 23-25 October 2019. <https://doi.org/10.32040/2242-122X.2019.T357>,
- Anastasovitis, E., Nikolopoulos, S., & Kompatsiaris, I. (2019). Experiencing the impossible through virtual and augmented reality. In Conference abstracts "They are not silent after all. Human remains in archaeological museums: Ethics and Display", pp. 64-65, 31 Oct. - 01 Nov. 2019, Acropolis Museum, Athens, Greece. Retrieved: https://humanremainsmuseums.gr/wp-content/uploads/2020/01/humanremains_Conference-Abstracts.pdf
- Anastasovitis, E., Georgiou, G., Nikolopoulos, S., & Kompatsiaris, I. (2020). EPANASTASIS-1821: Reviving the naval history of the Revolution through full-immersive Virtual Reality. In: Helin, K., de Antonio, A., & Reyes-Lecuona, A. (eds.) EuroVR 2020 Application, Exhibition & Demo Track: Proceedings of the Virtual EuroVR Conference. VTT Technology No. 381, pp. 65-70. <https://doi.org/10.32040/2242-122X.2020.T381>, Valencia, Spain, 25-27 November 2020.
- Anastasovitis, E. & Roumeliotis, M. (2021). Creative Industries and Immersive Technologies for Training, Understanding and Communication in Cultural Heritage. In: Ioannides M., Fink E., Cantoni L., Champion E. (eds) Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection. EuroMed 2020. Lecture Notes in Computer Science, vol 12642, pp.450-461, Cyprus, 02-05 November 2020. Springer, Cham. https://doi.org/10.1007/978-3-030-73043-7_37
- Anastasovitis, E., Tsita, C., Satratzemi, M., & Roumeliotis, M. (2021). User Experience Design of Full-Immersive Serious Games for improvement of Cultural Heritage Communication and Understanding. In Proceedings of Computer Applications & Quantitative Methods in Archaeology Conference "Digital Crossroads". CAA 2021. Limassol, Cyprus, 14-18 June 2021.

Anastasovitis, E. & Roumeliotis, M. (2021). Factors for the Evaluation of the Experiential and Full-Immersive Virtual Museum for the Antikythera Mechanism. In Proceedings of International Conference "Cultural Heritage in the Digital Dimension". Perm, Russia, 20-22 October 2021.

Perceptual BRDF manipulation by 4-Degree of Freedom Light Field Projection using Multiple Mirrors and Projectors

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Keywords: Light Field, Spatial Augmented Reality, BRDF

Introduction

Spatial augmented reality (SAR), among other applications, can also be used for appearance manipulation and making objects appear in the real world by projecting light through a projector. As part of the ongoing SAR research, we propose viewing-direction-dependent appearance manipulation through light field projection.

Amano et al. (2017) proposed a viewpoint-dependent appearance manipulation using four pairs of independently working projector-camera feedback units. These units individually enable appearance manipulation in each direction and show complex reflections such as structural color. However, its manipulation involved error as the independently working projector-camera units do not consider projected illumination from the other units in their projection calculation. Murakami et al. (2018) proposed a surface reflection model for viewing-direction-dependent appearance manipulation. Projection images for each projector are obtained using this model based on the reflectance analysis among multiple projectors and cameras with non-negative least-square optimization. This pixelwise reflection analysis enables precise viewing-direction-dependent appearance manipulation. Amano and Yoshioka (2020) combined these methods and achieved precise viewing-direction-dependent appearance manipulation capable of several reflection properties with the disturbance compensation.

The viewing-direction-dependent appearance manipulation potentially alternates the surface bidirectional reflectance distribution function (BRDF) in perception. This novel technology can be used for projection mapping, scientific simulation, product design support, optical restoration in the museum, eye-catching illumination for jewelry stores, and others. However, these applications require accurate geometrical registrations and optical calibrations among projectors and cameras. Therefore, this study proposes an approximated but versatile viewing-direction-dependent perceptual BRDF manipulation method by reproducing the predesigned light-field, which achieves the desired light reflection distribution.

Proposed Method

We reproduce the desired color at θ_o in a specular-reflecting object as shown in Figure 59. The color in the observation direction θ_o is first obtained from BRDF $f(\theta_i, \theta_o)$. We assume specular reflection on the display surface and determine the color to be projected from incident direction θ_o , which is mirror symmetry about normal vector \mathbf{n} . For the observation direction θ_o' , the reflected light ray can be displayed by another illumination casting from of incident direction θ_o' with the projection $f(\theta_i, \theta_o')$. The projection is performed in the same way for observation direction θ_o' . Although the normal vector depends on the object shape, we regard it to be flat and fix the normal direction to be perpendicular to the surface for versatility. However, the system cannot display reflected light rays in all observation directions. Therefore, we calculated projection color for possible all casting light ray directions by our projection system shown in Figure 60.

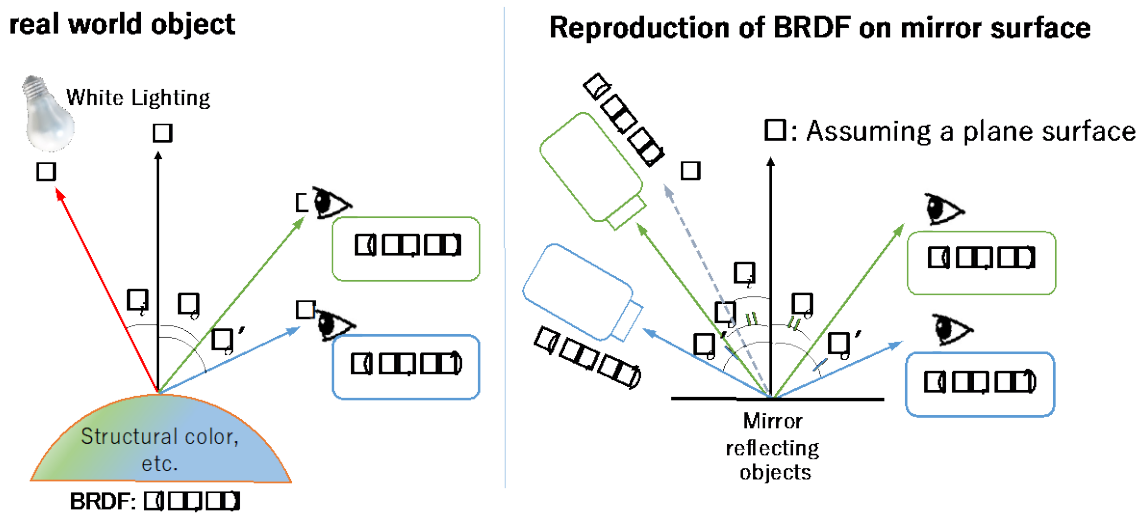


Figure 59. Reproduction of light distribution of structural color.

Projection Environment

We composed a light field projection system consisting of four projectors and nine mirrors (300 mm × 300 mm, distance between a stage and mirrors 850 mm), as shown in Figure 60. The stage on which the projection targets are placed is 300 mm square. An ultra-short-throw projector (RICOH PJWX4125) was used in this study, which enabled the projection of lights from a range of zenith angles $-40^\circ \leq \theta \leq 40^\circ$ at all points on the stage. When the projection from each projector hits all the mirrors and illuminate the entire stage area in the ideal situation, each point on the stage is illuminated by light rays from $9 \times 4 = 36$ different directions. Using homography, we describe the relationship among the projector, mirror, and stage coordinates. Then, we calculate the projection coordinates on the stage. Lastly, we calculate its incident angle (azimuth and zenith angles) from the coordinate on the mirror for each projection pixel.

Reproducing the RGL Material Database

In this study, the RGL Material Database (Dupuy & Jacob, 2018) was used as a target for the presented appearance. We placed a virtual point light source at $(X, Y, Z) = (0.0m, 0.2m, 1.0m)$ and generated projection images for each projector. Firstly, we sampled RGB color from the BRDF

database for all projection pixels. The incident angle and observation angle are given from the virtual light source position and the incident angle of the projection ray.

