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The application track, posters and demos of EuroVR

Proceedings of the 16th Annual EuroVR Conference - 2019

Kaj Helin | Jérôme Perret | Vladimir Kuts

VTT TECHNOLOGY 357

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VTT Technical Research Centre of Finland Ltd

Jérôme Perret

Haption

Vladimir Kuts

Tallinn University of Technology

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VTT
PL 1000
02044 VTT
Puh. 020 722 111
https://www.vtt.fi

VTT
P.O. Box 1000
FI-02044 VTT, Finland
Tel. +358 20 722 111
https://www.vttresearch.com

EuroVR 2019: Tallinn, Estonia

The focus of EuroVR 2019 is to present novel Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) technologies, including software systems, display technology, interaction devices, and applications. 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.

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.

23-25 October 2019

Tallinn, Estonia

Conference organizers

Preface

We are pleased to present these conference proceedings in the VTT Technology series, the papers accepted for the Application Track of EuroVR 2019, the 16th annual EuroVR conference, TalTech Mektory, Tallinn, Estonia, 23rd to 25th October 2019.

In previous years the EuroVR conference has been held in Bremen (2014), Lecco (2015), Athens (2016), Laval (2017), and London (2018). This series was initiated in 2004 by the INTUITION Network of Excellence in Virtual and Augmented Reality, supported by the European Commission until 2008, and incorporated within the Joint Virtual Reality Conferences (JVRC) from 2009 to 2013. The focus of the EuroVR 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 EuroVR association (https://www.eurovr-association.org/) provides a unique platform for exchange between researchers, technology providers, and end users around commercial or research applications.

This publication is 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.

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 ☺.

Enjoy your time in Tallinn!

On behalf of the organising committee,

Jérôme Perret

EuroVR Vice-President for EU issues and Collaboration, Haption CEO France/Germany

Kaj Helin

EuroVR EC member and Principal Scientist at VTT Technical Research Centre of Finland Ltd., Finland

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Application Track

Haptic Feedback for Digital Human Models

Jérôme Perret

Haption GmbH

Corresponding author: jerome.perret@haption.com

Keywords: Collision detection, Force-feedback, Haptics, Physics simulation, Rigid-body dynamics

For many applications of Virtual Reality (VR) technologies in the industry, the presence of a human avatar of the user is mandatory. This is especially the case for virtual assembly and ergonomic assessment. For such applications, not only is a full-body avatar needed, but it also has to behave in a realistic way. For example, the avatar should not interpenetrate other objects in the virtual environment. Using simulation techniques for rigid-body dynamics, which are now available in many computer game engines, interpenetrations can be easily prevented. However, when a collision occurs with an obstacle which is only present in the virtual environment (with no counterpart in the real world), a position mismatch appears between the user and the avatar, which creates confusion and interpretation errors. In this paper, we investigate how haptic feedback can contribute in solving those issues.

The importance of haptic feedback for virtual assembly and ergonomic studies is obvious and well documented. In many cases, it can be implemented by real objects, also called "physical props" (Jones et al., 2008). But sometimes the use of props is not practical, and haptic devices are required to give a feedback to the user. Although it is relatively easy to apply a force-feedback on the component or tool manipulated by the user without an avatar (Perret et al., 2013; Pontonnier et al., 2014), it is much more difficult when an avatar is present. Some of the challenges are scientific, while others are more related to the integration and to the practicality of the complete VR system.

The first challenge is the physics simulation, which needs to run at a high and stable frame-rate (close to 1 kHz), combining the joint constraints of the human model with the contact constraints or forces coming from the collision detection (Perret, 2019). Here we find a first pitfall, which lies in the combination of bilateral (force-feedback) and unilateral (motion capture) interaction devices while guaranteeing the safety of the user. The second challenge comes from the complexity of integrating many different devices and software packages into a coherent system, while keeping latency at the lowest possible level. Last but not least, the system must be practical, otherwise it will be rejected by the users.

In the presentation, we will give some details about the challenges and show different approaches to solve them. Then we will demonstrate some real use-cases coming from the manufacturing industry. We will conclude by pointing out the issues still open and how we intend to solve them.

Figure 1. Combination of optical motion capture and force-feedback.

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MobiPV4Hololens - HoloLens Based User Interface for Astronauts Procedure Viewer

Kaj Helin[1], Jaakko Karjalainen[1], Paul Kiernan[2], Mikael Wolff[3] and David Martinez Oliveira[3]

[1]*VTT Technical Research Centre of Finland Ltd, Tampere, Finland*
[2]*SKYTEK Ltd, Dublin, Ireland*
[3]*ESA – European Space Research and Technology Centre (ESTEC), Noordwijk, The Netherlands*

Corresponding author: kaj.helin@vtt.fi

Keywords: Mixed Reality, Hands-free, MobiPV, ISS procedures

This application abstract introduces a Proof-of-Concept (PoC) for Mixed Reality (MR) system to support an astronaut's manual work, the system is called MobiPV4Hololens. It has been developed in the European Space Agency's (ESA) project called "MobiPV4Hololens - Prototype a Media Helmet for MobiPV Implemented Using Microsoft (MS) HoloLens". The MS HoloLens mixed reality platform (Microsoft, 2019) was integrated as the hands-free user interface to the ESA Mobile Procedure Viewer system called MobiPV.

The International Space Station (ISS) tasks can range from laptop usage procedures, robotic teleoperation, biology experiments to ultrasound diagnosis. These manual procedures are based on standard task description schemas such as the Operations Data File (ODF) (NASA, 2010). During normal procedure execution, an astronaut would have a laptop nearby with step-by-step instructions to follow. The ESA's MobiPV (Boyd et al., 2016) solution supports astronauts through wearing a smartphone on their wrist that connects to the ODF library and shows the instructions on-screen.

MR and/or Augmented Reality (AR) has been tested within several projects of the space domain in the fields of training and manual work support (Tedone et al., 2016). and supporting robotics operation in the ISS (Maida et al., 2007). The MR and/or AR usability has reach acceptable level in space related training and maintenance support (Helin et al., 2018).

The objective of the activity was to complement the MobiPV astronaut smartphone with a wireless media helmet in this case MS HoloLens. The software implemented a Natural User Interface (NUI), i.e. a conventional graphical user interface (GUI) on the HoloLens head-up display, complemented with speech input for user interface commanding, and speech output for procedure readback.

MOBIPV4HOLOLENS MR-system

The operational MobiPV4Hololens MR-systems components can be found in Figure 2 (left). System includes (1) Microsoft HoloLens with MobiPV4Hololens app, which was the main user interface, (2) Mobile phone with web player for MobiPV for non-supported content e.g. reference documentations, (3) MobiPV – server (flight) for all ODF content and collaboration, and (4) MobiPV – server (flight) for all ODF content and collaboration for ISS.

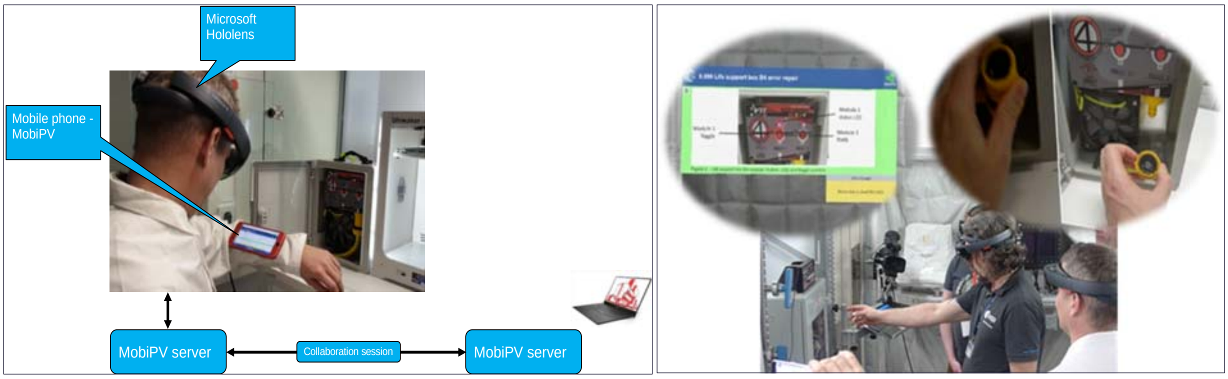

Figure 2. Left: MobiPV4Hololens system set-up. Right: Example of Pinned information in 3D space

The operational MobiPV4Hololens MR-system allows the astronaut to utilize the main MobiPV features, which have been implemented in the system. The main features implemented include:

1. Links to MobiPV server with standard MobiPV WebSocket communications
2. Working hands free with voice commands e.g. "Betsy pin image". "Betsy" added to all voice commands to minimize side-talk issues. There were in total 37 separate voice commands
3. Images and video notes clips captured with the built-in HoloLens camera;
4. Text-to-speech functions which allows the following of an ODF procedure without reading. Selectable by the astronaut as an optional feature
5. Pin information within 3D space e.g. text, note, video or image next to working area (see Figure 1- right)
6. Collaboration mode between the ISS and ground support

To cover the objectives the project identified a specific use case "Life support box B4 error repair" which involves end-user manual operations on the portable Life support box. The use case was transformed to an ODF-like procedure executing on MobiPV (see Figure 3). The final procedure was a step-by-step introduction which included 23 action steps with all supported features E.g. images, ODF symbols, video and audio notes and warnings. Also, procedures include pre-procedure information such as objective, location, duration, crew, items, tools and warnings

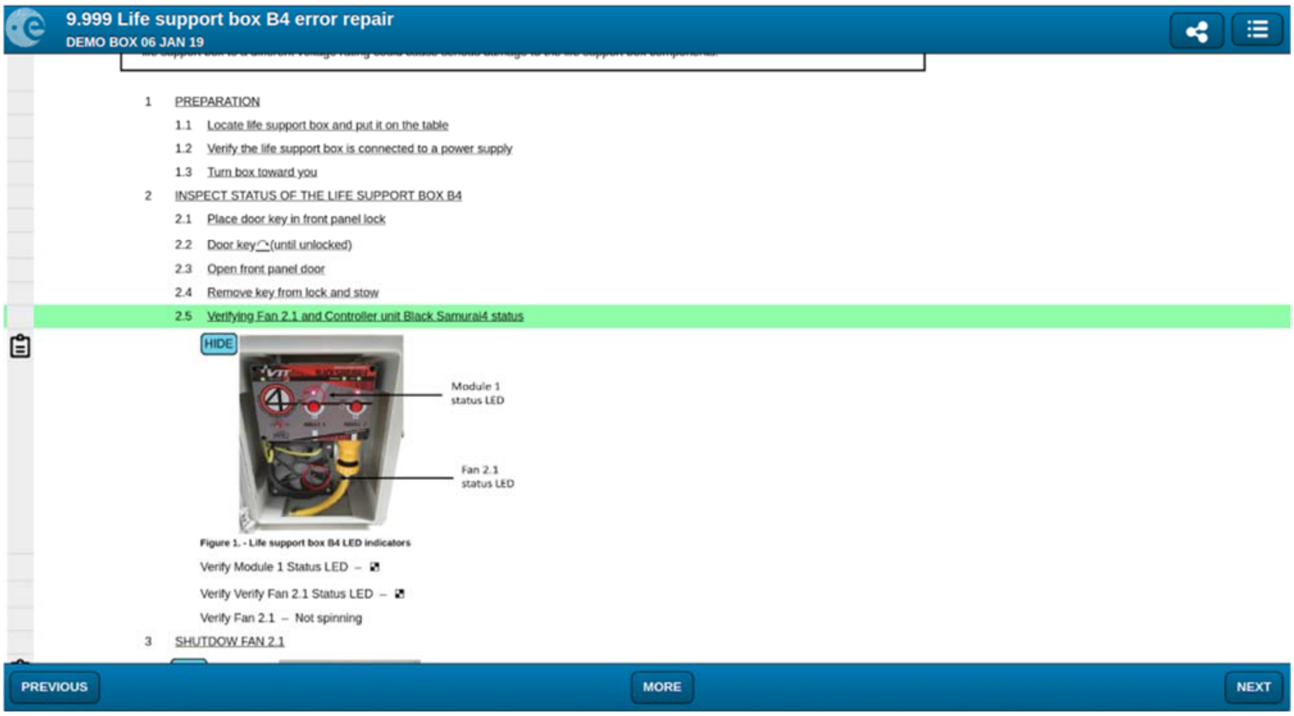

Figure 3. Life support box B4 error repair – procedure in MobiPV.

Conclusion and discussion

The MobiPV4Hololens is working properly as PoC and with no major voice command issues. MobiPV4Hololens was also tested on several different platforms. A build was made where the core components were tested with Linux, MacOS, native Windows and Android platforms. The core functionalities worked identically on all the platforms. This proves the flexibility of the system for future development. As there were 37 voice commands, it was really fruitful and easy to define a suitable list of voice commands working together with the ESA experts.

Future work also includes adding location dependent AR markers to the procedure at authoring time and rendering them on the head-up display at instruction appropriate times, as location correct overlays on the hardware to be operated upon, and MobiPV4Hololens is a good base for future AR based development within the space domain.

Last but not least, the MobiPV4Hololens system should be tested in the real environment and with real end-users to perform usability evaluations, refinements and then close the loop for a correct human centered design approach.

Acknowledgment

This study has been funded by ESA under contract 4000125238/18/NL/AF/as “Prototype a Media Helmet for MobiPV Implemented Using MS HoloLens”.

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Appendix

Video of MobiPV4Hololens: https://youtu.be/c-DVoLT4n9c

Laboratory Evaluation of AR / VR Based User Interface for Drones Control

Kaj Helin, Timo Kuula, Jaakko Karjalainen and Paul Kemppi

VTT Technical Research Centre of Finland Ltd; Tampere/Espoo, Finland

Corresponding author: Kaj.Helin@vtt.fi

Keywords: User Evaluation, Augmented and Virtual Reality, Drone Control, User Interface

This abstract introduces results from European Union Horizon 2020 research project ROBORDER (Autonomous Swarm of Heterogeneous Robots for Border Surveillance), and more specifically augmented reality (AR) and virtual reality (VR) user interface for drone swarms' mission control. The functional prototype was evaluated in laboratory environment with potential end-users and with real drone mission.

The functional prototype

With the functional prototype, the user is able to monitor and/or control real drone via VR and/or AR user interface. The user is able to see the drone in 3D environment via online 3D map, monitor sensor values and choose camera streaming (see Figure 4 – right). Mission planning and execution are supported by e.g. defining end-point for drone. The system has been built in modular architecture, which allows making the application in AR or VR mode for various devices, which are supported by Microsoft Mixed Reality Toolkit (see Figure 4 – left). Furthermore, desktop and mobile devices are supported with limited features (Helin et al., 2018).