At each stage point, multiple light rays are projected by the combination of nine mirrors and four projectors. We sampled BRDF for all combinations and generated image for each projector. Figure 61 shows the result of projecting the generated projection image onto the projection target. Each column corresponds to the viewing direction.

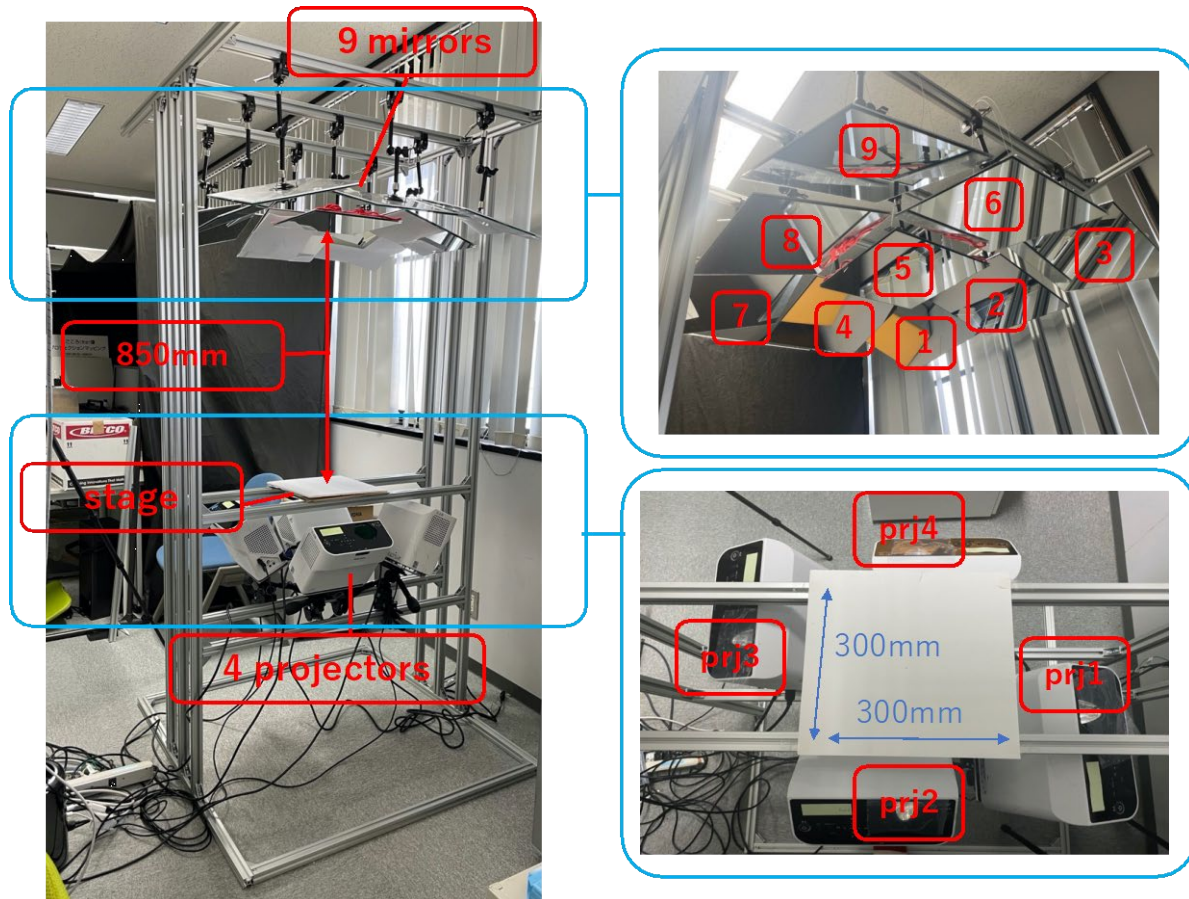


Figure 60. Light Field Projection System.

Discussion

Figure 61 shows that the specular area is emphasized in Golden Yellow, Silk Blue, and Aurora White, and that the color and specular area change as the viewing direction changes. In comparison, the specular of the matte sample Pink Acrylic Felt is weak. Its color is uniformed, and the matte appearance that reflects the BRDF model is well reproduced.

Figure 62 shows the results on various objects to confirm the reproducibility of RGL BRDF. The object shown in the first column (Laptop PC) has a strong diffuse reflection component. Thus, it is difficult to reproduce the strong specular reflection. But the color change around the specular area and the matte appearance of the Pink Acrylic Felt can be confirmed. In the second column (Studs), the color change reflecting BRDF can be seen, although the complex shape of the specular surface causes mutual reflections. We can observe the materiality expression even on transparent object (Glass bowl), as shown in the last column. In contrast, it was confirmed that it is difficult to alternate to a matte appearance such as Pink Acrylic Felt on objects with strong specular reflection (Studs, Glass bowl) despite the specular being suppressed.

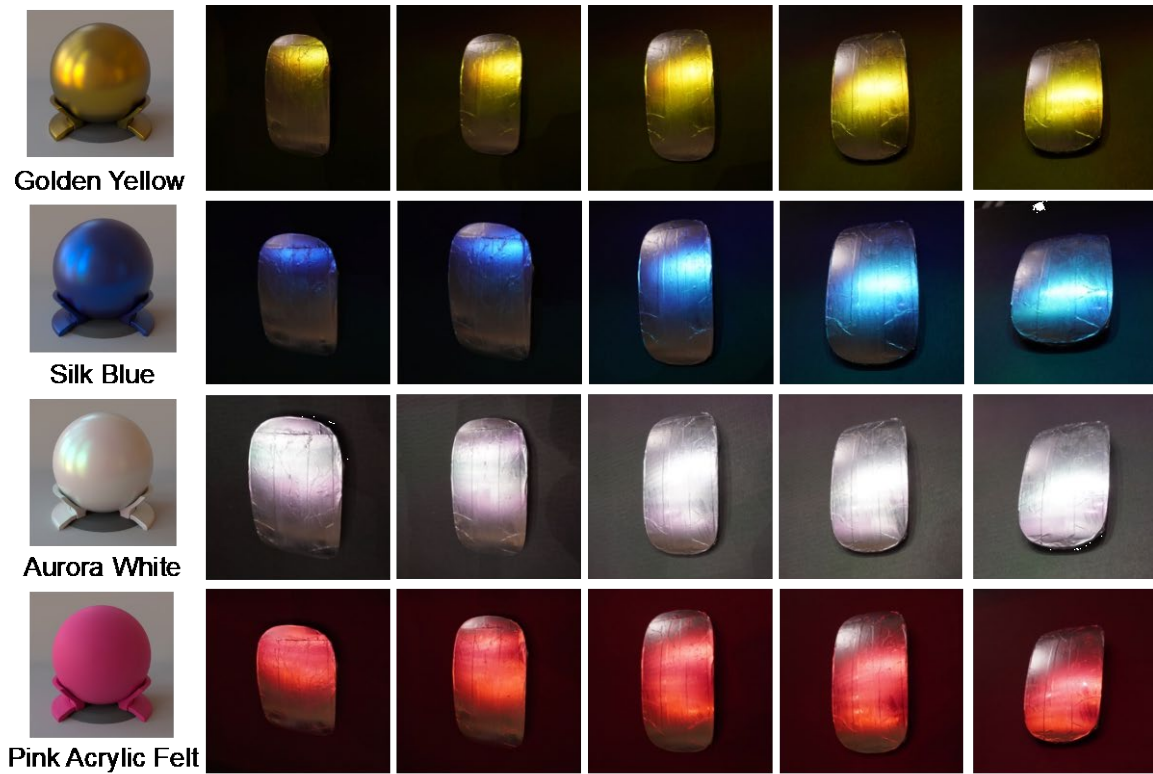


Figure 61. Reproduction of RGL Material Database on Mouse and aluminum foil.