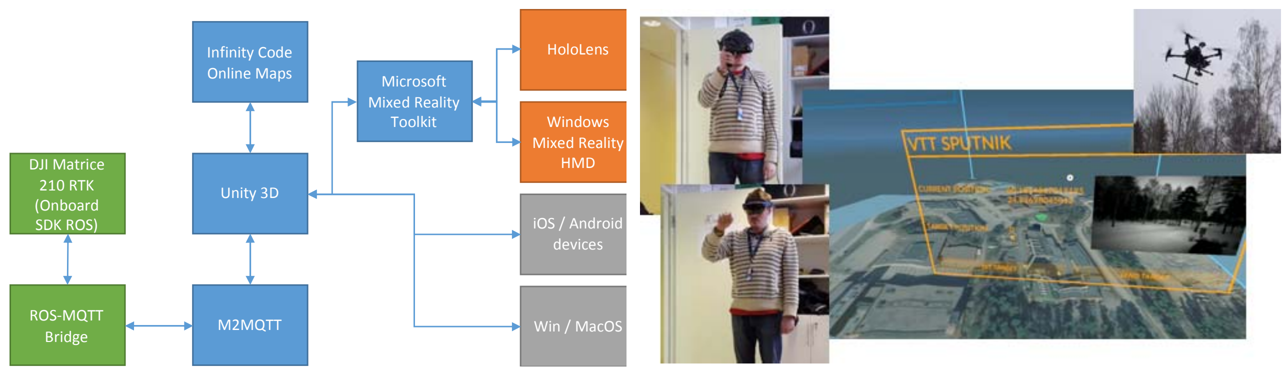

Figure 4. Left: System architecture based on Unity3D and Microsoft Mixed Reality Toolkit.
Right: The functional prototype of Novel UI for Drone Mission

Laboratory evaluation

Evaluation task

Eight (8) test users with professional background in robotics, usability and augmented reality participated in the evaluation. Users were able to observe recorded data of two drones, which included video streaming and position in 3D map. Users had the freedom to manipulate the UI e.g. by opening video data and zooming (see Figure 5), but they could not change drone's trajectory. The users were given two tasks: (1) Calculate the amount of red cars in parking area and, (2) identify the color of runner's shirt. Video feed of both drones had to be used in order to complete the given tasks.

Figure 5. Test subjects are executing mission with VR and AR UI.

Evaluation methods

Observation, interviews and questionnaire were used as evaluation data collection methods.

Observation & interviews

The development team evaluated the user experience (UX) and usability by observing the user test. The observations were written down while the users were testing the system, based on the comments and performances of the users. The idea of the evaluation was to allow the users comment freely their experience, without predetermined questions or framework, and thus let the users define what is significant for them. The approach was applicable also because of the small amount of test users. After the test, the development team summarized the written observations and drew the conclusions. In addition to observation, the test users were interviewed. The interview themes included questions about user experience and usability.

Questionnaire: System Usability Scale (SUS)

SUS is a tool for measuring both usability and learnability. The SUS scores calculated from individual questionnaires represent the system usability. SUS yields a single number representing a composite measure of the overall usability of the system being studied. Scores for individual items are not meaningful on their own. SUS scores have a range of 0 to 100 (Brooke, 1996; 2013). The Acceptability ranges are: 0-50 not acceptable; 50-70 marginal; 70- acceptable (Bangor et al., 2009; Brooke, 2013).

Results

The SUS score for VR UI was 71, which indicates that system has reached the range of acceptable system usability. The SUS score for AR UI was 41, which indicates not acceptable system usability. The observation and interviews support the SUS findings.

Conclusion

The concept of VR UI is suitable for future development, even though some improvement should be done, such as naming drones and the UI elements, as subjects sometimes were confused by the video windows. The concept of AR UI is not applicable, as SUS score indicates. The main issue with AR is the narrow field of view and limitation of AR devices' computing power. In addition, some users had issues in learning controlling gestures.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 740593.

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Appendix

Video of H2020-ROBORDER laboratory evaluations: https://youtu.be/p60zgnG2eos

Usability evaluation of WEKIT AR-player – Rover Maintenance in Mars/Moon Terrain Demonstrator

Kaj Helin[1], Timo Kuula[1], Liliana Ravagnolo[2], Jaakko Karjalainen[1] and Carlo Vizzi[3]

[1]VTT Technical Research Centre of Finland Ltd, Tampere, Finland
[2]ALTEC SpA; Turin, Italy
[3]EAC - European Astronauts Center, Cologne, Germany

Corresponding author: kaj.helin@vtt.fi

Keywords: Usability Evaluation, Augmented Reality, Work Support, Space Domain

This application abstract introduces the work done within the WEKIT - Wearable Experience for Knowledge Intensive Training – project. WEKIT is a three years project funded by the European Commission under the H2020 programme. Main focus of this abstract is usability evaluation of the re-enactment of the expert with Augmented Reality (AR), system called WEKIT AR-player. The project is supported by three Industrial Cases: (1) Aircraft maintenance: exploiting AR and WT for inspection, decision making and safety; (2) Healthcare: exploiting AR and WT for improving innovation in technology and responsibility in healthcare applications and medical imaging; (3) Space: exploiting AR for astronauts training and for supporting the Mars rover maintenance. And abstracts results are from the last use industrial case.

WEKIT AR-player

The WEKIT AR-system (Helin et al., 2018) is based on the Microsoft HoloLens mixed reality platform (Microsoft, 2019) and IEEE Draft Standard for an Augmented Reality Learning Experience Mode. The whole system is configured around the Activity and Workplace JSON files. The Workplace JSON describes workplace-related information such as points of interest, sensors, etc. It is parsed with the Workplace manager and information is transferred to the data layer. The Activity JSON describes all action steps and the content that should be active for each step. It is parsed with the Activity manager and information is transferred to the AR layer via local storage. The user can interact with the AR player via a multi-modal user interface (see Figure 6 - right). The following modalities can be used simultaneously (1) Gesture, e.g. doing a “Click” gesture to go to the next work step, (2) Voice commands, e.g. saying “Next” to go to the next work step or “Show sensors” / “Hide sensors”, (3) Physical HoloLens click button, e.g. “Click” to go to the next work step, and (4) Physical devices which have an IoT interface e.g. flipping switch to “Stand-by” mode enables IoT constraint in the Activity JSON.

Figure 6. Left: Mars rover in Mars/Moon terrain simulator. Right: WEKIT UI and video in 3D space for task support

Evaluation case of the WEKIT AR-player

The final evaluation of the WEKIT AR-player was executed at ALTEC facility (Turin, Italy) in 2018. Evaluation case was a futuristic astronaut procedure on a physical mock-up of Mars Rover in Mars/Moon Terrain Demonstrator. The evaluation case contains 15 steps procedure of mars rover inspections and maintenance e.g. "Visually inspect the solar panels right side and verify that they are undamaged - no scratches or holes" (see Figure 6– right). 199 subjects were testing the system for 6 months period. Data and feedback from the participants were collected by means of a questionnaire composed by several sections (technology acceptance model, system usability, smart glasses user satisfaction, user interaction satisfaction and transfer mechanisms) and some additional questions that were asked to a smaller subgroup of the participants in order to get a more comprehensive feedback on their experience. This extended abstract is reporting results of the system usability.

Evaluation results - System Usability Scale (SUS)

The SUS scores calculated from individual questionnaires represent the system usability. SUS yields a single number representing a composite measure of the overall usability of the system being studied. Scores for individual items are not meaningful on their own. SUS scores have a range of 0 to 100 (Brooke, 1996; 2013). According to validation studies, the SUS score starting from 68-70 represents the level of acceptable system usability. The Acceptability ranges are: 0-50 not acceptable; 50-70 marginal; 70- acceptable (Bangor et al., 2009; Brooke, 2013). The SUS score for Player (69) has reached the range of acceptable system usability.

Conclusion

As the AR-system usability has reached a reasonable level (average SUS score 69), both the pragmatic and emotional aspects of the user experience were considered fulfilling. It can be suggested that the AR-system is potentially a useful tool for supporting and facilitating the assembly and training procedure in the space field, even though the tool is still in prototyping phase. There are however many usability issues still to be resolved. For instance, the narrow field-of-view is one the most significant issues.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687669.

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Appendix

Video of WEKIT AR-layer evaluations: https://youtu.be/JRMLs9SYg6k

Development of a Smart Workstation by Using AR Technology

Kätlin Värno[1], Tauno Otto[1], Kashif Mahmood[1] and Vladimir Kuts[1]

[1]*Tallinn University of Technology, Tallinn, Estonia*

Corresponding author: vladimir.kuts@taltech.ee

Keywords: Digital Technology, Augmented Reality (AR), Smart Workstation, Monitoring and Application Design.

The recent development in the area of digital manufacturing demands the manufacturing industry to adopt industry 4.0 technologies to be competitive in the global market. Product development processes are becoming complex as products are getting more versatile, and product variations increase the trend of mass customization. Therefore, manufacturing processes need to be more systematic and well-organized in order to be economically competent and efficient at the same time. The application of Virtual Reality (VR) and Augmented Reality (AR) technologies may provide an effective and innovative solutions in the manufacturing work environment. Especially, AR can help to speed up the assembly process by facilitating the assembly workers to assemble a product without involving into the detailed manual instructions. It may also use as a training aid for new workers to get familiar with the assembly process by visualization and provide easiness in work. An approach to creating a digital instructions application by AR was described in this study, and the relevance of the approach has shown through a case study.

Approach to develop an application

CESAR approach, as shown in Figure 7, was used to develop an AR application for the selected use-case. To design a smart work-place, it is necessary to find the right tools to make the work environment more flexible, and VR/AR technologies have the potential to offer flexibility and capability. First of all, for planning the digital assembly workstation, there is a need to define manufacturing needs and opportunities. The evaluation helped to choose tools and techniques, which enabled to create Augmented Reality solution for the defined needs.

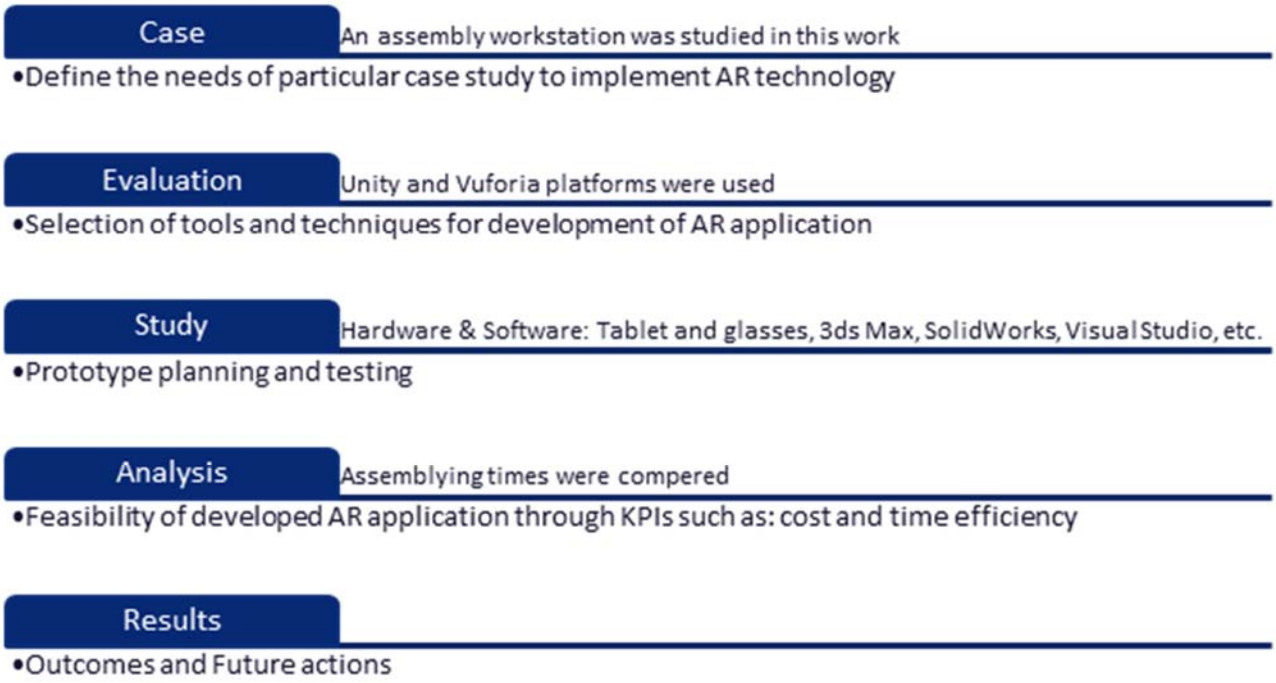

Figure 7. CESAR approach for AR application development

The AR application consists of Unity (game engine) (Okita, 2015; Unity, 2019) and Vuforia (Cushnan & Habbak, 2013; Vuforia engine, 2019), which provides to display the augmented reality picture. Unity is designed to create interactive content. The development environment is suitable for both operating systems (Windows and Mac OS X), which creates an Android platform application. The gaming engine allows using 2D and 3D models, which applies physical laws, sound, scripting, animations, artificial intelligence, scene graphics, and more. Scripting is a different form of conventional programming, and Visual Studio helped to manage it. Using the scripts allows to define GameObject behaving and also additional components that need to communicate with each other. On the other hand, Vuforia can activate the AR solution. Vuforia Engine 8.1 gives the possibility to develop the application with AR tools, where the most important is to the AR camera option, which visualizes the necessary information based on the augmented reality. It supports the choice of devices for smartphones, tablets, head-to-head devices to provide the most dynamic detection of objects, perception of images and 3D models. The steps of operating the AR application are illustrated in Figure 8, and the testing of the AR application can be depicted in Figure 9.

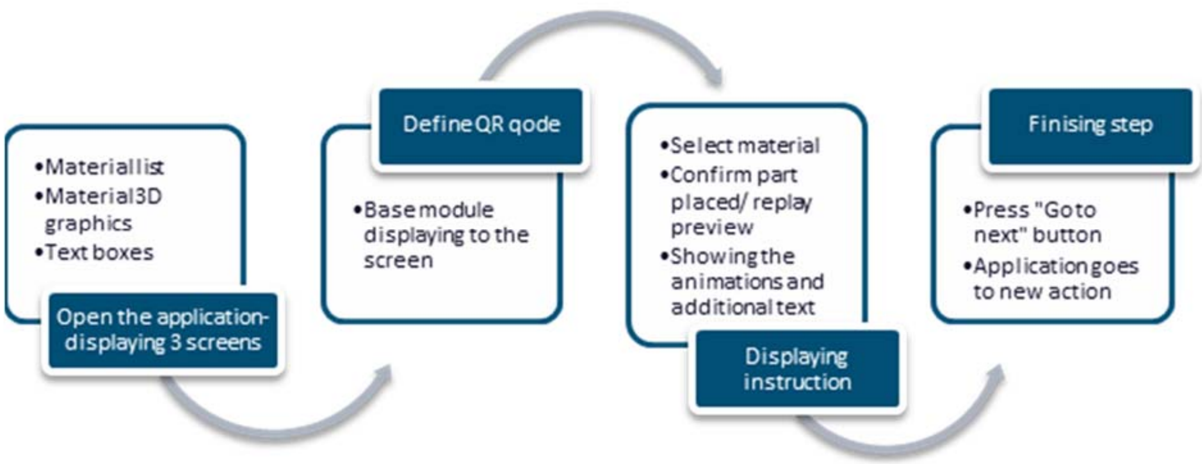

Figure 8. Working steps of AR application

Figure 9. Testing of AR application

To test the prototype solution, there is a need to set up a tablet and download the application. The test performed in TalTech IVAR laboratory by a student who has not previously been involved in line component work and seen the guide before. The time factor is measured and observed over the experiment. The assembly of the module does not require the use of power tools or other accessories (E.g., cleaning cloth, thermal paste). The components were spread out on the desktop in small cardboard boxes which were marked with the respective component codes. Following the paper instruction manual, the assembly time was 28 minutes, and the digital working (use of AR app) time was 27 minutes. The errors in the paper example were misunderstanding the image because it was not understood the need to turn around the Insulator and the Busbar components. Besides, there was confusion about the color code, which resulted in a change in an assembly line. There are no errors in assembly work with the AR application. Moreover, paper instruction tracking was more difficult. The order of the color codes had to be followed very precisely. Conversely, tablet component movements were shown with animations that made tracking materials easier. As a result of the test placing, traceability and user-friendliness has improved, which helps to navigate better in the order of assembly.

Conclusion and Future Work

The use of AR creates opportunities to reduce the time spent on work. It is possible to follow the instructions faster. Usually, the guides are long and monotonous. Using conventional solutions, it is difficult for the compiler to read and monitor the assembly processes in text format when performing new tasks. The created application encompasses all the 3D models of the module by selecting precisely the right material to be displayed on the screen with 3D images, quantities and instructions. The aim of the project was to create an intelligent workplace for electro-technical sector factory, which has a kind of transformer cooling assembly. Based on analyzed information of digital technology and considering the following factors: user-friendliness, energy efficiency, system logic and quality, the smart workstation should be quickly learnable and safer workplace. The results were found to be enhancing traceability and have a faster assembly process, increasing the quality, reducing cost and time, for example, reduction in the rework. The application was completed and tested in a more straightforward form in the TalTech IVAR laboratory. The appearance of the application, user interface, the components animation, and optimization of viewpoints were sufficient, and the feedback from the test users was positive. The test confirmed that the digitalization of the manual work is an essential part as the user has interactive guides and 3D graphical models, which are giving a better idea of the assembly work. Further improvements could be the addition of more specific components properties into the application. Especially, add color and a structure to further impart material authenticity.

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Appendix

AR application experiment video - https://youtu.be/8KkmlfJ2wW0

Augmented Reality in Higher Education: An Active Learning Approach for a Course in Audiovisual Production

Gergana Lilligreen, Sascha Keuchel and Alexander Wiebel

Research Group User Experience & Visualization, Hochschule Worms University of Applied Sciences

Corresponding authors: lilligreen@hs-worms.de and wiebel@hs-worms.de

Keywords: Augmented reality, Active learning, Audiovisual production

Augmented reality (AR), as a future-oriented technology, is of growing interest in recent times. It is listed by Gartner not only as a general technology trend, but also as an important future perspective in the field of education and as a technology "on the rise" (Gartner, 2019).

Although the technological part is very important for the development of educational augmented reality applications, "innovations in digital teaching are not just technical innovations but rather academic, curricular, organizational and structural" (Hochschulforum Digitalisierung, 2015). Therefore, in this paper we examine the combination of suitable didactic methods and innovative technologies, in particular of augmented reality, in an audiovisual production course.

The goal of the presented didactical concept and its corresponding AR-application is to solve problems, identified in our case study, a university-level course in audiovisual production, and at the same time to integrate the advantages of augmented reality technology in the developed application and teaching scenario. We present which tasks and methods are useful in combination with augmented reality and discuss obtained results and future issues.

Definitions and Theoretical Fundamentals

According to Azuma, three conditions must be met in augmented reality: the real environment must be combined with virtual objects, there must be interaction in real time, and registration in 3D (Azuma, 1997).

There are a lot of different characteristics for the active learning approach. As said by Bonwell, active learning "involves students in doing things and thinking about the things they are doing" (Bonwell, 1991). Students must do more than just listen and they should be engaged in activities. In our approach, augmented reality technology is used to encourage the active participation of the students.

Related Work

The combination of augmented reality and didactic scenarios in higher education has been evaluated by different researchers. In this section some examples are described. Fehling discusses social learning, mobile learning and augmented learning, combined with specific teaching-learning forms and didactic concepts, although not at a university but at professional school/trainee program (Fehling, 2016). Technologically, they use smartphones and tablets, which do not fully exploit the benefits of current AR devices.

Considering our case study – audiovisual production – there are mobile apps for film planning like Shot Designer for shotlist creation, storyboard integration and camera diagrams (Hollywood Camera Work, 2019). However, these applications developed for filmmakers are often intended for individual work and are unsuitable for the group work desired in a teaching-learning situation. Among HoloLens apps, there are also applications that make scene design or planning possible. Project Aura (Lab3, 2019), for example, offers the manipulation and storage of 3D objects, but this has no reference to teaching and learning. A suitable didactic concept therefore does not exist for these applications and the usage of augmented reality in this field of education is, according to our investigations, not (completely) studied.

Augmented Reality in Higher Education

With the popularity of mobile devices (smartphones, tablets, etc.), the use of AR as e-learning and mobile learning technology has also been spreading. However, both the use of AR in teaching and the development of appropriate didactic approaches is largely limited to AR as a combination of the camera image of the hand-held mobile device with additional information or interaction possibilities added to the image (FitzGerald, 2013). In some studies, AR with a computer, in combination with cameras and markers, is also implemented. The use of augmented reality has been investigated in many educational areas. Examples are physics laboratories (Akçayır, 2016) and chemistry (Wojciechowski, 2013 and Cai, 2014). Many of the studies show some advantages in this kind of use, but technologically and didactically do not exploit all benefits of the current possibilities of AR. Replacing handheld devices and markers with AR devices like the HoloLens glasses and appropriate teaching methods can eliminate some specific disadvantages in the current state of the art.

The use of AR glasses is especially suitable for setups in which learners should practice and work practically with their hands, which was previously problematic with the use of handheld devices. Learners can keep an eye on the actual subject in their environment instead of fixating the device with their gaze. With newer hardware, such as AR-glasses, it is not necessary to be connected to a computer by cable, or to use handheld devices in combination with markers. Users can move freely and interact with virtual objects without additional markers. For the German higher education system, where our case study is set, Thees and Kuhn describe the use of HoloLens glasses in physics labs (Thees, 2016). In their example, however, the possibility of moving freely in space is not fully explored.

There is also research on the application of AR in anatomy classes (Nørgård, 2018). Although HoloLens glasses were used here, attention was paid only to the visualization of the contents. Nevertheless, it is known from teaching and learning research, that the most effective way to learn is to be active oneself and not only to act as a recipient of content (Waldherr, 2014). The use of AR creates not only better spatial possibilities for activeness of the students, but also for communication and interaction in the teaching-learning situation. This active learning approach is implemented in our work through the assignment of a more active role to the students by using the AR application and tasks developed by us.

Akçayır lists in his systematic review paper a lot of advantages of AR in education like: enhancing learning achievement, enhancing learning motivation, helps students to understand, increases enjoyment (Akçayır, 2016). Some specific aspects of AR technology are also mentioned: combining the physical and virtual worlds, enabling visualization of invisible concepts, events, and abstract concepts, reducing laboratory material cost, providing interaction opportunities (student-student). A lot of these advantages are given also in VR or while using different technologies, but the combination of some of them is only possible in AR.

In a recent review of AR in education (Hantono, 2018) it is described that most AR applications only demonstrate the possibilities of AR technology. “There is still enough homework to be considered by researchers to make AR technology more useful and effective." Our concept is intended to do more research on using AR for teaching purposes and combining it with useful didactic tools and methods. Additionally, the benefits of working in space are applied and researched in our case study in an audiovisual production course.

Active Learning in Higher Education

Pirker (2014) lists several active learning formats, used or developed in different universities: peer instruction, student-centered activities for large enrollment undergraduate courses, studio-physics and Technology-Enabled Active Learning (TEAL, 2005). The project TEAL combines collaborative activities with modern technologies such as networked laptops or whiteboards and was used for physics teaching at MIT. A lot of other universities have active learning classrooms (ALC) which support small group work and the usage of technology (Baepler, 2014). Although we do not use a special ALC, the laboratory, in which the course in audiovisual production is held, does facilitate group work. A more detailed description of our setting is given in the next section.

Case Study Audiovisual Production

In this paper, we approach our research on the use of AR in higher education as a case study in a course on audiovisual production. The course is held at a university of applied sciences. This implies some of the setting details described in the following.

Most students participating in the course specialize in the field of media informatics. The size of the group varies, but it is always a small group – between 10 and 15 participants. In our case study, 10 students tried the AR application that we developed. The AR sessions took place on three different days during the audiovisual production course with a duration of about three hours each day.

The AR-supported parts of the course are supervised by one lecturer, who also acts as a researcher. The audiovisual production course is offered every semester. It consists of a lecture and a laboratory, which take place on the same day. The main themes of the course are planning a short movie (pre-production), shooting a film (principal photography) and post-production. The topic of the film used for the exercises was "Students' opinions (testimonials) about the computer science bachelor degree program". In short movies the students talk about their study of computer science and their experiences. The location for the shootings was indoors, in the lab, where the lecture takes place.

The course takes place in a room similar to ALCs, which "…typically feature tables with moveable seating that support small group work…" (Baepler, 2014). It is possible to move the tables to the side and in that way to offer an open space, which is suitable for working in a group and with AR-glasses, i.e. in our case with the HoloLens as AR-hardware.

Initial Analysis and Preliminary Design Assumptions

In the beginning of the case study, we analyzed 28 students' works and film projects from three semesters (fig.5 in grey). We identified a couple of problems, one of them being that most students did not submit requested pre-production documents like storyboards, lighting diagrams, or screenplays. However, learning about planning and pre-production is part of the goals of the course. Thus, we focused on how to make this part of the lecture more interesting for the students and how to increase their intrinsic motivation.

Research on motivation and the self-determination theory of Ryan and Deci (Ryan, 2000) show three important needs that influence the intrinsic motivation of learners:

– competence – autonomy – relatedness

The didactic methods and the augmented reality app developed in our work aim at strengthening these three aspects.

Furthermore, many studies have shown that learning does not function according to a transmitter-receiver principle. It is not limited to the mere perception of an input, see e.g. Böss-Ostendorf and Senft (Böss-Ostendorf, 2010). However, the situation in a lecture is very often characterized by frontal teaching, which places students in a rather passive "recipient" role. In digitally supported exercises, students are often more active, but they usually sit in front of a "personal computer", a workplace that is best suited for one person. In the case study presented here, these forms of teaching are extended by the use of spatially-aware augmented reality as an additional interaction possibility in an active learning approach. Also, compared to virtual reality (VR), the social competence is supported better in group exercises, executed in the room with AR, because the students and teacher still can see the environment and each other, and thus communicate more easily. With VR the immersion is bigger and the person is more isolated from the real world.

The courses' topics of storyboard, lighting setup, and framing can benefit from the spatial work with AR-glasses. More detailed information on the exact way of implementation is given in the next section.

Development of a Didactic Scenario for a Course in Audiovisual Production

An overview of our conceptual work about educational methods and media is given in Figure 10. Starting with pre-analysis and the identified problems we decided step-wise how to integrate augmented reality in an active learning approach and which topics are best suited for the technology and for solving problems.

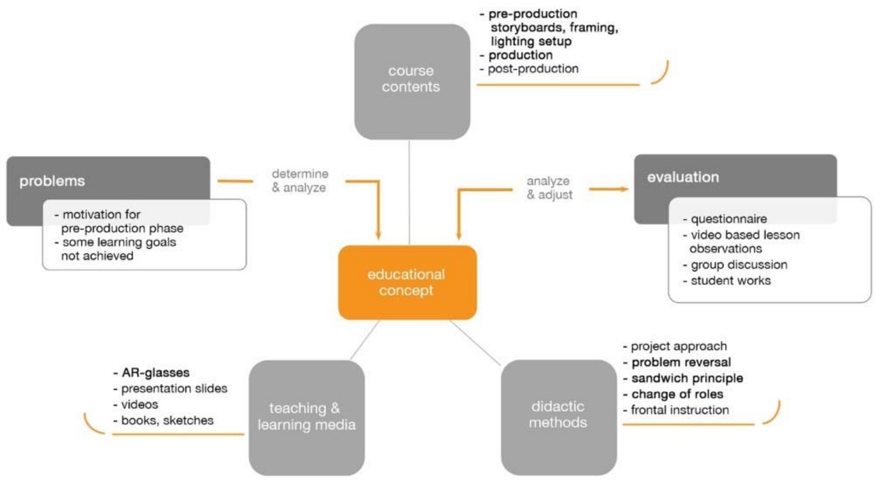

Figure 10. Development of the educational concept for the course in audiovisual production with the use of augmented reality and active learning methods

Analyzing and evaluating the test phases in the course give us hints on how to adjust the mix of teaching methods (active formats, traditional/frontal), topics and media (AR application, presentation slides, videos). For example, in a very early (short) test in the course last year we explained the usage of the HoloLens glasses (gesture, gaze, speech) and the usage of our application in one step. This was a little bit confusing for the students. Therefore, for our next (the actual) test we modified the scenario and separated the introduction of the HoloLens from the introduction of our application (step 2 in Figure 11) in two sessions on two different days.

For the first usage of the app the teacher applies the *problem reversal* method (Waldherr, 2014), (step 4 in Figure 11). The students have to build a "wrong" storyboard - a given screenplay should be transformed into a storyboard, which does not fit the story or has wrong framing. This method is used because the application and the usage of gestures is new to the students. In this first task they should concentrate more on the new interaction possibilities and have fun doing "pictures" with the application. With this method the creativity can be strengthened and in the next step the students have more ideas of what could be a good storyboard. For correcting the "wrong" storyboards, the method *change of roles* (Methodenpool, 2019) is used and the students can correct each other in groups (Figure 10 and step 4 in Figure 11). This way they have to go over the designed storyboards again and have to think about the discussed topics. This step is also a good motivation for social interaction as the students have to decide in small groups what is good and what should be changed.

In a group discussion at the end of the exercise, the created storyboards are discussed and the teacher can show off mistakes or good examples.

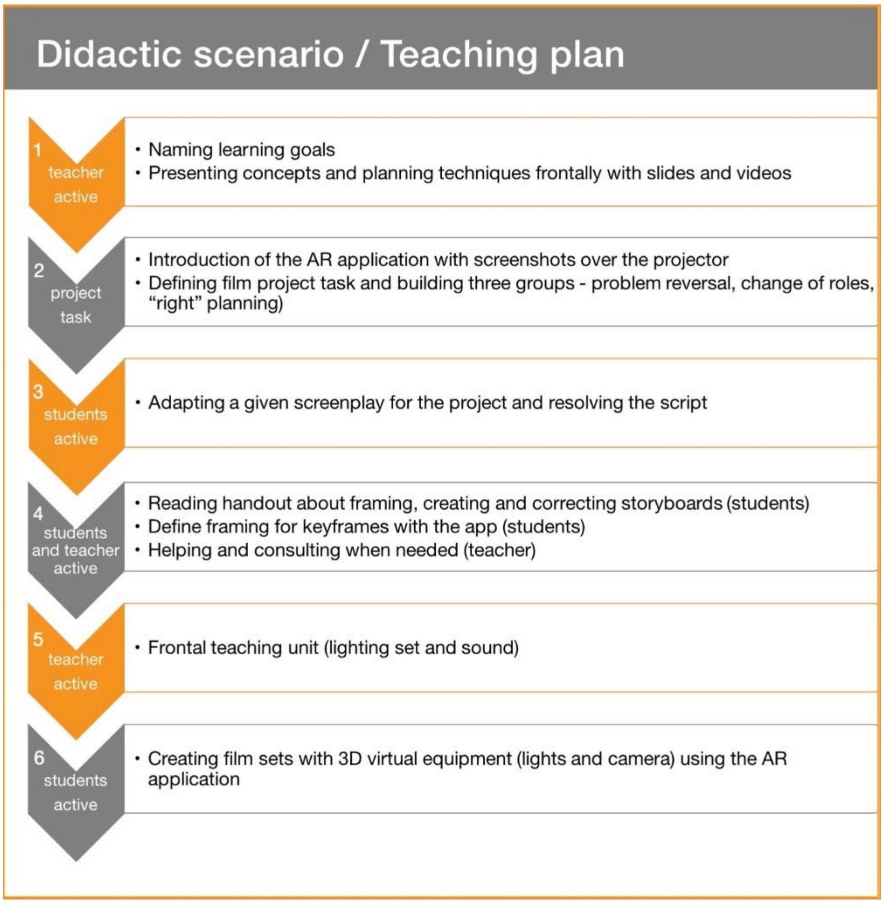

Figure 11. Didactic scenario for the second session with usage of AR in the audiovisual production course.