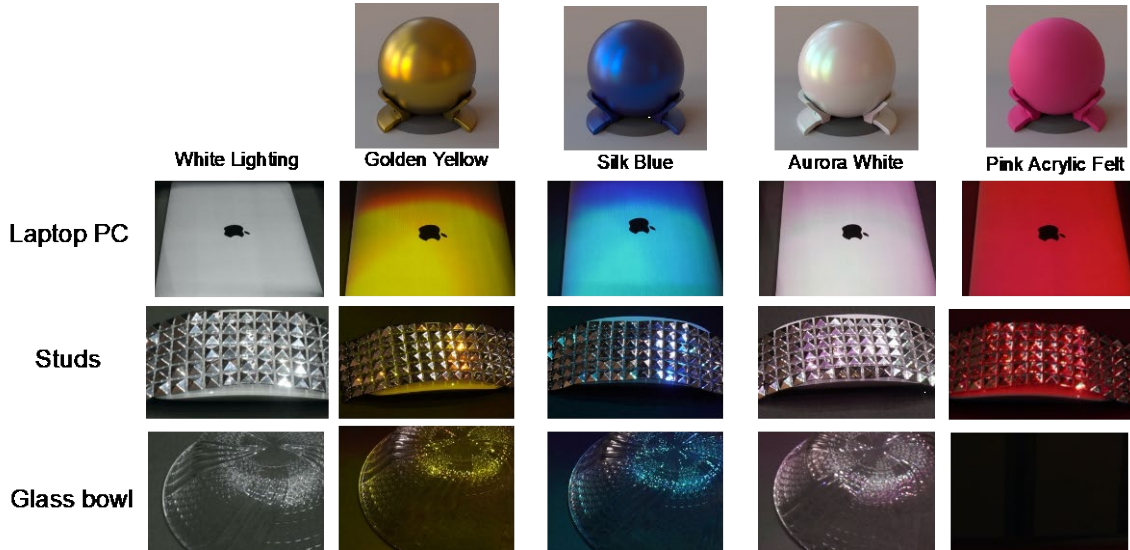


Figure 62. BRDF presentation results on various objects.

Conclusion

We proposed a method to display BRDF aiming for complex reflection such as structural color on the arbitrary shape surface with precisely designed light field projection. Consequently, we confirmed that the change in color according to viewpoint reflected the BRDF data. In future work, it is necessary to clarify whether the BRDF is correctly represented in terms of the relationship between view-point shift and normal direction and show the limitation.

Acknowledgements

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References

- Amano, T., Ushida, S., & Miyabayashi, Y. (2017, November). dependent appearance-manipulation with multiple projector-camera systems. In Proceedings of the 27th International Conference on Artificial Reality and Telexistence and 22nd Eurographics Symposium on Virtual Environments (pp. 101-107).
- Murakami, K., & Amano, T. (2018). Materiality manipulation by light-field projection from reflectance analysis.
- Amano, T., & Yoshioka, H. (2020, November). Viewing-Direction Dependent Appearance Manipulation Based on Light-Field Feedback. In *International Conference on Virtual Reality and Augmented Reality* (pp. 192-205). Springer, Cham.
- Dupuy, J., & Jakob, W. (2018). An adaptive parameterization for efficient material acquisition and rendering. *ACM Transactions on graphics (TOG)*, 37(6), 1-14.

Gesture Profiles: Personalized Gesture Interaction with Augmented Reality

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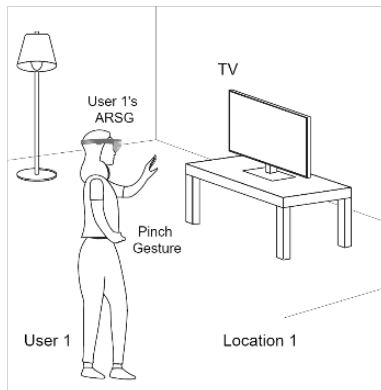
Keywords: Gestures Interactions, Personalization, Augmented Reality

Introduction

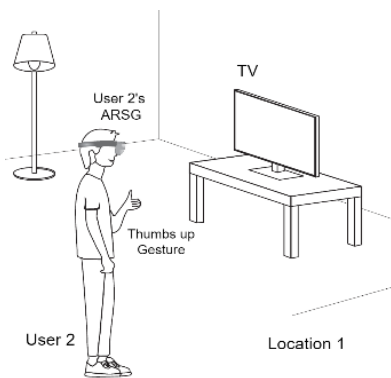
Gesture interaction is a prominent, accessible, and an emerging Natural User Interaction (NUI) technique. It has captivated Human-Computer Interaction (HCI) researchers for decades and continues to drive contemporary research in emerging technologies such as Augmented Reality (AR) and smart ecosystems. This is primarily due to the ubiquitous and personalized nature of gestures. Users' choice and meaning of a gesture could change across different countries, cultures, contexts, and user backgrounds (Aigner et al., 2012). Thus, gesture interfaces could cause ambiguities when users switch contexts, confusing those who are accustomed to a set of conventional controls, and negatively impacting their user experience (UX). Therefore, we investigate a design framework that could allow users to retain their preferred gestures when interacting with referents, even as the context (such as location, device type, etc) changes. We use AR Smart Glasses (ARSG) as the enabler of the framework which does the recognition of user-preferred gestures and establishes communication with relevant smart objects. This paper presents a use case along with a functional prototype that we developed as a proof of concept (PoC) using HoloLens 2 (HL2) and a pilot user study to describe the current position and the future directions of this proposed framework.

Conventionally, gestural interfaces are designed by experts or professional system developers without input from end-users (Wu et al, 2019, Rekimoto et al., 2002). Hence gesture vocabularies differ from one manufacturer to another, resulting in a greater variation in ways to interact with devices, even with the same affordances. A general user may interact with smart ecosystems such as smart homes, hotels, and offices which may have these different manufactured devices that support miscellaneous gestures to interact with similar affordances. Further, certain users may not be able to perform the 'manufacturer design gestures' due to disability which makes the system

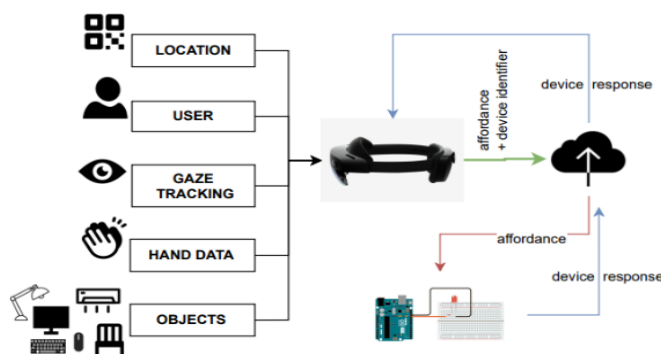
inaccessible for them. Instances such as these compel users to learn and memorize new gesture interactions or give up altogether on some features, negatively impacting their UX. This postulates the necessity of either a common standard for mid-air gestures (similar to what we see in gestures used in touch interfaces) or a design to reduce having to learn new interactions. Focused on the latter, we propose 'gesture profiles' per user. This concept allows users to maintain a personalized gesture set that they prefer to interact with referents. i.e., for instance, a user may seamlessly use their preferred hand gesture to interact with common referent such as turning on any smart TV regardless of the manufacturing differences.



(a) User 1 interacting with Turn On TV referent in location 1 using thumbs up gesture.



(b) User 2 interacting with Turn On TV referent in location 1 using pinch gesture.



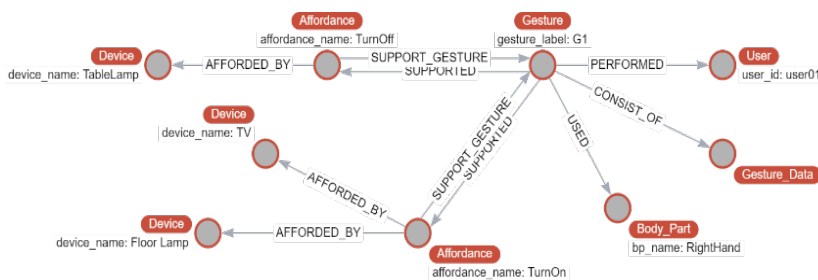
(c) List of inputs an ARSG uses to query UGI-KG and ARSG data exchange with a server.

Figure 63. Use of personalized gesture profiles per user using ARSGs.

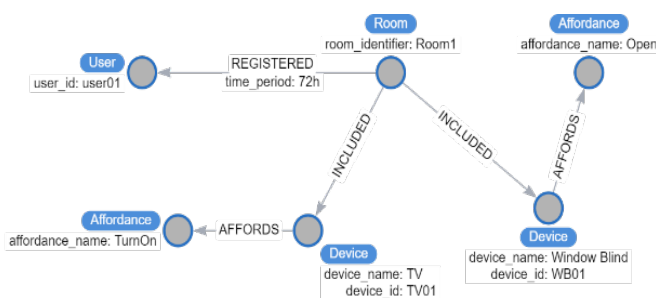
On the design and engineering side of this challenge, we have to deal with complex data and relationships between devices, affordances, user preferences, and context (e.g., locations). While we acknowledge that there are different device communication protocols, in this work we used HTTP as the general communication protocol for data exchanges and focus on data modeling and mapping problems mainly.

Use Case

We take a use case of a smart hotel (Yang et al., 2021) to discuss the architecture that we propose. Our design involves two KGs as shown in Figure 64. i) H-KG which contains details of the hotel room (Figure 64b) ii) UGI-KG contains the user’s gesture interaction profile (Figure 64a). During the process of user check-in, the hotel creates the relationship ‘registered’ in H-KG allowing the user to access room facilities information for a specified time. This connectivity allows the user’s ARSG to identify the details of the devices and their capabilities in the hotel room. Once the user enters the room, ARSG can track the user’s gaze and list the affordances of the devices the user is gazing at (extract from H-KG). If the user has already interacted with the same affordance before, then the user can use the same gesture they prefer without having to adapt to a new gesture. For example, Figure 2(a) shows that the ‘user01’ has gesture ‘G1’ calibrated for the ‘TurnOn’ affordance of a TV. So, the user can perform ‘G1’ gesture seamlessly with the TV in ‘Room1’ which has the same affordance. On the other hand, if there’s a new affordance ARSG can identify it from UGI-KG and ask the user to configure a gesture and store it in their UGI-KG (e.g., see the window blind open affordance in H-KG in Figure 2 (b)). This new gesture can be used later in any location with a device that has this capability. During this workflow, ARSG uses input data listed in Figure 1 and uses UGI-KG and H-KG accordingly to identify the relationships. Once the user checks out from the hotel, the ‘registered’ relationship will be deleted from H-KG and users no longer will be able to communicate with those devices outside the hotel intranet. Neither H-KG nor UGI-KG exchanged users’ personal data during this process, preserving privacy. The overall design is inspired by commercially available voice hubs (like Amazon echo dots), with the ARSG playing the role of the hub. This way, device manufacturers do not have to embed cameras in their devices for gesture recognition (which is not feasible sometimes with devices such as window blinds, coffee machines, etc). Further, ARSG has the potential to offer a bespoke experience for individual users and is predicted to be personal computing devices like smartphones (Orchard et al., 2022). Thus, the proposed interaction and development architecture will be helpful in building seamless user experience and privacy-preserving interactions.



(a) User Preferred Gesture Interaction - Knowledge Graph (UGI-KG)



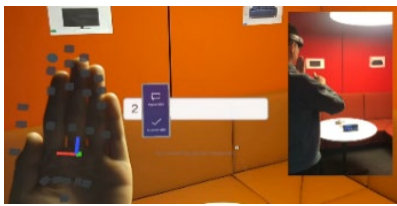
(b) Hotel Room Data - Knowledge Graph (H-KG)

Figure 64. Use of Knowledge Graphs for data modelling.

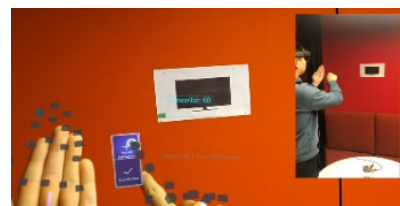
Prototyping

We developed a functional prototype as a PoC using HL2 ARSG and Arduino Uno development board. We used tiny YOLO v2 with HL2 to detect symbolic device figures (which represent devices as shown in Figure 65 pasted on the wall (referred to as 'smart object' hereafter). Each smart object is color-coded. This color-coded smart object functionality is represented by an LED. We only considered one affordance, 'Activate smart object', with three smart objects and considered static gestures for this prototype. The representative LED will turn on once a user performs their preferred gesture with each smart object.

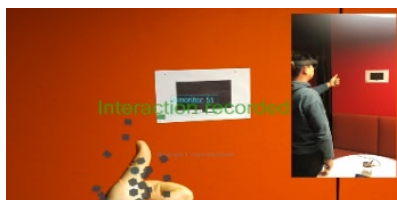
The user is asked to enter a participant ID to get started (See Figure 65 a and e). Once the location and user ID are identified HL2 can query the user preferences. Once a user gazes at the smart object, HL2 will detect it and offers the option to record a gesture if the entered user ID has not interacted with this smart object before (The first time there will be no gesture preferences, so users must calibrate gestures). See Figure 65 b and f. The recorded gesture data is labeled by HL2 (this is not a semantic label but a representation such as G1, G2, etc.). Next time when the user looks at the smart object and performs the calibrated gesture, HL2 will provide the feedback 'Gesture Recognized' to the user and update the server with relevant affordance and device info (Figure 63). Then the corresponding LED will be lit indicating the device response as shown in Figure 65 d and h. A video of the process can be found [here](#).



(a) User 2 enters their user ID



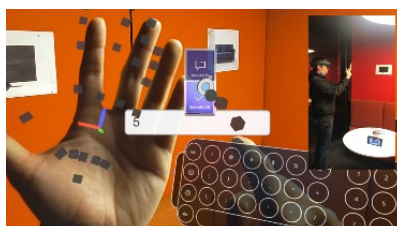
(b) HL2 detect smart object



(c) User 2 - Gesture calibration



(d) HL2 recognize user 2 specific



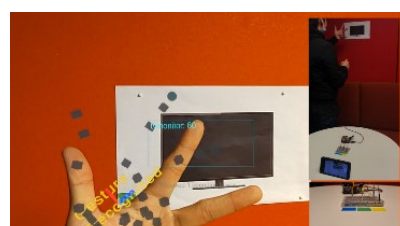
(e) User 5 enters their user ID



(f) HL2 detect smart object



(g) User 2 - Gesture calibration



(h) HL2 recognize user 2 specific gesture

Figure 65. Prototype - Use of HoloLens 2 with personalized gesture profiles.

Study Design

With the prototype, we conducted a between-group pilot study with 6 participants (3 in each group). Our aim was to conduct a descriptive investigation (Rosenthal and Rosnow, 2008) prior to conducting experimental research (Kirk, 1982). All the participants had used HL2 before, so we skipped a training session. The investigator showed the first group of participants how the system works by explaining the use case and asked them to imagine they are in a smart hotel room i.e., once the participant entered the room, they were primed (Schacter et al., 1998). They could observe three smart objects and how the investigator performed three static gestures to interact with them. Each smart object had a color label that was mapped to an LED. After that, participants were brought outside the room and the smart object positions were shuffled. Then the participants were invited back to the room, and they were asked to interact with the same smart objects. Participants had to recall the gestures that they observed at the beginning. They were given two chances per object. The second group of participants was also primed with the same use case, but they were given the chance to calibrate the gestures of their preference rather than observing the investigator. They first entered the room and calibrated their preferred static gestures. Then, similar to participant group one, they walked out. Smart objects were shuffled and were asked to interact with their celebrated gestures. They were also given two attempts per smart object.