The topics "lighting" and "technical equipment setup" are first presented traditionally by the teacher with slides (step 5 in Figure 11). In this phase the students have a break from the active work. In the next step (step 6 in Figure 11) they can practice again with the AR application by constructing a virtual light setup for the previously designed storyboards. More about this step is described in the next subsection.

Augmented Reality Application for a Course in Audiovisual Production

During the design process of the application, we addressed and concentrated on the learning objectives, the problems encountered, and the possibilities of augmented reality as a technology. The target groups are the students and the teacher. One of the defined goals is to increase the activity of the students, so the application was constructed to provide a lot of interaction possibilities. We conducted user tests at an early stage of the development and improved the app incrementally.

We used the interaction possibilities given by the HoloLens - selection with gaze and gestures – "AirTap", "AirTap and Hold", etc. (Microsoft, 2019). For bigger movements of virtual objects and for their translation far away from the initial place the movement with hand gestures ("AirTap and Hold") can be difficult, as the HoloLens has a small field of view and the hand has to stay in it, when moving the object. For that reason, we provided an additional option for repositioning – the object is attached to the gaze and when the desired position is fixated with the gaze, an AirTap places the object at the position. The virtual objects used in our application can also be rotated, because the orientation is important for lights and camera planning. Every 3D object has a submenu located next to it which is used to perform this action.

In early versions of the application we tried to position parts of the user interface directly on real objects, e.g. the menu and storyboard panels hung on the wall. User tests showed that the natural position could be a problem, because the reconstruction of the real world by the HoloLens is not always very precise. Effectively, users were unable to select menus, because they were located in the wall instead of in front of it. We decided to deal with this problem by letting the ray cast for selecting and activating items penetrate the walls. Probably because menus are not real-world objects, selecting menus inside walls did not feel unnatural for the users.

Because the motivation of most students for the pre-production phase is not that high, several of the courses' themes were integrated into the application: The students do not have to use many individual programs, but can learn film planning and filming with AR usage in a single application. Not all the contents and tasks are implemented with AR. For example, the use or creation of a film script was not integrated into the application, since AR does not offer any obvious advantages for text design. With AR, reality is only extended and it is still possible to deal with analog information such as texts while using the application. This is also one of the benefits of AR, which is not possible with VR.

Some functions of the AR application and the tasks given by the teacher are designed to motivate the students to participate actively in the exercises for the course topics discussed earlier: storyboards, framing, camera perspectives, and lighting setup.

As described in the last subsection, given a screenplay the students have to build an AR-storyboard (Figure 12). A storyboard is a graphic version of the screenplay with defined framing and perspectives (Klant, 2008). Instead of sketching each frame of the storyboard, the students can setup the scene with virtual props and use the "take photo" function of our AR application. When creating a storyboard with people in it, the students can be part of the picture. Doing this, they have to consider how to stand and position themselves or the virtual 3D objects. They move in the room and automatically have to think about framing, perspectives, and the storyboard picture. The spatial character of the AR technology is a big benefit for this task and for the students' understanding of the space dimension in film making. Discussions concerning the spatial situations were observed during the exercises in the course. We recorded them for later analysis.

Figure 12. Augmented reality storyboard, positioned on the wall (low quality of the picture, because taken with the HoloLens).

The course topics “lighting” and “technical equipment setup” are also supported by the AR application Figure 12. After building the storyboards, the students can plan a setup for every keyframe. To do this they can position virtual 3D lights and cameras in the room and try out some of the typical setups, as presented by the teacher by slides, e.g. “three-point lighting”. This exercise gives them more intuitive demonstration of the methods used in film planning and making, because with AR the diagrams or “sketches” are built in 3D (in the room) and not on paper or screen.

In the next step of a film project – the shooting – the saved 3D setups can be brought up at the film location and the real equipment can be aligned to the planned, virtual objects. This kind of 3D planning is much more intuitive then sketches on paper or a 2D screen. For that reason, it is useful for beginners and additionally motivates them to work on planning. Using AR with hand-held mobile devices is also possible, but with a head-mounted display (HMD) like the HoloLens, the students have their hands free for moving the real technical equipment to the virtually planned positions. The combination of the real and virtual equipment was part of the third session with usage of AR in our study.

Methods and Data Collection

As one of the goals in our study is to integrate the augmented reality tool to be useful for teaching and learning, we need to know when and how our concept and app are helpful. In section *Initial Analysis and Preliminary Design Assumptions* and *Analysis and Results* we discuss the points relevant for our study. Further on in the current section, we describe how and what kind of data was collected.

Here, we combined different research methods. We did a participant observation in the course. As already mentioned, one of the instructors also carries out the research. Teaching and simultaneously taking notes for the observation could be problematic, so we chose to film the teaching-learning situation in the lecture and exercise. Since the course topic is about audiovisual production, the students are used to handling a lot of technical equipment. Therefore, the situation of being filmed is not that uncomfortable and unfamiliar for them. The camera and microphone were put in one corner of the room, so they do not disturb the lecture and the activities in the room. For analyzing activities with augmented reality technology, the filming of the entire surroundings enables us to have more detailed information on the spatial interactions of the group. For coding and annotating the video materials we used the ELAN software (Max Planck Institute for Psycholinguistics, 2019). When building categories, we considered the identified problems and the benefits coming with the augmented reality technology, discussed in previous sections.

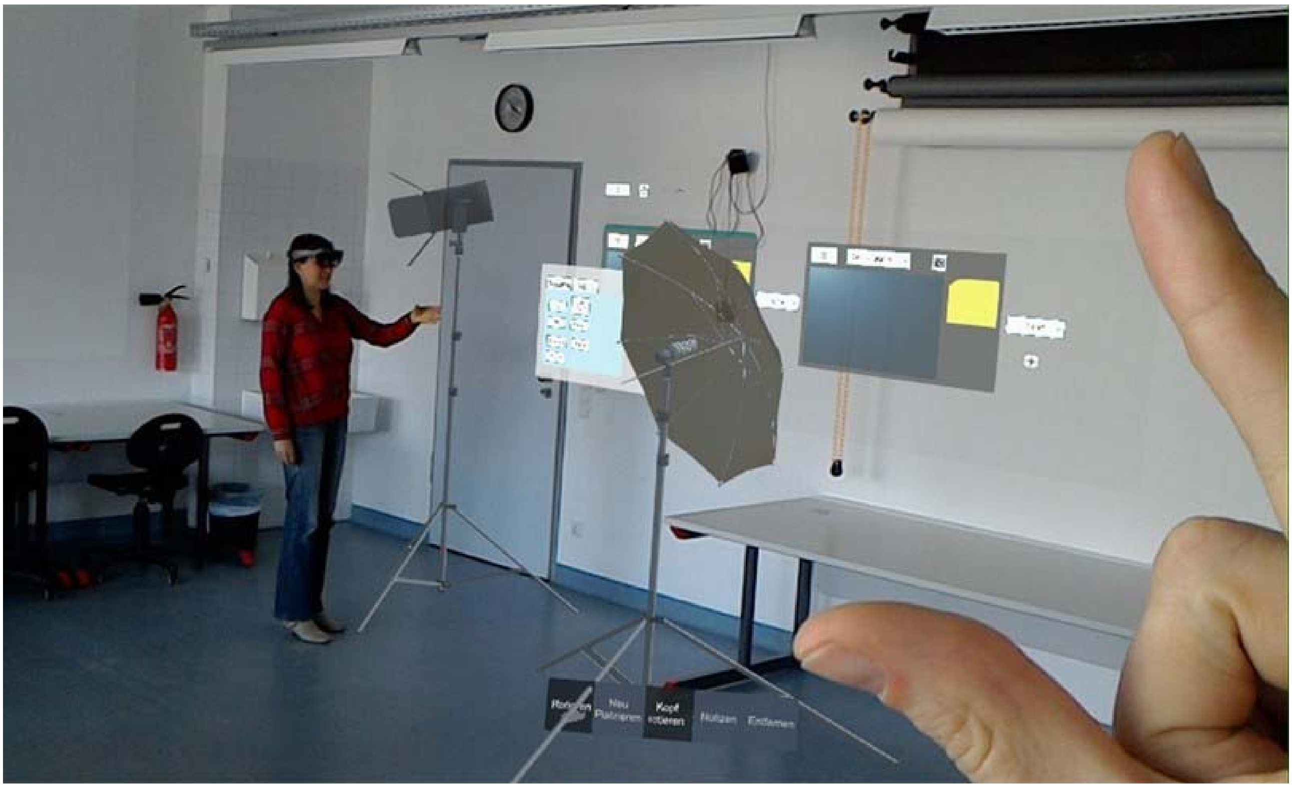

Figure 13. Learning with 3D virtual objects (spot and umbrella light) for planning a film set in the room. In the background: virtual storyboards for the scene.

While undertaking the observation and the analysis afterwards, attention was paid to the various aspects in the “field”, i.e. in the teaching-learning situation in the laboratory. We adapted the list described by Daymon by *augmented space* and *virtual objects* (Daymon, 2010). We need the augmented space dimension, because when using augmented reality, we extend the reality and it differs from the real space. With the HoloLens glasses we have a small field of view, and it has to be observed how the students deal with it. Additionally, the virtual objects play an important role in our augmented course. For our field, we had dimensions such as real space, augmented space, actors, activity, virtual and real objects, time, goals and feelings or mood.

Because observation alone does not provide direct information about what the person is thinking during an action (Eriksson, 2008), we decide to collect more answers and ideas during a group discussion with open questions at the end of the lecture. This provided our study with more data to analyze and to support the other used methods.

For more specific data, we also used a questionnaire (fig. 6 in the appendix) with a Likert-like scale (Likert, 1932), based on Intrinsic Motivation Inventory (CSDT, 2019). We combined the results with the video observation and the group discussion. The questionnaire included 22 statements with a 1-to-5 Disagree-Agree response scale (fig. 6 in the appendix). Because the application was tested in three different sessions, some students were not present on all days. Thus, we added a sixth answer ("I didn't use this") for statements referring to tasks or functions of the AR application, that were not performed or used by these students. For our questionnaire we developed categories and then assigned statements to the categories. For example, for the category "competence", which was defined based on the discussion in section *Initial Analysis and Preliminary Design Assumptions*, we had five statements assigned (no. 9, 13, 16, 17, 18 in fig. 6 in the appendix).

Analysis and Results

We calculated the mean value (Table 1) for a statement from our questionnaire (Figure 14) in the appendix) filled by the students. Because we have a five-scale questionnaire, the highest score for a statement was five and the lowest was one.

Table 1. Some results from the questionnaire (Note: results are mean values).

Categories	Results
Active work	4.1
AR technology is interesting	4.6
Social interaction	3.6
Competence	4
Working with gestures and gaze in space	3.7

80% of the students experienced better understanding of the themes storyboards, framing and film planning ("competence" in Table 1) and confirmed their active participation using the AR application in the classroom ("active work" in Table 1). 8 of 9 students think that the augmented reality application and technology are interesting (answer "is true"). 8 chose a positive answer for usage also in other lectures (6 - "is true", 2 - "is more likely to be true").

A statement about taking notes with the application was included in the questionnaire and the results show very low mean value (1.9). Even though the notes field was thought to be only for short 1-2 words notes, the students found it exhausting to type "in the air" with virtual keyboard using gestures. This is an issue which has to be considered for future work.

Results and notes according to the dimensions of the field, presented in the previous subsection, are described next.

After examining the observation recordings, it is positive to note that the students *participated* much more *actively* in the exercise by using the AR application. This observation matches the results from the questionnaire. The work in the room and not in front of the desktop computer is more visible to everyone and motivates for participation. Nevertheless, it should be mentioned, that this is not that easy for all students. The students are often accustomed to frontal teaching or computer work and need some time to start actively moving around in the room. This must be considered when planning the teaching time with AR. Regarding the *time* dimension it can be said, that a too long duration of the active parts in the exercise showed some negative effects towards the end of the lecture. In the afternoon (which is the time setting of the course) the active parts have to be short or interrupted with breaks, because most students looked tired at the end and this can affect the motivation and the *mood*. The fatigue could be also an issue regarding the work in *real space* while standing and working with *virtual objects* using gestures.

Observing the dimensions *activities* and *actors*, it is noticeable that some students do not want to act in front of the camera and be part of the storyboard image. In this case virtual characters can be used, which are then placed by exactly these students. Consequently, they also participate actively, but do not have to be in the picture if they do not feel comfortable with it.

Analysis of the group discussion, which has also been recorded, showed that the highest total duration time was in the category "ideas and new features for the application". Almost the same total duration had the categories "spatial work", "framing in the storyboards" and "does not function optimal". Some of the categories were defined before the discussion, some of them were brought up by the students, as the teacher started the discussion with open questions and the students decided which topic to discuss longer.

Analysis of the questionnaire (Figure 14 in appendix) shows mean values 3.6 and 3.7 for the categories "social interaction" and "working in space with gestures and gaze" (Table 1). The lower acceptance was confirmed by the observation and the group discussion. One of the most discussed themes "does not function optimally" was associated with working in space and with gestures. It was mentioned also that after a familiarization phase it was easier to work with the virtual items. Some students also had problems with the tracking and recognition of the room by the HoloLens glasses. Therefore, attention has to be paid to issues regarding the *real space* and *real objects*. The HoloLens glasses work well in a space which is not too big or small. The optimal zone for hologram placement is between 1.25 and 5 meters in front of the user (Microsoft, 2019). Too many real objects could affect the group work in the room, as the students need a free area to move.

The social interaction was higher than when doing tasks on the computer, since the computer is usually used by a single person. But it was not that easy to work together in the *augmented space* directly, as only the person wearing the glasses sees the virtual augmentations. Improvements for this problem are discussed in the future work section.

Several students mentioned in the group discussion that they prefer to use the augmented reality application rather than paper and pencils or web program. There were a lot of ideas for the program, which indicates interest for the topic. The group discussion shows, that the active participation and motivation of the students for the preproduction phase was successful.

At the end of the semester we analyzed the students' assignments as we did in the initial analysis mentioned in previous section. This way we were able to compare data of the course with AR usage with results achieved without AR. Our results show an increase of the percentage of submitted pre-production documents, which the students had to create as a part of their project report (Figure 14 in orange). This is an indication, that the pre-production phase is considered more important by the students than without AR and their motivation for that phase seems to be higher. Analyzing the projects reports in the next semester will help to collect more data and to verify the results.

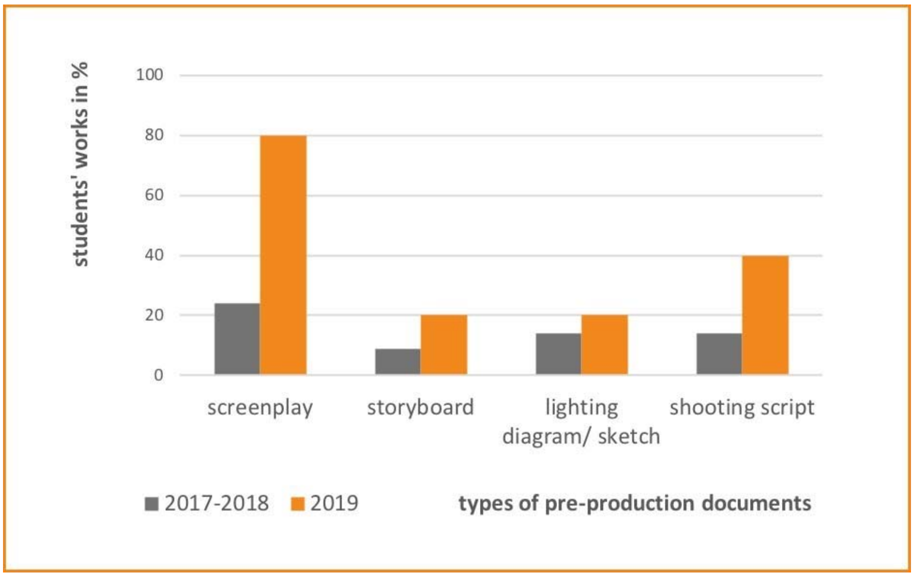

Figure 14. Comparison of number of students' pre-production documents

Lessons Learned

We would like to emphasize a number of lessons we learned during our tests. They are results of observations and our case study on how to deploy AR in an optimal way and what activities are recommendable to integrate.