Participants from both groups were interviewed using semi-structured questionnaires post-experiment. The investigator observed the successful attempts, aiming to infer the success rate of performing the same gestures. Since the aim of the pilot study was to do a descriptive investigation, and due to the low sample size, we did not conduct a comprehensive statistical analysis. The results of the pilot showed a 0.75 success rate while group two participants reported a 0.91 success with only one participant missing their first attempt. In the questionnaires, we asked whether the participant preferred to use their own gesture or predesigned gestures. All the participants showed very high interest (on a Likert scale) in the gesture profiling concept. They all liked the idea of maintaining a gesture profile and being able to carry a gesture set unique to them that can be used seamlessly.

Discussion and Conclusion

ARSGs, are a relatively new development in consumer-level personal computing. Yet ARSGs' inclined growth predictions (Global Market Insights (Wadhvani et al., 2017) can be a cornerstone in the process to overcome concerns of implementing gestural interfaces for smart ecosystems, combined with knowledge modeling techniques. With this wearable technology, personalization of interactions has become a feasible research direction, given the proliferation of ARSG capabilities. Our descriptive investigation identifies and resonates with Nacenta et al's (Nacenta et al., 2013) finding that user-preferred gestures are memorable and easy to use and offer a promising direction towards future research of the concept 'gesture profiles'. We aim to ameliorate the prototype by embedding the UX elements and 3D object identification along with the integration of calibration of dynamic gestures. We believe this work paves the way for researchers to investigate further the concept of 'gesture profiles' and integration of immersive computing and internet of things applications.

Overall, in this research, we looked at how wearable ARSG can be used as a medium to enable the concept of gesture profiling. This allows users to seamlessly interact with the smart environment with their accustomed gesture interactions by mitigating the gulf of execution

caused by ambiguities in current gestural interfaces. Further, in the instances where experts design gestures that are not feasible, personalization could provide increased accessibility. Therefore, the proposed architecture elevates the accessibility of gesture-controlled interfaces by allowing users to calibrate the gestures that they prefer or are feasible for them to perform. We discussed a designed roadmap with a use case and developed a functional prototype as a PoC and conducted a pilot study to identify the usability of the proposed architecture.

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References

- Aigner, R., Wigdor, D., Benko, H., Haller, M., Lindbauer, D., Ion, A., ... & Koh, J. T. K. V. (2012). Understanding mid-air hand gestures: A study of human preferences in usage of gesture types for hci. Microsoft Research TechReport MSR-TR-2012-111, 2, 30.
- Kirk, R. E. (2012). *Experimental design: Procedures for the behavioral sciences*. Sage Publications.
- Nacenta, M. A., Kamber, Y., Qiang, Y., & Kristensson, P. O. (2013). Memorability of pre-designed and user-defined gesture sets. In *Proc SIGCHI Conf on Human Factors in computing systems*, 1099-1108.
- Orchard, A., O'Gorman, M., La Vecchia, C., & Lajoie, J. (2022). Augmented Reality Smart Glasses in Focus: A User Group Report. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts*, 1-7.
- Perera, M., Haller, A., Rodríguez Méndez, S. J., & Adcock, M. (2020). Hdgi: A human device gesture interaction ontology for the internet of things. In *Int. Semantic Web Conf.*, 111-126, Springer, Cham.
- Rekimoto, J. (2002, April). SmartSkin: an infrastructure for freehand manipulation on interactive surfaces. In *Proceedings of the SIGCHI Conf on Human Factors in Computing Systems*, 113-120.
- Rosenthal, R., & Rosnow, R. L. (2008). *Essentials of behavioral research: Methods and data analysis*.
- Schacter, D. L., & Buckner, R. L. (1998). Priming and the brain. *Neuron*, 20(2), 185-195.
- Wadhvani, P., & Gankar, S. (2017). Global Market Insights Inc. Mixed Reality Headsets Market Size - Industry Share Report 2017-2024. [online] Available at: <https://www.gminsights.com/industry-analysis/mixed-reality-headsets-market>
- Wu, H., Luo, W., Pan, N., Nan, S., Deng, Y., Fu, S., & Yang, L. (2019). Understanding freehand gestures: a study of freehand gestural interaction for immersive VR shopping applications. *Human-centric Computing and Information Sciences*, 9(1), 1-26.
- Wu, M., & Balakrishnan, R. (2003, November). Multi-finger and whole hand gestural interaction techniques for multi-user tabletop displays. In *Proc 16th Ann ACM symp on User interface software and technology*, 193-202.
- Yang, H., Song, H., Cheung, C., & Guan, J. (2021). How to enhance hotel guests' acceptance and experience of smart hotel technology: An examination of visiting intentions. *International journal of hospitality management*, 97, 103000.

Demos

The Immersive Virtual Reality Classroom: Teaching VR inside VR

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Keywords: Virtual Reality, Education, Immersive Learning

Social virtual reality (SVR) refers to immersive *virtual reality (VR)* systems that prioritize and focus on the in-environment communication between multiple users (Liu & Steed, 2021). The applications of SVR are ranging from recreational to business contexts and enable embodied users to interact and participate in shared activities. For educational use, SVR furthermore promises a pedagogic potential going far beyond classical remote lectures, by enriching lectures with first-hand experiences, interactions, embodiment, and presence. With the aspiration to revolutionize our university-level lecture on VR, to convey a deeper understanding of VR through hands-on experiences, we developed our own SVR platform, the *Virtual Reality Classroom (VRCR)*, and brought several lectures on the medium itself into a virtual world, shared between students and lecturer. Figure 66 shows an excerpt from a lecture in the VRCR.

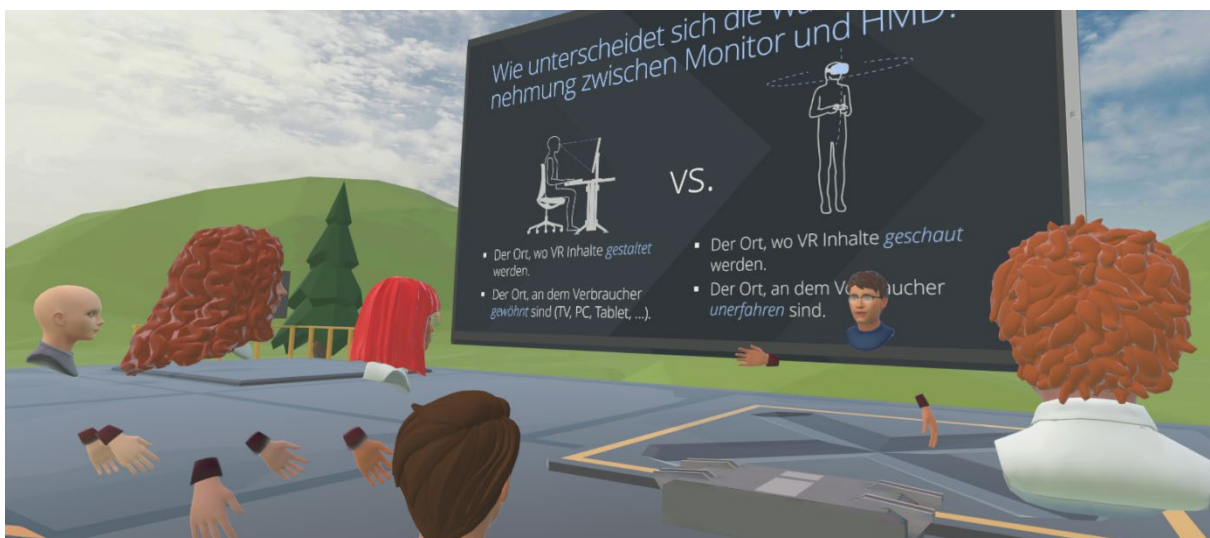


Figure 66. Snapshot of a lecture in the VRCR.