A special introduction to working with AR glasses is necessary.

It is better to explain the AR application with standard tools (like presentation slides) instead of using the app and showing time-delayed via projector.

Alternation of active and passive phases for the students is helpful to prevent fatigue.

AR activities in the room help students to participate more actively during the course.

Small groups are more suitable for using the AR application, because for working with AR in the room one needs more space.

Conclusion and Future Work

Teaching and learning at the university is no longer thinkable without digital media. Therefore, innovative scenarios should continue to be conceptualized, tested and researched. It is important to develop and investigate approaches at an early stage of technology so that the universities do not fall behind, but remain innovators and one step ahead. In our case study “audiovisual production” some of the assumed advantages of augmented reality were confirmed. AR is suitable both for use in spatial work and for increasing the activity and motivation of students. As to be expected, challenges could also be identified. The social interaction is supported with the use of augmented reality, but it can still be optimized. The “augmented space” should be visible for more than one person. The integration of shared experiences is the next step for our future work on the application. Another feature to implement and test is audio notes, as the results from the questionnaire showed that writing notes (even short ones) is exhausting using gestures in AR.

Regarding the didactic scenario, it is planned to add a fourth session for using the AR application in the course. This way the students can have more time for learning to work with gestures and gaze. In the next semester, the active parts with the AR application will be shortened and mixed with different tasks or frontal presentation. For the AR sessions in the future an additional instructor or assistant is planned, as the three groups in the exercises need more attention or support with the new interaction and hardware.

The developed AR application and the corresponding teaching scenario will be tested in similar lectures at other universities in the near future. This will be helpful to determine which differences the changed context (different rooms, different group size, technical equipment etc.) brings and where similar advantages or problems arise from the use of AR.

In order to integrate AR into teaching permanently, hardware-specific upgrades are necessary. At the moment, the technology is still expensive, but there is the expectation that it will become more accessible over time and that the universities will then be able to purchase a higher number of AR devices.

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Appendix: Questionnaire

The questionnaire for evaluation of the case study is shown in Figure 15.

Feedback for the educational AR application in the course *audiovisual production*

Dear students,

with this questionnaire we would like to examine your experiences with the AR application in the exercise. How did you find using the application? In the following statements, check the column that most closely corresponds to your opinion.

Thank you very much.
The SAARTE project team

I was present during the exercise on 11.4.2019. Yes / No
I was present during the exercise on 18.4.2019. Yes / No

		is not true	is rather not true	is partly true	is more likely to be true	is true		I didn't use this
	Statements on specific functions							
1	Selecting the framing/shots via drop-down was possible without much effort.							
2	Creating a storyboard image was easy.							
3	Creating notes was exhausting.							
4	The placement of the objects/menus via gaze was easy right from the start.							
5	The placement of the objects/menus via gaze was unproblematic after a familiarization phase.							
6	Selecting the transitions between the storyboards was possible without much effort.							
7	Displaying the storyboards in the room was not optimal.							
8	Saving the storyboards was unproblematic.							
9	The application was helpful for the tasks I had to perform.							

		is not true	is rather not true	is partly true	is more likely to be true	is true		I didn't use this
	More general statements							
10	The application gave me enough visual hints to the current input position or action (e.g. textual hint, color, cursor etc.).							
11	I found the use of the application in the exercise interesting.							
12	It was not difficult for me to learn how to use the application.							
13	I am satisfied with my performance in the exercise.							
14	The terms used in the application were understandable for me.							
15	By using the application, I was able to actively participate in the exercise.							
16	I was able to practice subject terms such as storyboarding, framing, shots.							
17	I learned a lot about film planning.							
18	I think I was pretty good at creating storyboards.							
19	To use the application, I had to move around in space a lot.							
20	In order to use the application, I had to remember many details.							
21	While using the application, I worked and discussed a lot with other students.							
22	I would also use this technology in other teaching and learning scenarios.							

Thank you very much for your participation!

Figure 15. Questionnaire for the students (translated)

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A Virtual Reality and BIM Approach for Clash Resolution

Pierre Raimbaud[1,2], Mateo Bonilla Palacios[2], Juan Pablo Romero Cortes[2], Pablo Figueroa[2], Ruding Lou[1], Florence Danglade[1], Frederic Merienne[1] and Jose Tiberio Hernandez[2]

[1]LiSPEN, Arts et Metiers, Institut Image, Chalon-sur-Saone, France
[2]Universidad de los Andes, Colombia

Corresponding author: pierre.raimbaud@ensam.eu, p.raimbaud@uniandes.edu.co

Keywords: BIM, virtual reality, immersion, clash resolution, clash analysis

In the Architecture, Construction and Engineering (AEC) industry, a crucial task is Building Information Modelling (BIM) models coordination. Clashes can be detected automatically by current BIM tools. Clash origins (parn et al., 2018), or avoidance (Singh et al., 2015) have been studied. But, clash resolution still needs the civil engineers' expertise. Currently, in a computer with a 3D BIM tool, they use annotations. As previous research showed that Virtual Reality (VR) can help to perform better AEC tasks, in terms of time and accuracy (Chalhoup and Ayer, 2018), we propose an immersive VR tool to solve clashes.

Methodology

As for us, immersion is missing in the current method, so, in VR, clashes may be understood and solved faster and better. Comparison with the current method in a within-subjects design experiment allowed to evaluate our solution, measuring time and solution quality. Experts had to use annotations in both methods to explain their solution. Preliminary results tend to confirm initial hypotheses: they solved the inconsistencies faster in VR, and for some clashes, they solved it better. So, new experiments with more experts are necessary to get more conclusive results.

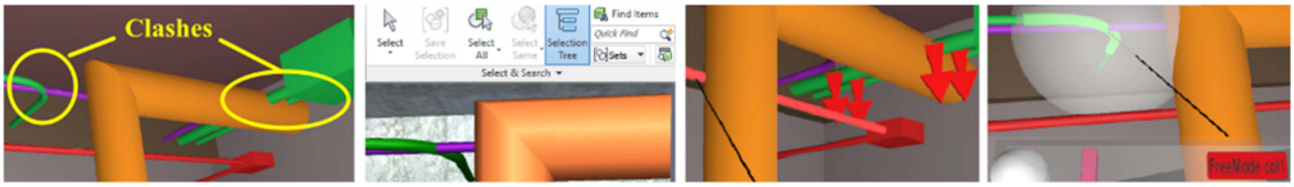

Figure 16. From left to right: clashes examples; BIM tool interface; annotations in our VR tool: narrows, spheres.

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WEARABLE THEATRE –
Theatrical VR and the art of immersive storytelling

Markus Wintersberger, Marcus Josef Weiss, Colleen Rae Holmes, Christian Munk,

Thomas Wagensommerer, Ulrich Kühn and Georg Vogt

St. Pölten University of Applied Sciences, Austria

Corresponding author: georg.vogt@fhstp.ac.at

Keywords: VR, theatre, arts, art-based research, presence, realism, embodiment, self-representation, avatars.

The application refers to the specific employment of VR in Theatre as developed in the 3-year research project WEARABLE THEATRE. THE ART OF IMMERSIVE STORYTELLING.

The art-based research project explores the connection between 360° storytelling and Virtual Reality through the artistic use of wearable devices. Now in its final year, the Project Team is consolidating its conclusions and workflows and intensifying its dissemination. (Vogt / Weiss 2018, Vogt 2019, Fischer 2018, Fischer 2019, Wintersberger 2018ab). A Follow up PEEK research-proposal inquiring into the theatrical potential of XR technology has been submitted.

VR is an amplifier for immersion and empathy. When the 360° environment is constructively exploited in the application of compositional elements, staging and acoutic design, the immersive experience of a narrative world can be opened up to the User. The WEARABLE THEATRE project has focused on identifying and structuring the aesthetic variables and applying them in 12 experimental settings, each focussing on a specific aspect of VR sensory experience. The goal is to understand and master the visual, acoustic and atmospheric possibilities that 360°VR offers and to merge these variables with a narrative to produce a unique immersive VR art-experience. First-person narratives of three authors: Fyodor M. Dostoyevsky, Albert Camus and Max Frisch, whose writing is both existential and highly atmospheric, were chosen to provide a literary starting point for the research.

The diverse approaches and ideas of the interdisciplinary team of media artists, media technicians and theatre producers from the University of applied Sciences St. Pölten and the OAA-Conservatorium for Acting in Vienna were essential, providing a deeper understanding of the connection between 360° storytelling and media-art production as pertains to new immersive media technology. By means of wearable VR devices the emotional realities of both the actors and the Users are able to interact transforming traditional storytelling into a dreamlike immersive VR experience.

Within the delineation of a structured scientific process this emerging media technology was examined, questioned and optimized from the varied perspectives of 360° VR-storytelling. Like any art form that depends on technology and craftsmanship, certain terms and concepts had to be investigated and analysed in order to be understood according to their specificity and application. In the first two years the technical and aesthetic variables of 360° VR were explored. The interfacing between the narrative and Wearable VR-Media was investigated as to its artistic potential regarding the treatment of dramatic subject-matter, acting, the use and manipulation of space and the relationship of these aspects to the

User. The artistic and scientific assumptions laid down in the application were explored the 12 experiments which were divided into three fundamental components:

- VR-story: Components comprise character, plot and dialogue
- VR-setting: Components comprise surroundings, atmosphere and the placement of the 360°Camera
- VR-sound: Components comprise dialogue, sound effects and music.

Additionally, the principles of Points of Orientation - visual or acoustic cues, signalling to the user where the events are taking place, and Points of Attention - visual or acoustic cues which draw the User into the narrative (defined in the PEEK application Wearable Theatre: The Art of Immersive Storytelling in 2016), were evaluated in-depth in 2017 and 2018 according to the content-related objectives and prerequisite technology.

In 2018 the central evaluation point, and a milestone of the three-year FWF art-based research project "Wearable Theatre. The Art of Immersive Storytelling", was a short experimental theatre piece: “Nachtgerüche" (Night Rumours), written by Marcus Josef Weiss and premiered as part of the Festival #Wien 5 - The Art of the Neighbourhood - a city project by the Junge Volkstheater Wien in the district of Margareten. “Nachtgerüche" inspired by the central theme of the novel "Demons" by Fyodor Dostoevsky, condenses the dramatic, structural and media-technological findings from the series of experiments in the first year of research into the form of a 10-minute play, which could be experienced virtually, or directly physically in two separate settings (Black Box & White Box). The intention behind this piece was to draw conclusions about the effect and emotional connectivity of the experimental forms and the results of these inferences have been further evaluated in literary and media-art terms. "Nachtgerüche" was performed on May 25th and 26th 2018 at the Black Box Theatre, OAA-Conservatorium for Acting in co-production with the Volkstheater Wien.

In 2019 the research project has continued to expand and develop its findings into prototypical implementations at the interface of theatre, installation, VR setup and media-art. These developments were demonstrated in the live-performative installation "NOMED" - a prototype developed in the video studio of the FH St. Pölten during an intensive research week in February 2019 and presented as a performance installation and exhibition in the gallery Zentrale in Vienna. The "NOMED" VR installation and visualization was also shown as part of the "Digital Natives 19" festival organized by the Volkstheater and the Union Theatres Europe.

This festival in June 2019 was also host to “AEON”, a WEARABLE THEATRE project employing VR Video in a setting that included the entire spatial arrangement of the theatre from basement to stage. Human actors performing live on stage were supplemented by live-stream interactive footage of actors performing beneath the stage and were experienced simultaneously in an altered form through the transmission of footage relayed in real-time to VR glasses worn by audience members also on stage. The dichotomy of audience and actors was blurred, as was the temporal unity of the theatrical event by utilizing live-streaming and recorded media. Furthermore, the material - mixed with archived rehearsal footage, added as a third experiential layer of rewinding and interaction - was transmitted to alternate Virtual environments and social networks.

Figure 17. AEON Stage, Volkstheater Wien, June 2019.

XR theatre

The theatrical experiments of WEARABLE THEATRE have clearly indicated that VR as well as XR technology can prove highly beneficial for theatre. The follow-up project, XR theatre, develops this even further. As a Hypermedium, theatre is able to incorporate other media and art forms without them losing their specific medial and artistic qualities and is thus the ideal space for material practices (bodies, lights, sound…) to meet and intra-act. XR Theatre, focusing on the material processes constituting the theatrical event, has the potential because of its strong material/sensory component, to advance corresponding material practices of "difference".

XR Theatre represents a further development of the live theatre experience as a social institution of collective cultural practice that negotiates difference and creates knowledge and awareness though artistic processes. XR theatre expands the way stories might be told by incorporating XR elements into theatrical spaces and interlinking them with other public spheres. XR Theatre follows the conceptual and practical shift from the reflective subject, author, actor and participant as separate entities, to a form of knowledge generated by diffraction or "diffractive analysis" as theorized by Karen Barad and Donna Haraway.

Acknowledgements

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Mobile augmented reality for teaching physics to secondary school children

Kumari Moothedath Chandran, Sagar Biradar, Niyati Shukla,

Arvind Iyer and Balan Gurumoorthy

Indian Institute of Science, Bangalore, India

Corresponding author: kumarimc@iisc.ac.in

Keywords: Augmented Reality, STEM education, Secondary school education

Traditional learning environment in K12 system of India to teach STEM education is based on classroom learning and laboratory sessions. The laboratory sessions are less frequent, and usually each session involves introducing one experiment kit to one cohort of students. Often, students do not get individual access to the experiment kits in the laboratory. A school might own only one experiment kit each for a topic, and in resource-deprived schools, none. Therefore, many times, for a particular topic, the scheduling of laboratory sessions are not aligned with the theory lessons. On the other hand, for the end-term evaluations of students of classes 11 and 12, there is a practical component, where students have to individually perform a laboratory experiment. But students do not get access to the experiment kits, to revise using them. This was the motivation for this research where digital animations (3D and Augmented Reality) of experiment kits of different topics in Physics from K12 curriculum were created for use in mobile devices such that students can learn and revise how to perform these experiments.

Several researchers have studied on the advantages of using mobile devices for education and have found that it has potential to play a major role for pedagogical purposes (Nincarean et. al, 2013; Chen et. al, 2003; Denk et. al, 2007; FitzGerald et. al, 2012; Hwang et. al, 2009; Uzunboylu et. al, 2009; Zurita and Nussbaum, 2004). India's mobile use is 90.15 per 100 people (Highlights of Telecom Subscription Data, 2019), which makes the use of mobile devices for learning a much more accessible option to a majority of school students. Mobile-learning (M-learning) can enable access and interaction with the educational content through a student's mobile device. Augmented reality technology overlays virtual objects (augmented components) into the real world making them appear to coexist in the same space as objects in the real world (Akçayır and Akçayır, 2017; Azuma et. al, 2001). The increased use and availability of devices for Augmented Reality (AR) has made AR apps for research and education widespread in the recent years (Lindner et. al, 2019; Li et. al, 2017; Wojciechowski and Cellary, 2013). AR plays a dominant role in M-learning as it can enrich the real world with virtual content and information, like videos, animations, maps, images, texts and other tools (Lindner et. al, 2019; Dunleavy et. al, 2009).

Use of AR in education has been studied by many researchers (Cabero-Almenara et. al, 2019; Han et. al, 2015; Santos et. al, 2016; Akçayır and Akçayır, 2017; Aguayo et. al, 2017; Pedraza et. al, 2017; Chang and Hwang, 2018; Ibañéz and Delgado, 2018; Rauschnabel et. al, 2018). AR is used in all levels of education from K-12 (Akçayır and Akçayır, 2017; Chiang et. al, 2014b; Kerawalla, 2006) to the university-level (Akçayır and Akçayır, 2017; Ferrer-Torregrosa et. al, 2015). Garzón and Acevedo (2019), from a meta-review of 64 papers claim that AR is found most useful at bachelors or equivalent level and has a higher impact in learning outcomes when used to teach subjects in Engineering, Arts and Humanities (Garzón and Acevedo, 2019). There are several papers reporting research where AR was used in university-level mathematics and geometry education (Tsou et. al, 2017), engineering (Cai et. al, 2014; Sorby, 2009) and architecture education (Cai et. al, 2014), university-level physics laboratory skill development (Akçayır and Akçayır, 2017; Akçayır et. al, 2016), junior high school chemistry education (Cai et. al, 2014; Stull et. al, 2013), secondary school level astronomy education (Lindner et. al, 2019).

This research will compare the impact of teaching Physics topics to secondary school students using virtual replicas of experiment kits using mobile-Augmented Reality animations versus mobile-video animations. The purpose of this research is to establish if teaching Physics topics to students with simultaneously explaining the theory and demonstration of virtual experiment kits would enable students understand the topic better. The comparison approach is taken to understand whether AR's unique capability of overlaying virtual objects in the real-world space adds more value in students' learning. Therefore, it is compared to 3D CAD animations which does not have this capability alone, but all the rest. Mobile-Virtual Reality (VR) was not chosen for comparison with AR as mobile-VR requires a VR headset which is not as pervasive as mobile devices in the context of K12 schools in India.

Teaching Physics topics: Experiment and Method

Two Physics topics of Class 11 were chosen for this comparative study. The first topic was 'friction', which involved introducing the concept of friction, and finding the angle of least friction for a given surface and mass. The second topic was on introducing the concept of 'moment', and finding the force and distance to attain equilibrium in a system. The teaching content for both topics were prepared as slides and animations to be viewed in 8-inch tablet devices. The slides for each topic consisted of basic definitions, formulae, figures and applications. Physical experiment kits designed by the same research group were chosen (Figure 18) and digital 3D-video animations (Figure 19) of these physical kits were created for different input cases in 3DStudio Max. These animations were imported in WakingApp software to create mobile-AR animations (Figure 20) using a marker. AR markers were used to make the AR content appear as if it is kept on a table, similar to the physical experiment kits, as well as the video animation content. The 3D-video and AR animations were identical, except that in AR the animation would be seen overlaid to the real-world with the flexibility to change the view-point by a user. The viewpoints of video animations were selected such as it best captures the experiment.

Thirty-one students from classes 7, 8, 9 and 10 participated in this study who had no prior exposure to the two topics chosen from Class 11. The gender ratio and the distribution of students across various classes are in Figure 21. The curriculum of 17 students were the Central Board for Secondary Education (CBSE) of India and 9 students from the Indian Certificate of Secondary Education (ICSE), two each from the International General Certificate of Secondary Education and the Karnataka State Education Board (Figure 22).

Figure 18. Friction (left) and Moment (right) experiment kits

Figure 19. Mobile video animation seen in the tablet device

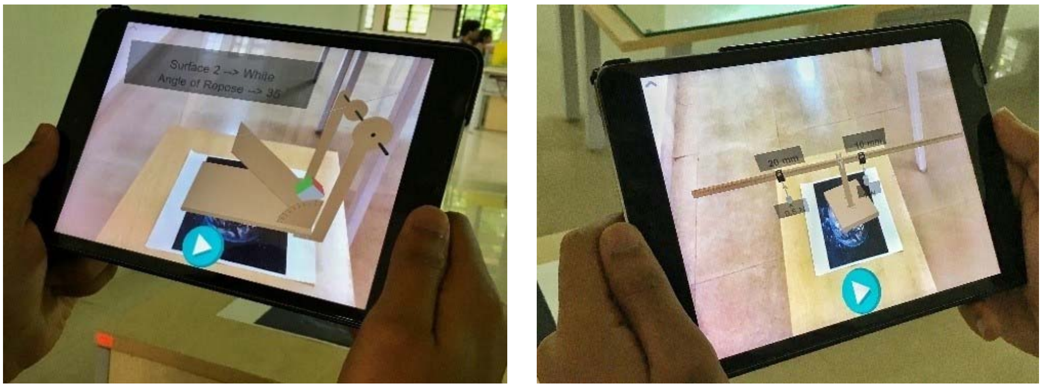

Figure 20. Mobile AR animation seen in the tablet device

Method

Each student was seated in a room with a desk and chair, and an 8-inch tablet device. One tutor was present for each student, and the tutors were the second, third and fourth authors. The two topics were taught to each student one after the other by one tutor. The first topic was taught using slides and mobile-video animations, and the second topic was taught using slides and mobile-AR animations. The topics were alternated to each participant such that one topic was taught using mobile-video animations for half the subjects and using mobile-AR animations for the other half. Figure 23 shows the sequence of the experiment method with the topic and the technology used for teaching for the two cases.

Figure 21. Gender ratio of students (left); and number of students from each class (right).

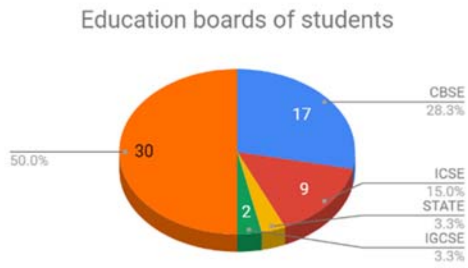

Figure 22. Education boards of students.

The slides, video animations, and AR animations were available in the tablet device. The marker for the AR animation were printed and kept on the table. For the sessions taught using video animations, the slides were shown on the tablet while the tutor was teaching, and the video animations showing the experiment kits were played on the tablet itself. Similarly, for the session taught using mobile-AR animations, the slides were shown on the tablet, and the AR marker kept on the student's table was scanned using the camera of the tablet device, so that the AR animations appear as if the experiment kits were placed on the student's table. The tablets were given to the students so that they get a hands-on experience of interacting with AR (Figure 22). For the video animations as well, the students were given the tablet to play it hands-on.

Each student was given a pre-test before the exam, followed by teaching, and a post-test to evaluate the learning. The tests were paper-based and 15 minutes each were given for both pre-test and post-test. The pre-test and post-test had different set of questions. Two separate quiz sheets were prepared for each topic, labelled as Q1 and Q2. Each quiz had 10 questions each with theory and numerical questions, with the same pattern involving multiple-choice answers or descriptive answers. The questions with higher difficulty level carried 2 marks and lower difficulty level carried 1 mark. The maximum marks of both papers were 18 points. As there are two cases, with the topics swapped among video and AR animations as the technologies for teaching, the pre-test and post-test quiz sheets of a topic were also swapped in Case 2. This was done so that the difficult level of a particular quiz sheet does not influence the research. The swapping of pre-test and post-test sheets (Q1 and Q2) among both cases are shown in Figure 23.

All participants had no prior exposure to experiencing AR. Therefore, mobile-AR animations were introduced second in all cases as there is a chance that students would show less involvement and motivation in attending the second session using mobile-video animations which was not an entirely new medium.

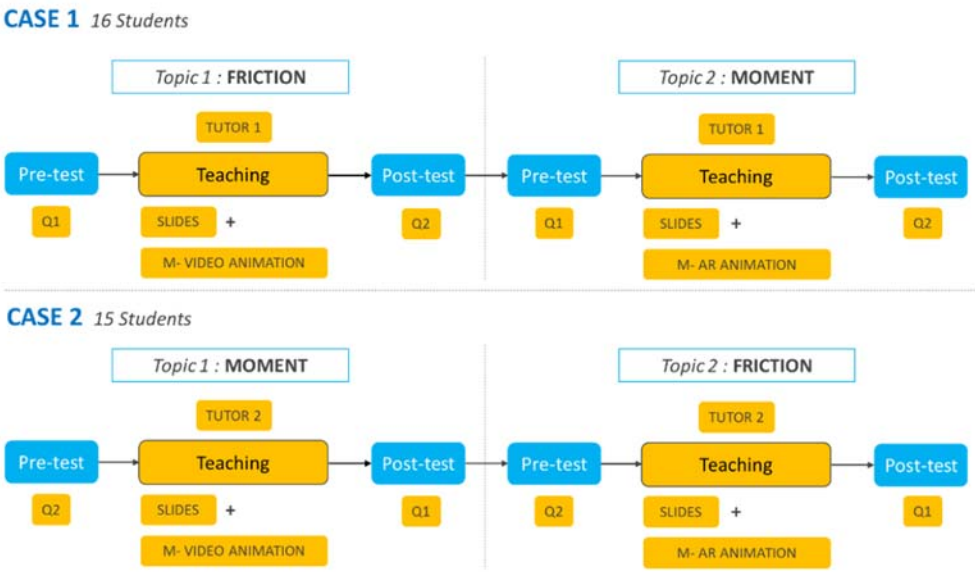

Figure 23. Two cases of experiments with topics, teaching medium and question paper information.

Results and discussions

The quiz sheets of the 31 students were evaluated, and the difference in scores were found from pre-test and post-test scores of each student. Figure 24 and Figure 25 show a bar chart of the mean of scores of pre-test and post-test for Case 1 and Case 2 respectively. Table 2 and Table 3 report the Mean, Standard Deviation and number of subjects for Case 1 and 2 respectively.

A paired t-test was performed on the results, as we have two quiz results of the same individual for one topic, i.e., before and after teaching using one of the technologies (mobile-video animation or mobile-AR animation). There were two pairs of pre-test and post-test for each case, Case 1 and Case 2, one pair taught using video animations and the second pair using AR animations. As the topics were swapped in Case 1 and 2, there are overall 4 pairs of pre-test and post-test scores for 31 students. The paired t-test was performed on each of these 4 different pairs. The null hypothesis for paired t-test was that there is no gain in scores after teaching using video animations for the two cases taught using video animations. Similarly, the null hypothesis for paired t-test for cases taught using AR animations was that there is no gain in scores after teaching using AR animations.

Figure 24. Individual student scores in pre-test and post-test for Case 1

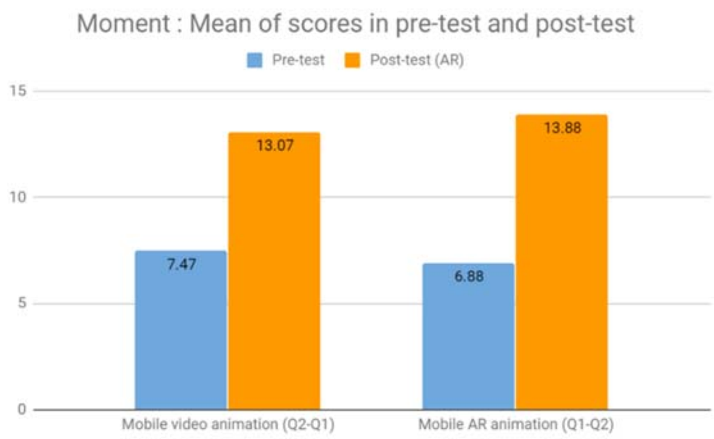

Figure 25. Individual student scores in pre-test and post-test for Case 2

Table 2. Case 1 Quiz result statistics

Case 1	Friction (Video)		Moment (AR)	
	Pre-test	*Post-test*	*Pre-test*	*Post-test*
	Q1	Q2	Q1	Q2
Mean	8.75	10.19	6.88	13.88
Standard Deviation	2.75	2.43	4.70	3.12
Count	16	16	16	16

Table 3. Case 2 Quiz result statistics

Case 2	Moment (Video)		Friction (AR)	
	Pre-test	*Post-test*	*Pre-test*	*Post-test*
	Q2	Q1	Q2	Q1
Mean	7.47	13.07	6.07	11.47
Standard Deviation	4.64	4.22	3.39	3.56
Count	15	15	15	15

Table 4 shows a compilation of the results from the individual paired t-tests for both topics, Friction and Moment while taught using video animations and AR animations. The paired t-test results show t-Statistic values are greater than t-Critical for all cases which means, we can reject the null hypothesis, which is there is no gain in scores. The p values are less than the significance value of 0.05. If you look at p values of topics taught using AR, it is significantly lesser than 1% or 0.01 for both topics, that even at significance level 1% we can say the teaching using AR is improving the scores. In all the cases, the null hypotheses were rejected.

To study the influence of the specific technology used for teaching, among both populations in Case 1 and Case 2 combined, an independent t-test was performed to compare the gains in scores of students taught using mobile-AR animations and video animations. For this, the gains in scores of both topics, Moment and Friction, were combined into two groups labelled, Video and AR. The independent t-test assumes the variances of the two groups are equal in the population. If the variances are unequal, this can affect the Type I error rate, which is about incorrectly rejecting the null hypothesis. The variances were tested using Anova single factor test and the p value (0.77) obtained was greater than 0.05 which means the variances are equal in the two groups.

For independent t-test (two sample assuming equal variances), the gains in scores of students taught using mobile-AR animations (Mean = 6.23, Standard Deviation =4.25, n = 31) was hypothesized to be greater than the gains in scores of those taught using video animations (Mean = 3.45, Standard Deviation = 4.1, n = 31). Therefore, this is a one-tailed situation. This difference was significant from the results, t (60) = 1.67, p = 0.01 (1 tail), $p < 0.05$. Also, the t-Statistic (2.67) is greater than t-Critical one-tail (1.67) which shows using AR is significant. The results show that the gains in scores in AR group is statistically significant and teaching using mobile-AR animations have more effect on the students' gains in scores compared to teaching using mobile-video animations.

Table 4. Paired t-test results from pre-test and post-test among participants

	Video		AR	
	Friction	Moment	Friction	Moment
t Stat	2.5225526	4.7523007	5.8391582	5.8639547
t Critical one-tail	1.7530503	1.7613101	1.7613101	1.7530503
P(T<=t) one-tail	0.0117189	0.0001545	0.0000215	0.0000155
Mean of Difference	1.4375	5.6	7	11.47
Std. Dev. of Difference	2.2794370	4.5638329	4.7749435	3.5816995
Std. Error of Difference	0.5698592	1.1783766	1.1937336	0.9247908

Discussions

The paired t-tests demonstrate topics taught using mobile-AR animations have significantly higher t-Statistic values and shows an increase in scores of students. The independent t-test results show the students' gains in scores are a real difference while teaching using mobile-AR animations than mobile-video animations, and the average difference between Video and AR group is statistically significant. This means the gains are not random and that there is real difference in the students' gains in scores achieved by teaching using mobile-AR animations as against mobile-video animations.

From both the tests performed, we can conclude teaching using mobile-AR animations helped students understand the Physics topics taught better, and solve the problems given in the quiz better. As the content of animations were exactly the same for video and AR cases, the only difference was the additional capability of AR to merge virtual 3D content to actual environment and the 3D interaction capabilities. The 3D-video animation helps user visualise the experiments, but lacks user-interaction with the 3D-content to change view-points. The video animations needed to be created in a viewing angle that supported best visualisation of the experiment kits. These could be potential factors that affected the results. Teaching using video animations were done before the AR animations in both the cases, but the topics were different, and the question papers were swapped across the cases. The experiment was controlled on the effect of topic, and the difficulty-level of the question paper. The influence of teaching mobile-AR animations first, are being looked at in our ongoing work.