The field of VR in higher education is highly multifaceted and difficult to convey in a classical form of lecture, without students ever having worn an HMD. The life-long learned rules of the physical world do not apply similarly in virtuality and unenlightened listeners face the challenge to only imagine the presence an immersive VR application is able to convey in comparison to traditional desktop applications. For example, specificities of VR application design, like movement techniques in a limited playspace, or object interactions with no haptics and weight can have very different manifestations in virtual worlds in comparison to reality. We implemented various state-of-the-art as well as experimental forms of movement and interaction techniques currently found in the landscape of VR applications and enabled students to try them out during lectures. To foster the experience further, the VRCCR additionally facilitates an understanding of the medium by employing learning frameworks, like experiential learning and game-based learning. Students are given the possibility to experiment with the content during lectures in a playful way, for example, as seen in Figure 67, by trying out different forms of artificial movement like teleportation, controller bound, or gestural-based movement in a parkour challenge against their fellow students. Similarly, in a lecture on artificial interaction techniques, students could experiment with different methods specific to immersive VR such as raycasts, direct interactions, or occlusion-based techniques, in a game of virtual volleyball. The suitability of the interaction techniques for different applications was conveyed through differently sized and weighted balls. Intricacies and suitability of different VR design choices like movement techniques or interactions can thus be learned first-hand in the VRCCR and discussed as part of the lecture.



Figure 67. Experiential learning of virtual movement techniques in the VRCCR.

The VRCCR can also be used as a space for students to demo and present their own developments. For example, 3D models developed as part of practical lessons can easily be loaded into the common space to be observed and discussed. Next to the lecture content, the shared virtual environment also contains some leisure activities, such as a basketball court (see Figure 68), where students can chat or play before or after lectures.

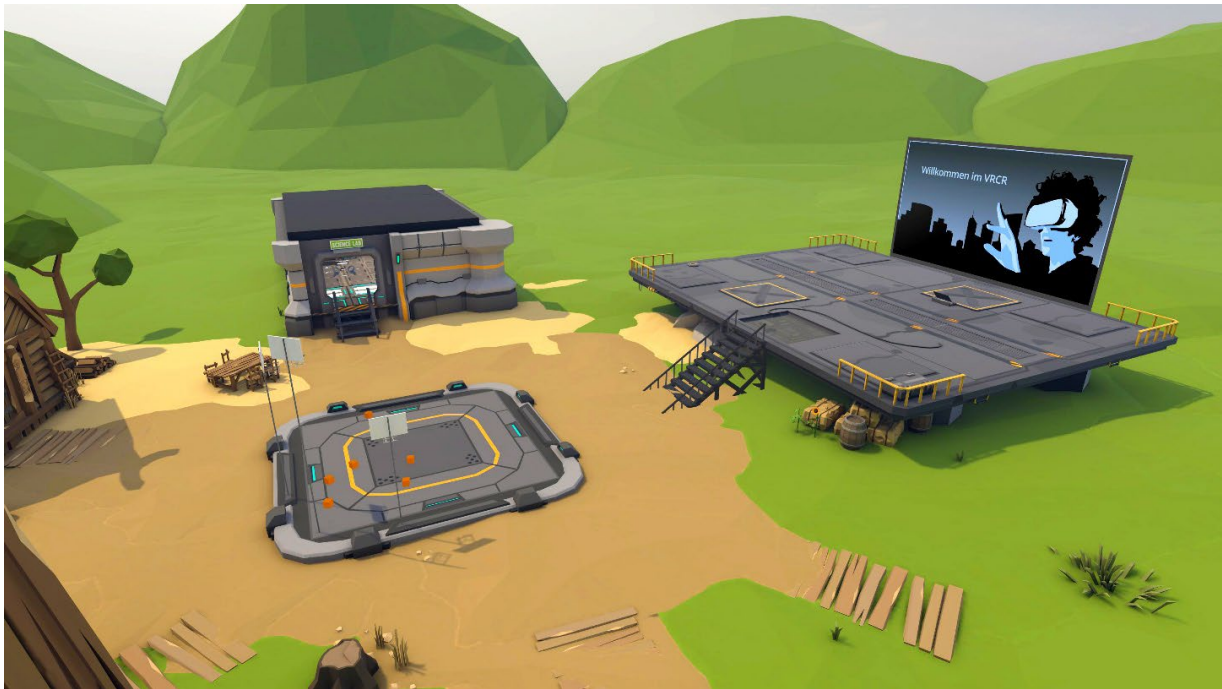


Figure 68. Overview of the common virtual lecture space.

The VRCR is developed at the Karlsruhe University of Applied Sciences in the game engine *Unity*⁴ and distributed to students via 50 available *Meta Quest 2* head-mounted displays (HMD). The multiplayer application is networked with the open-source *Mirror*⁵ netcode and hosted on the federal state service *bwCloud*⁶. Before joining the VRCR, students and lecturers create their own avatars via a browser-based *Ready Player Me*⁷ avatar configurator, which can then be loaded live into the application. It supports voice communication as well as non-verbal, gestural interactions through the individual virtual embodiment. To aid lecture and student presentations, the VRCR includes interfaces to load .PDF and .OBJ files live into the classroom.

The in-house development greatly benefits from a continuous evaluation by the students and the possibility for quick feedback loops. Preliminary evaluation of the first semester already showed great appreciation of the new format by students. For the following semester, it is planned to open the course and the VRCR for students from other universities of applied sciences and to evaluate open questions regarding virtual education further. For example, the duration of VR lectures to the onset of pertinent adverse symptoms is still the subject of research. Furthermore, the education quality has still to be assessed and compared to real world lectures as well the influence of the virtual environment design on content comprehension and well-being.

Our demo setup consists of five *Meta Quest 2* HMDs, with which visitors can explore the VRCR and meet other visitors. Selected elements of the virtual lecture, such as various movement or interaction techniques, can be tried out first-hand.

⁴ <https://unity.com/>

⁵ <https://mirror-networking.com/>

⁶ <https://www.bw-cloud.org/>

⁷ <https://readyplayer.me/de>

Acknowledgements

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References

Liu, Q., & Steed, A. (2021). Social Virtual Reality Platform Comparison and Evaluation Using a Guided Group Walkthrough Method. *Frontiers in Virtual Reality*, 2, 668181.

Interacting with 3D Avatars and Laser Pointers in a 360° Image

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Keywords: Virtual Reality, 360° Image, 3D Avatar, Collaborative Environment

A standard rule in 3D rendering is that if two users are at two different positions in space, they will have two different renderings. However, a complete model of the space must be known to respect this rule and create different renderings. With a single 360° image, only the view of the space at the camera position is available. This restriction is challenging when creating a collaborative environment with 3D avatars from a 360° image. Here, we propose a method to integrate avatars in a coherent way in a 360° image. To add interaction between users, a laser pointer metaphor is developed to select elements on the 360° image.

Avatars Insertion

To add avatars consistently in a 360° image, a full 3D reconstruction from the image may be performed. However, because the problem is ambiguous, the reconstruction can be noisy or far from the ground truth. These errors become particularly visible when the user visualizes this reconstruction moving away from the camera position. Our idea is rather to render in VR the same image in all user head-mounted displays, and to shift for each user the position of the other avatars to give the illusion that they see the environment from a different point of view. The principle is illustrated Figure 69 by a case with two users. In the absolute coordinate system, the camera is placed on the origin and the user avatars are around it. Displaying the same image for all users consists in shifting the origin of this absolute world, the camera position, on each user. The avatars of other users are then shifted in a consistently and the user has the impression that the other avatar is at another position in space. The 360° image seen by the users is shown in Figure 70

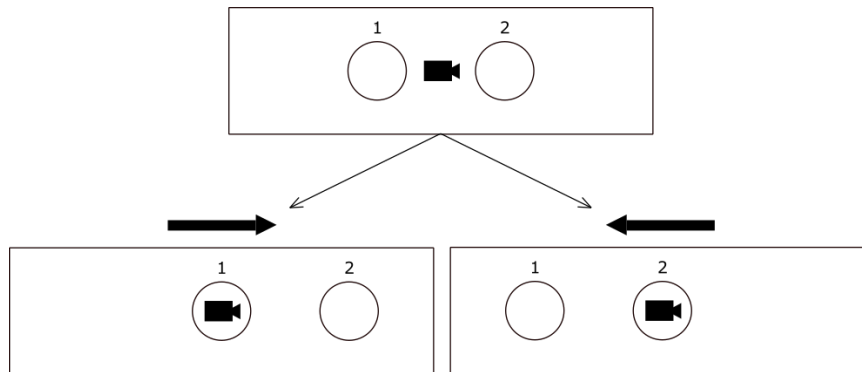


Figure 69. Displaying the same 360° image for two users in different positions. *Top*: Top view of the world in absolute coordinate system. The camera is in the center and the user avatars are around. *Bottom-Left*: Top view of the world seen by user 1. The world is translated to the right to center the camera position on user 1. *Bottom-Right*: Top view of the world seen by user 2. The world is translated to the left to center the camera position on user 2.



Figure 70. 360° views of user 1 and user 2. The images are viewed in the user HMD. In both cases, the image is the same, but the other avatar is not placed at the same position.

Laser Metaphor

To provide additional interaction between users, a pointer metaphor is proposed. This metaphor enables to point to an element in the 360° image with a laser directed by the user controller. The laser starts from the avatar hand and stops at the point of contact with the environment. However, since the origin of the world depends on the user, this contact point is valid only for the controlled user. This contact point must then be translated from the other user perspective to reach the correct element. The problem and the resolution are illustrated Figure 71. If the user receives the targeted contact point from another user, the coordinates of the target in the user world are recovered by applying a translation to the received target. The translation to apply corresponds to the vector from the coordinates of the other user to the coordinates of the controlled user. A laser is then drawn from the other avatar to the corrected target.

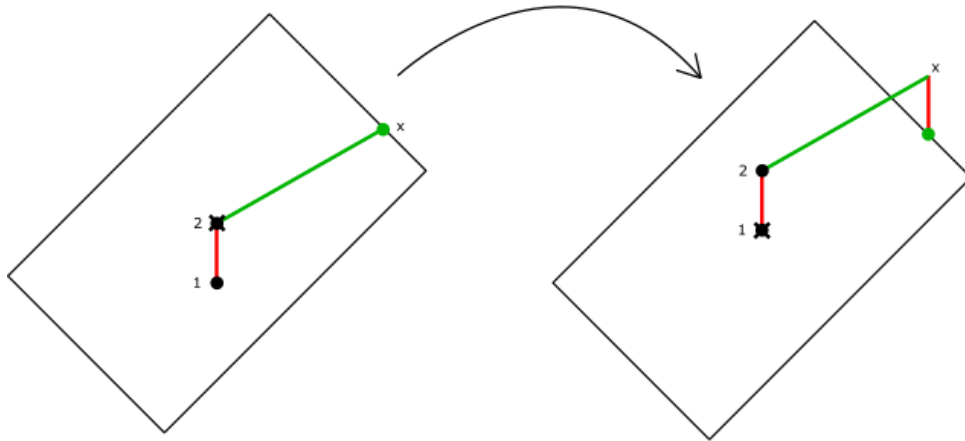


Figure 71. Laser metaphor and target correction. *Left*: Top view of the world centered on user 2. User 2 casts a laser on the environment. The laser intersects the environment at the contact point x . *Right*: Top view of the world centered on user 1. User 1 receives the contact point x , but since the origin of the world is not the same an offset must be applied. The offset is the translation between the two worlds, so in the user 1 world, the right target is recovered by applying a translation of the vector between user 2 and user 1.

The main challenge is that to find this point of contact, a 3D reconstruction of the place must be estimated. Many proposals in the literature solve this task with a deep learning network taking as input only the 360° image (Da Silveira et al., 2022; Sun et al., 2019; Wang et al., 2020; Jiang et al., 2021; Zou et al., 2020). These networks usually give a 360° depth map (de Dinechin & Paljic, 2018) as an output, which can be converted into a mesh (Dziembowski et al., 2016), enabling the calculation of the intersection between the laser and the environment. We used HorizonNet (Sun et al., 2019) because we observed that it seemed to be the most robust neural network. This problem of offset on the laser target is only present for indoor images. If the 360° image represents elements that are interpreted as being far away, then the length of the laser may be seen as infinite, so the offset to be applied becomes negligible.

Demonstration

The demonstration consists in immersing two users in a 360° video with HMD. Each user sees the video with the other user avatar as shown in Figure 70. One user can point his laser at different elements of the environment to ensure that the other sees the same target, so that the environment appears to him to be plausible. An interesting feedback would be to check if the users notice that they have the same view of the environment if the system is not explained to them.

Conclusion

We present a method to add multiple avatars in a single 360° image without 3D reconstruction. This method works by locally centering the 3D user position on the camera and consistently shifting the avatars of other users. A laser pointer metaphor is proposed to add interaction between users. To operate, the coordinates of the target pointed by the laser must be retrieved, and an offset must be applied. Then, to implement this metaphor, a 3D reconstruction of the environment must be performed.

Various improvements can be made to this system. For a better immersion, a motion parallax effect could be added. Several methods implement this effect from a single 360° image (Serrano et al., 2019), or from the omnidirectional stereo (ODS) (Attal et al., 2020; Lai et al., 2019; Mühlhausen et al., 2020), which can be obtained from a 360° camera. User experiments may also be conducted to evaluate the acceptance of this environment and the relation with the distance between users.

References

- Attal, B., Ling, S., Gokaslan, A., Richardt, C., & Tompkin, J. (2020, August). MatryODShka: Real-time 6DoF video view synthesis using multi-sphere images. In *European Conference on Computer Vision* (pp. 441-459). Springer, Cham.
- da Silveira, T. L., Pinto, P. G., Murrugarra-Llerena, J., & Jung, C. R. (2022). 3d scene geometry estimation from 360 imagery: A survey. *ACM Computing Surveys (CSUR)*.
- de Dinechin, G. D., & Paljic, A. (2018, October). Cinematic virtual reality with motion parallax from a single monoscopic omnidirectional image. In *2018 3rd Digital Heritage International Congress (DigitalHERITAGE) held jointly with 2018 24th International Conference on Virtual Systems & Multimedia (VSMM 2018)* (pp. 1-8). IEEE.
- Dziembowski, A., Grzelka, A., Mieloch, D., Stankiewicz, O., Wegner, K., & Domański, M. (2016, December). Multiview synthesis—Improved view synthesis for virtual navigation. In *2016 Picture Coding Symposium (PCS)* (pp. 1-5). IEEE.
- Lai, P. K., Xie, S., Lang, J., & Laganière, R. (2019, March). Real-time panoramic depth maps from omnidirectional stereo images for 6 dof videos in virtual reality. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (pp. 405-412). IEEE.
- Mühlhausen, M., Kappel, M., Kassubeck, M., Bittner, P. M., Castillo, S., & Magnor, M. (2020, November). Temporal Consistent Motion Parallax for Omnidirectional Stereo Panorama Video. In *26th ACM Symposium on Virtual Reality Software and Technology* (pp. 1-9).
- Serrano, A., Kim, I., Chen, Z., DiVerdi, S., Gutierrez, D., Hertzmann, A., & Masia, B. (2019). Motion parallax for 360 RGBD video. *IEEE Transactions on Visualization and Computer Graphics*, 25(5), 1817-1827.
- Sun, C., Hsiao, C. W., Sun, M., & Chen, H. T. (2019). Horizonnet: Learning room layout with 1d representation and pano stretch data augmentation. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition* (pp. 1047-1056).
- Wang, F. E., Yeh, Y. H., Sun, M., Chiu, W. C., & Tsai, Y. H. (2020). Bifuse: Monocular 360 depth estimation via bi-projection fusion. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition* (pp. 462-471).
- Jiang, H., Sheng, Z., Zhu, S., Dong, Z., & Huang, R. (2021). Unifuse: Unidirectional fusion for 360 panorama depth estimation. *IEEE Robotics and Automation Letters*, 6(2), 1519-1526.
- Zou, C., Su, J. W., Peng, C. H., Colburn, A., Shan, Q., Wonka, P., Chu, H.-K., & Hoiem, D. (2021). Manhattan Room Layout Reconstruction from a Single 360° Image: A Comparative Study of State-of-the-Art Methods. *International Journal of Computer Vision*, 129(5), 1410-1431.