The results obtained shows the potential for AR in teaching science topics, and how its capability to merge virtual content to actual environment is proving beneficial for students' understanding of the topic. AR content would help students see laboratory experiment kits in their mobile devices alongside the theory sessions in classrooms. The results denote that students are able to relate to the experiment kits to the theory taught. This is a promising result even when the topics taught were from the syllabus of class 11, a higher level than that of the students participated in the study. One observation is that students of class 8 had no exposure to trigonometry before, and therefore found it difficult to understand the calculation of co-efficient of friction. Yet, these students were able to perform better after teaching using AR animations.

Conclusions

Many positive effects on students have been reported by the use of AR apps for teaching STEM topics, like increased attention, interest and motivation levels, as well as increased cognitive and social skills (Lindner, 2019; Li et. al, 2017). Research so far has reported benefits of using AR in teaching for university-level students in STEM topics. The results from the research presented here on secondary school students show promise in using AR content for teaching Physics topics. The potential of AR to help address the present issues in India's K-12 education is to be noted. It not only addresses the lack of sufficient number of physical experiment kits, and low student-to-kit ratio, but also improves students' learning by bringing virtual content of laboratory experiments into the theoretical classroom teaching environment and by enabling exclusive access of these experiments to individual students. This would have widespread implications on the way STEM topics are taught in Indian K12 classrooms especially in resource-constrained situations. At present, this research is being extended with more experiments with different topics in actual school environments.

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Practice and experience in high quality 3D graph visualization in virtual reality

Jonas Müller, Jakob Harlan, Marc Stamminger and Roberto Grosso

Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany

Corresponding authors: jonas.ej.mueller@fau.de, jakob.harlan@fau.de, marc.stamminger@fau.de and roberto.grosso@fau.de

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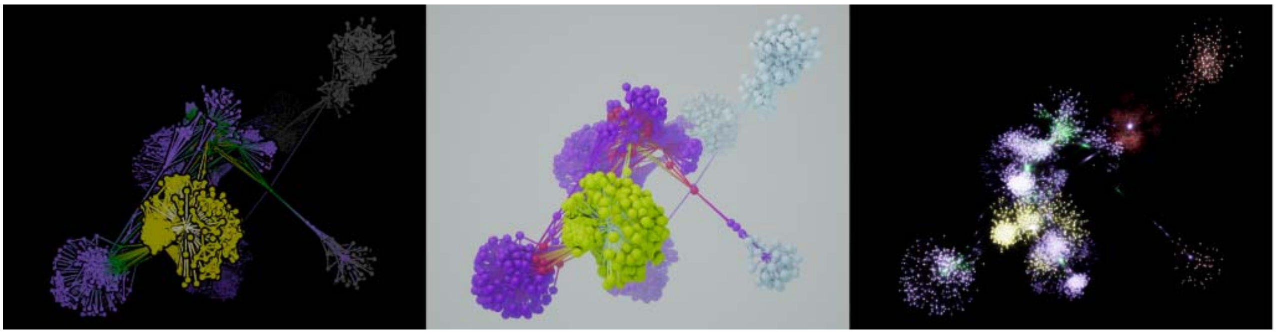

Figure 26. Screenshots of high quality 3D graph visualizations in VR: (left) flat colored drawing with **halos** to improve depth perception, (center) shaded **solid** surfaces with **ambient occlusion** and (right) transparent surfaces with **additive** blending. All configurations are applied to the same graph (Social circles: Facebook) and perspective. The color is used to visualize different graph theoretic distances to a selected node in the center of the yellow cluster in the foreground.

The visualization of complex graphs (abstract networks of **nodes**, connected by **edges**) is a long-standing research problem. Virtual reality (VR) offers a very intuitive access to the third dimension in visualization, which can help for the perception of the structure of complex graphs. However, interactive exploration of a graph in VR requires real-time rendering, which is challenging for complex graphs, even on latest high-end GPUs. Furthermore, visual effects that improve perception of the structure of the graph are desirable, but often increase render time even further.

In this paper, we describe our experiences with the high-quality rendering of 3D graphs. We show practical solutions for the efficient renderings of such graphs and for the inclusion of visual cues that improve the perception of the graph structure, without hampering real-time exploration capabilities. As a result, we present the three graph rendering techniques that are also shown in the teaser figure. We describe the real-time rendering algorithms behind these techniques, evaluate their perceptual properties, and present performance numbers on a state-of-the-art VR system.

Introduction

Graphs are widely used to represent relational data in different application areas such as software analysis, citation networks or the World Wide Web. Large graphs are visualized using node-link diagrams in different layouts or as matrix plots. Node-link diagrams are considered more instructive and popular (Ghoniem et al., 2004). Nevertheless, depending on topological structure and size of the graph, node-link diagrams can suffer from visual clutter induced by edge crossings or node overlaps. Common graph exploration tasks - such as the search for nodes with high centrality, hubs or the visual perception of high level, large scale structures such as communities - are interfered or even impeded by clutter. The problem of cluttering can be addressed by methods that locally reposition vertices or change edge shape (Wong et al., 2003; Wong and Carpendale, 2007) or globally recompute the edge routing (Holten, 2006; Holten and Wijk, 2009; Zielasko et al., 2016). Force-directed graph layouts (Fruchterman and Reingold, 1991) are often preferred because they visually represent large scale structures such as communities or clusters and are well suited for large networks. These algorithms are well understood, and efficient implementations exist. Issues with regard to computational complexity and stability of graph layouts, in particular for very large graphs were discussed in (Harel and Koren, 2001; Meyerhenke et al., 2018).

While most graph visualizations are 2D, we look into graph visualizations in 3D, in particular in virtual reality (VR). The additional dimension allows for a final layout with lower overall tension and therefore edges closer to the desired length. By displaying graphs in VR, the third, additional dimension is very intuitive to access, and the user can interact with the visualization very naturally, which can make the graph and its structure better accessible. Meanwhile, 3D graph layouts can be found in common software packages such as Gephi, e.g. Force Atlas 3D or OpenOrd 3D. Although the extension of 2D algorithms is simple and straightforward, the visual representation of graphs in 3D poses new problems like object occlusion. Thus, seen on a 2D screen, 3D layouts do not in general improve graph exploration tasks. However, Ware and Mitchell (2008) demonstrated that 3D graph layouts complemented with appropriated depth cues in an immersive virtual environment can certainly be used for graph analysis and evaluation (Halpin et al., 2008). With state-of-the-art virtual reality setups, extending this area of research is getting more reasonable, as the technology is available to a broader spectrum of users.

In this work we revisit the results proposed by Ware and Mitchell (2008) and describe our experiences when implementing a 3D graph visualization tool in VR. We demonstrate that the interactive visualization of graphs of a considerable size in an immersive virtual environment providing high quality rendering and visual cues enables users to explore and analyze their data. We propose three different real-time rendering techniques, which use different visual effects to show proximity of objects such as shadows or advanced shading to further improve intuitive understanding of the relation between data-elements.

Related Work

Graphs as given by vertices and edges edges ($G = \{V, E\}$) and their related algorithms form a large and continuously growing field in computational science. 3D graph layouts have demonstrated their applicability a time ago (Teyseyre and Campo, 2009; Brath, 2014). Commonly, data is visualized using standard 2D display where the spatial character of the visual representation is given by standard depth cues such as perspective, occlusion and shading, supported by interaction (Cutting and Vishton, 1995; Ware, 2012). As head-mounted displays become more affordable, the research on algorithms for immersive representation of non-spatial data has considerably increased in the last few years.

In a study presented by Halpin et al. (2008) the use of a 3D interface proved to significantly improve inference from non-spatial data in an immersive system. Huang et al. (2017) developed a gesture system to facilitate interaction, manipulation and analysis of graphs in a virtual environment. Erra et al. found improvements of interaction possibilities of a virtual environment compared to interactions based on mouse-keyboard or joypads when interacting with 3D graphs in their study Erra et al., 2019). Ware et al. showed that stereo vision and motion cues enable skilled users to complete the same tasks in 3D graphs up to an order of magnitude larger (Wade and Franck 1994, 1996; Ware and Mitchell, 2005). Kwon et al. (2015, 2016) have developed a spherical layout for immersive graph visualization providing a study which demonstrates the advantage of their technique. Modeling the immersive environment in a spherical space with the user's viewpoint at the center is offering a large uniform display area. Wu et al. (2006) visualize multivariate network data on the surface of a sphere by generating layouts of nodes and edges via a self-organizing map. Nevertheless, such methods even if they are on a sphere, remain 2D and are well suited for graphs of a decent size and a clear structure. Observations show that this is not the case for many important applications such as large graphs from twitter data. In order to enhance 3D perception, effects of global illumination can be added. Physically based rendering or shading often is a computational expensive task. There exist multiple methods to acquire similar effects in real-time, e.g. ambient occlusion as described by LineAO (Eichelbaum et al., 2013). Halos can help enhance perception of relative depth between lines (Everts et al., 2009, 2011; Luboschik and Schumann, 2008; van der Zwan et al., 2011). Shadowing and shading of geometry greatly assist users in understanding the geometric features. Current game-engines are a good starting point, because they already provide many of the algorithms needed for physically accurate real-time shading out-of-the-box. In this work implementations were carried out within the Unreal Engine 4.

Real-Time 3D Graph Rendering

When working with abstract graphs in general, the first step of a visualization is to generate a graph layout. The layout generation in this paper is done offline using a force-directed method (Fruchteman and Reingold, 1991) in 3D space. The layout generation is not further discussed here as it is not our focus. For 3D rendering of such graphs, most often spheres are used as the geometric representation of nodes and long-stretched cylinders as edges. Other geometric shapes such as cubes, 3D paths or glyphs can be desirable to encode further information. We will stick to spheres, but the extension to other geometry is straightforward. Render time and thus the size of a graph that can be displayed interactively in VR depend on two design choices. First, the complexity of the geometry to render the geometric objects, i.e. the spheres and cylinders. Rendering these as tessellated triangle mesh generates a huge amount of tiny geometry and is only practical for small graphs. In Section "Billboard-based rendering with Efficient Anti-Aliasing" we revisit the rendering of such primitives using billboards. Our proposed approach is significantly faster and thus allows us to render more complex graphs. Furthermore, it allows us to include anti-aliasing and thus to increase visual quality significantly in a very efficient manner. Second, we can apply more sophisticated shading techniques and special effects that improve depth and proximity perception. We consider techniques that are cheap enough to not hamper real-time rendering in Section "Shading Techniques and Special Effects". Based on these rendering techniques, we propose in Section "Proposed Render Modes" three different real-time visualization modes, which are fast enough to display complex graphs in VR, but also exhibit an improved perception of depth and proximity. In Section "Interaction in the Virtual Environment", we describe our VR interaction model for graph exploration.

Billboard-based rendering with Efficient Anti-Aliasing

Using billboards instead of complex meshes is a common strategy of reducing geometry processing complexity. To approximate spherical and cylindrical geometries, the billboard paradigm can be easily applied. For both nodes and edges, the camera-facing bounding-quadrilateral of the geometry in screen-space is calculated in the geometry pass (Figure 27). In order to obtain correct shape and shading of the geometry, accurate normals, 3D position and depth are then calculated per fragment of the billboard and outlying fragments are discarded.

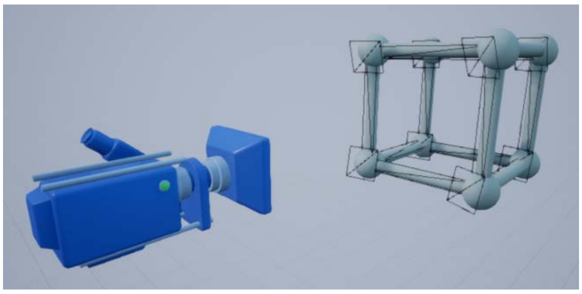

Figure 27. Billboards (black wire-frame quadrilaterals) being used instead of the actual geometry for the given camera.

For complex graphs, nodes and edges can become very small and thus will suffer from severe shader aliasing, i.e. from strong flickering. The rapid and small-scale camera-movement occurring with virtual reality magnifies the resulting flickering. For our special case of graph rendering, we propose a very simple and efficient anti-aliasing technique: Since normals are computed on-the-fly during rendering, we can adapt these normals for small structures. As soon as the footprint of the billboard in screen-space is becoming small, we smooth the normals towards the average normal. As a result, the shading becomes smoother and aliasing disappears without a visible transition, as shown in Figure 28.

When using transparent billboards, an additional transparency towards edge- or node-borders is introduced to prevent aliasing between elements. Traditional anti-aliasing methods like multi-sampling-anti-aliasing (MSAA) and temporal-anti-aliasing (TXAA) are orthogonal and can be applied additionally, e.g. to fight geometric aliasing from thin edges.

Shading Techniques and Special Effects

The shading of nodes and edges can provide important visual hints and additional depth cues. Shading with direct illumination for example helps identifying one node as unique and differentiating it from other nodes. In addition to direct shading, the relative position of nodes and edges can be clarified with advanced shading effects such as shadowing and ambient occlusion.

Ambient Occlusion

Ambient occlusion (AO) approximates indirect light transport between surfaces that are occluded by proximate geometry. In a graph environment AO serves identifying objects being close together and recognizing surface structure of larger clusters of nodes. One common and computationally cheap approach of obtaining AO is a screen-space post process (SSAO). However, with SSAO techniques, occlusion coming from objects that are not visible to the camera is missing. Furthermore, due to the high frequency changes in depth and normals typical for graph renderings, getting a stable SSAO is problematic.

With deep-screen-space, Nalbach et al. (2014) proposed a more accurate method, including occlusion from non-visible objects. Like their approach, we use splatting to accumulate the effects of ambient occlusion generated by the geometry. In addition, we directly use the properties of our sphere- and cylinder- geometry to compute analytical AO for a sphere to a surface point with the formula (Quilez, 2019):

$$I_{AO} = \max\left(0, \boldsymbol{n} \cdot \frac{\boldsymbol{d}}{|\boldsymbol{d}|}\right)\left(\frac{r}{|\boldsymbol{d}|}\right)^2$$

Where, $\boldsymbol{n}$ is the surface normal, $\boldsymbol{d}$ is the vector from the surface position to the center of the node or to the closest point on the edge and r is the radius of the node or edge. Note that, this formula is not accurate for edges, but in our experience, it still yields plausible results.

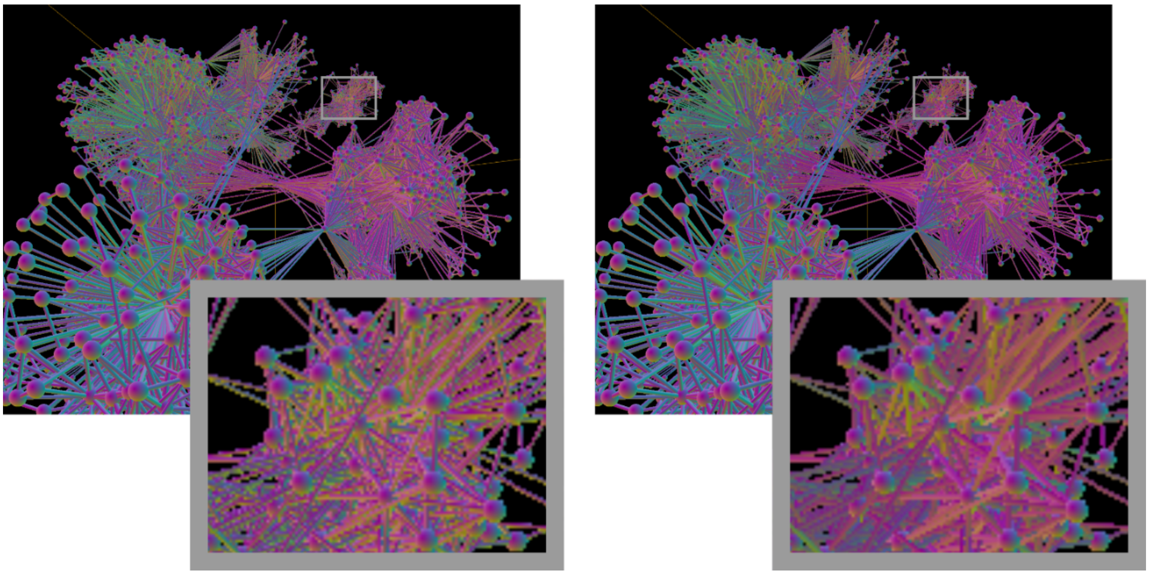

Figure 28. Elements colored by the normal at the given fragment. (left) Accurate normals showing heavy aliasing. (right) Anti-aliased normals depending on the billboard's footprint in screen-space. Note that, anti-aliasing with this method is only applied to shad

As with deep-screen-space, our splatting of ambient occlusion suffers from overestimation that is reduced by limiting the radius of influence. The splats are generated like the billboards for nodes and edges mentioned in Section "Billboard-based rendering with Efficient Anti-Aliasing". The effects of our AO-splatting (especially overestimation) and a comparison to SSAO can be seen in Figure 29.