Live demo and business case of FIREDRILL - AR evacuation exercises

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Keywords: Augmented Reality, Indoor Navigation, User Experience, Business Case

There will be about 5 quick PowerPoint to give context of the App and the Business case. After that I will be screen mirroring my phone to the laptop and walk the users through the app.

I will start with a simple escape route (see Setup of Experience). During this I will explain the Initialization of routing and the type of routing (door to door) we are doing. I will show how this type of training gives the users and fire prevention officers some additional information they will not get during a regular group evacuation exercise. If there is enough time, I will also give a glimpse into route creation mode.

At the end I will show / hand out QR-Codes so people can download and experience a training themselves (see Setup of Experience).

I will leave about 10-15 minutes open for questions or. If there are not enough, I can give some more insights into:

- Microsoft Azure Spatial Anchors - the tracking technology we use
- Accuracy connected to environment and hardware factors
- How we calculate routes
- Why trainings are data privacy conform
- Our journey with public authorities (DGUV: Deutsche Gesetzliche Unfallversicherung)

Technical Setup

For the presentation I will mirror the screen of my Samsung S20+ via Samsung Dex to my laptop. Everything which will be visible on my Phone will be visible on the projector screen.

Additional Notes:

- A Wi-Fi connection is preferable but an LTE connection with about 2 bars is enough to run the app. I've been in "Haus der Wirtschaft" some years ago from my experience this should not be an issue at all.
- If there is a LAN cable available for the laptop, I can connect my phone directly to the laptop via Hotspot. This will reduce the latency between phone image and projector image.
- Additionally, I have an iPhone and a MacBook at hand. I've been told by my sales college that the connection via AirPlay might be the better option. At least that is what they are using. I will evaluate this option and use the better one.

Setup of Experience

Sometime before the presentation. I will setup two routes:

- A short route directly in the presentation area. This is what I will use during the presentation. This setup will take less than 15 minutes and will be the one I show during the presentation.
- A longer route outside of the presentation room. This will be a route anyone can experience themselves after downloading the app from the App Store or Play Store and scanning a QR-Code for the login. I will provide them at the end of the presentation. This training will be doable anytime and must not be done directly after presentation.

About FIREDRILL

FIREDRILL is a mixed reality evacuation exercise.

Today's evacuation drills are often implemented as group exercises that take place once a year. Employees who are not on site on that day do not take part in the exercise and have no other chance to deal with this sensitive topic. More flexible working time and workplace models, as well as the effects of the pandemic, exacerbate this problem and highlight the inefficiency of the group exercise in this regard.

FIREDRILL offers a solution to this problem: employees can complete an exercise on their own, by following the step-by-step instructions of the AR App.

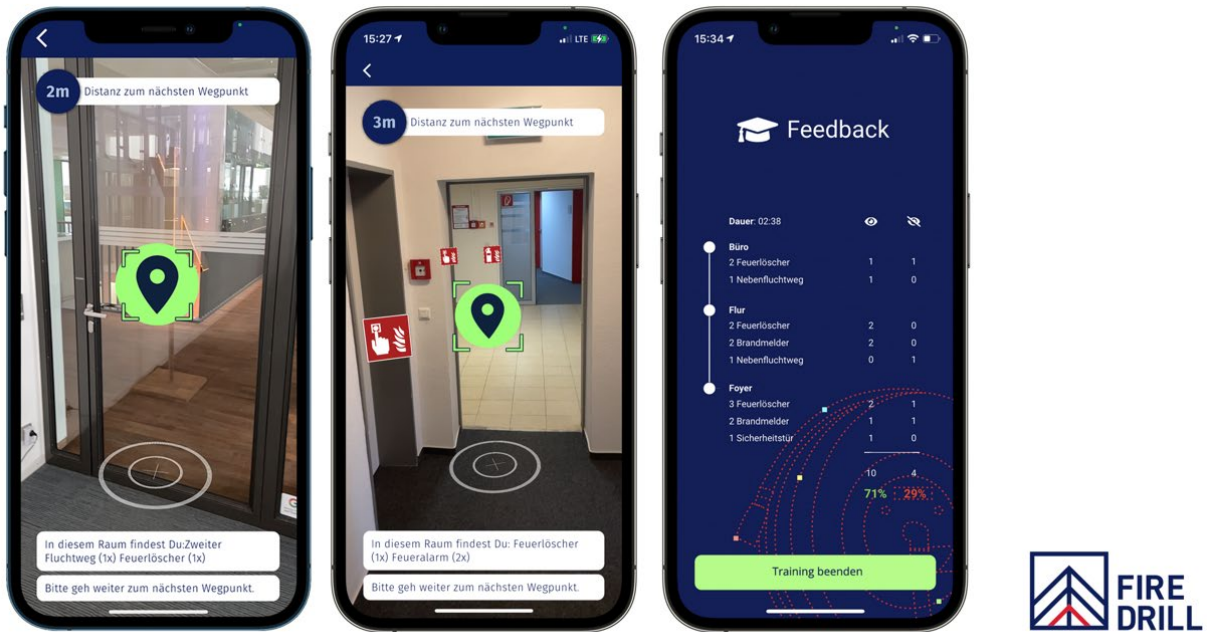


Figure 72. In app view of FIREDRILL during AR indoor navigation and training summary.

References

Homepage FIREDRILL - <https://firedrill.de/>

In app recording of video <https://vimeo.com/574365699> (This video will be used as backup if there are issues with the internet Wifi & Mobile.)

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Title	EuroXR Proceedings of the EuroXR Conference
Author(s)	Kaj Helin, Arcadio Reyes-Lecuona and Christoph Runde (eds.)
Abstract	<p>The focus of EurXR 2022 is to present novel Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) technologies, including software systems, display technology, interaction devices, and applications.</p> <p>Besides scientific papers reporting on new advances in the VR/AR/MR interaction technologies, the conference programme includes application-oriented presentations, creating a unique opportunity for participants to network, discuss, and share the latest innovations around commercial and research applications.</p> <p>As in previous years, we welcome industrial and academic exhibitors, as well as sponsors, all within the same exhibition area, to connect with our community. Our major priority is to provide authors the opportunity to prestigiously disseminate their innovative work within the wide community of end-users, from large scale industries to SMEs.</p>
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EuroXR 2022

Proceedings of the EuroXR Conference

The 19th EuroXR International Conference – EuroXR 2022 – taking place on 14-16 September 2022 organized by the Virtual Dimension Center in Stuttgart, Germany.

The conference follows a series of successful European VR/AR conferences taking place since 2004 and known as INTUITION, JVRC and recently EuroVR (Bremen 2014, Lecco 2015, Athens 2016, Laval 2017, London 2018, Tallinn 2019, Valencia 2020 and Milan 2021).

EuroXR 2022 will bring together people from research, industry, and commerce. Its members include technology developers, suppliers, and all those interested in Virtual Reality (VR), Mixed Reality (MR), including Augmented Virtuality (AV) and Augmented Reality (AR), and more globally 3D user interfaces, to exchange knowledge and share experiences, new results and applications, enjoy live demonstrations of current and emerging technologies, and form collaborations for future work.

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