Shadowing

Shadowing improves depth perception (Ware, 2012; Luboschik et al., 2016) (Figure 30). In our setup, shadow maps provided by the Unreal Engine are used.

Fog

The aspect of fog is receiving its own section not because of its high complexity or innovation, but because of its simplicity and yet effective application. The introduction of fog has the advantage of giving additional depth cues to the user. Furthermore, fog is a cheap way of reducing the high frequencies in the background. This eases aliasing and causes the user to focus on objects in his proximity where stereo vision works best. The application of fog can be observed in Figure 30 and Figure 32.

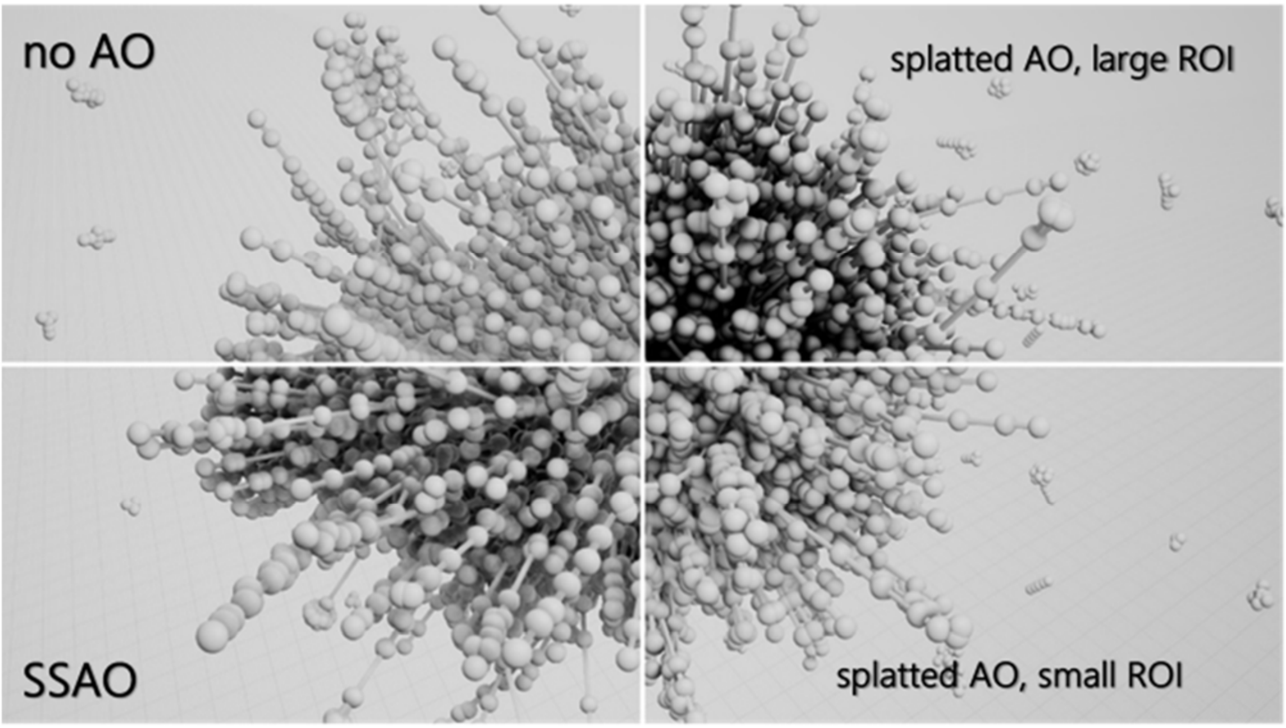

Figure 29. Ambient occlusion is giving necessary depth and proximity cues supporting the 3D perception. Direct illumination without AO (top-left). While giving a good impression, the shading of the detailed inner structure is misleading with SSAO (bottom-left). With our splatted AO (bottom-right), inter object proximity information is conveyed more accurately even for geometry not visible to the camera. When increasing the radius of influence (ROI) of our method (top-right) the problem of overestimation can be seen. Despite the lack of realism, overestimation can work as additional proximity cue - e.g. to show crowded parts like the center of the above cluster.

Halos

Depth-dependent halos Everts and Bekker, 2009) are outlines of nodes or edges, with their size varied by the depth of the scene around the object. Such halos produce a good perception of depth for 3D scenes seen on a 2D screen even for static views (Figure 32). Transparent halos (Figure 33) further improve this scenario by reducing aliasing and smoothing the otherwise sharp halo borders.

Transparency

In graph drawing, transparency can be used to overcome visual occlusion of geometry. The easiest and most widely used method of transparency in this application is realized with additive blending for example in (Royston et al., 2016). Additive edges are beneficial for localization of crowded parts of the network or dense clusters (Figure 34 and Figure 35), similar to density based approaches (Zinsmaier et al., 2012).

Proposed Render Modes

Based on the previously described rendering techniques, we derived three display modes, which are all efficient enough to display large graphs in real-time in VR and offer additional depth and proximity cues:

- Halos refers to drawing solid unilluminated geometry with halos.
- Solid & AO refers to drawing solid geometry with direct illumination, shadows and ambient occlusion.
- Additive refers to drawing additive blended transparent edges and bright nodes.

Example renderings showing these modes are shown in the teaser image, as well as in the Figure 30 to Figure 35. We will examine these three modes in more detail in the following sections “Graph perception” and “Perception” with respect to the perception of graph structures and the performance of the rendering techniques.

Interaction in the Virtual Environment

To position and orient the graph we have implemented a VR interaction suite using tracked hand-held controllers. An explanatory situation can be seen in Figure 36. Static geometry around the user (e.g. the floor) is beneficial to avoid losing orientation. To rotate and scale the network, the two-handed handlebar interaction scheme is employed (Bettio et al., 2007). The graph can be translated, rotated and scaled as if the user would grab an elastic object. Using a ray, the user can select a node to focus on. This node and its neighborhood are emphasized with different colors according to the graph theoretic distance to the selected node. In addition, the transparency of such elements is increased with increasing graph theoretic distance. This coloring scheme can be seen for example in the teaser image (ref teaser). When an illuminated visualization is chosen, a hand-held flashlight can be simulated. Having an additional light source can help in understanding compact structures by providing lighting and shadows from a user-controlled angle.

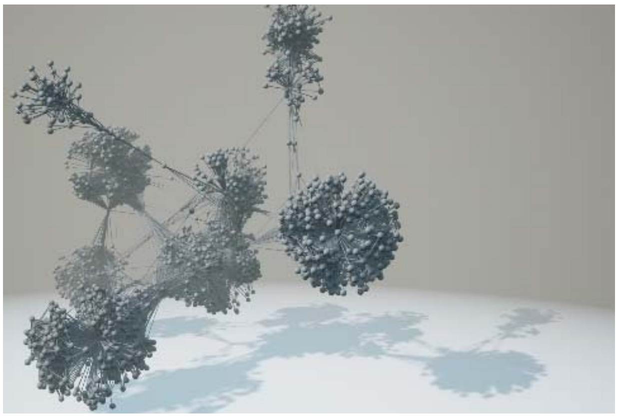

Figure 30. Shadows form an important depth cue.

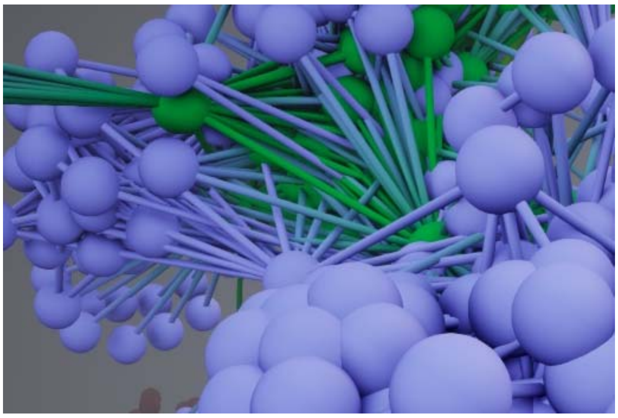

Figure 31. Depth perception for this solid & AO rendered graph is supported by ambient occlusion emitted by the edges - especially noticeable with the top green bundle of edges.

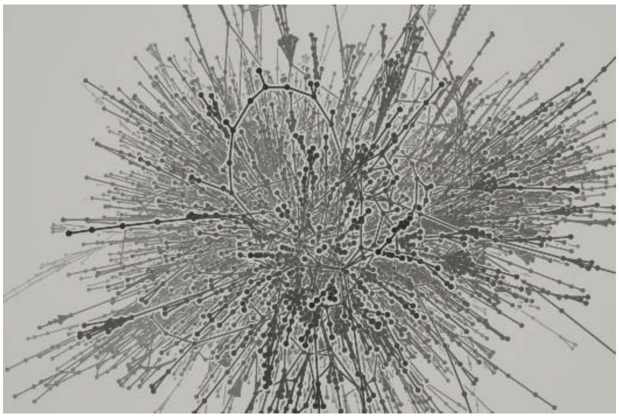

Figure 32. Illustrative halo drawing showing structure in a complex network. The relation between the nodes in the foreground can be easily observed due to the halos and the fog making them stand out from the background

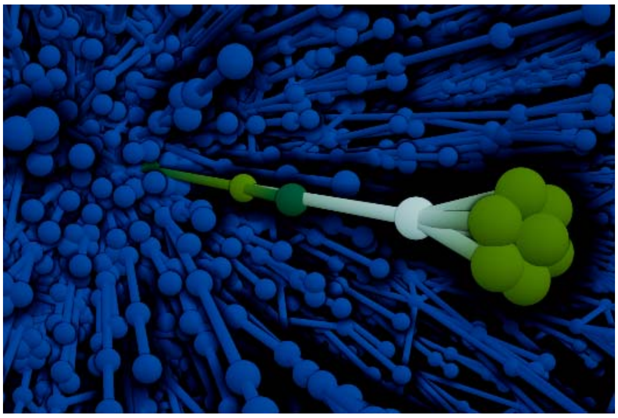

Figure 33. Transparent smooth halos deliver a good understanding of the 3D structure and depth geometry of the graph in a 2D domain like this image. In VR however, this method tends to irritate the visual system of a user.

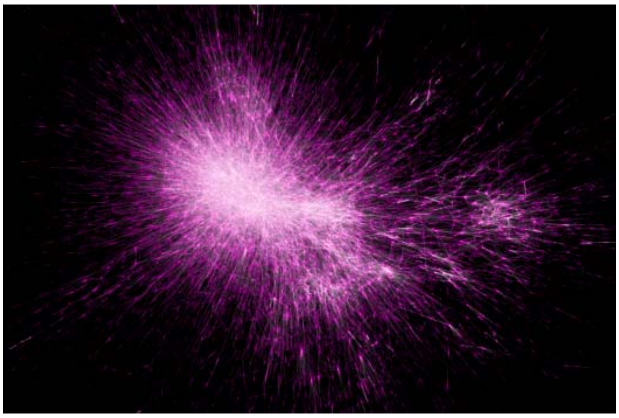

Figure 34. Edges drawn with additive blending visualize clusters and crowded areas of the graph

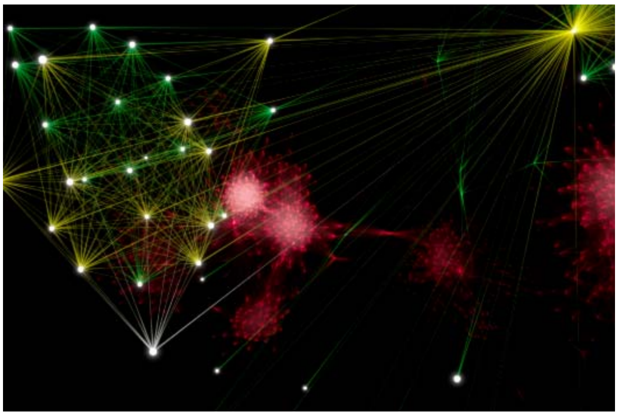

Figure 35. In additive graph drawing, close nodes are shown as bright dots, whereas in the distance only edges are drawn to remove cluttering

Figure 36. Schematic user interaction with the network structure.

Graph Perception

Evaluating the visualization's effectiveness to convey the graph information and generate excitement is a difficult task. The perception of complex structures not only depends on the visuals but also on the possible interactions a user can execute. In the following paragraphs, we present frequent feedback we got from persons who tried the system in a pre-pilot study with a size of about 10 persons and the task of freely exploring the graph at hand. As a second approach, we summarize the ease of perception based on the visible effects of each method resulting in pro and contra arguments listed in Table 1. We focus on inherent properties of the techniques that we observed looking at the participants interacting with the system and interacting with the system ourselves. The six images in Figure 30 to Figure 35 can serve as hints to retrace the arguments listed in Table 5.

Table 5. Properties observed with the collected methods that can be retraced in the figures referenced in the last column. Note that, the table reflects the authors' experience.

	Depth cues	Structural cues	Suited for stereo vision	Performance	See figure
halos	Good	No influence	Not Intuitive	Realtime	1 left, 7, 8
fog	Good	Hiding background	Good	As good as no impact	1 center, 5, 7
SSAO	Good	Missing occluded geometry	Good	Realtime	4 bottom left
splatted AO	Good	Good	Good	Interactive	1 center, 4 right, 6
solid	With shadows	With shadows	Good	Realtime	1 center, 4, 5, 6
additive	No	Clusters are emphasized	Ok	Realtime	1 right, 9, 10

Visuals

The majority of people who see the visualizations for the first time are enthusiastic about the high-quality visuals, immediately sparking their interest to take a closer look. The aesthetically pleasing presentation not only boosts engagement for the first encounter but also keeps the motivation to work with the system up, as low fidelity visuals can be a reason for frustration over time. When users switch the rendering style to the most fitting for the task at hand, their attentiveness is refreshed by the change.

Interaction

In contrast to the visuals, the users were not immediately comfortable with the two-handed interaction scheme. First, the possible operations have to be understood, then the corresponding buttons and triggers must be learned. Once a user has done this, the interactions are done fluidly. They confidently position themselves and the graph any way they want. Also selecting a node of interest and scaling graph space locally is executed without trouble.

Performance

To evaluate the achieved performance, we created simple test networks where the nodes are arranged on a regular three-dimensional grid. Adjacent nodes are connected, creating about three times more edges than nodes (Figure 37). All measurements were done on a computer equipped with an Nvidia GTX 1080 Ti graphics card, an Intel Core i7-6700 processor and 32 gigabytes of memory, rendering to an Oculus Rift. For an optimal VR experience, the frame times should be below 11 milliseconds resulting in 90 frames per second. Table 2 presents the achieved performance for rendering a network with more than 200000 nodes. Without splatted ambient occlusion we can render scenes within the specified time limit. Parameters such as the node respectively edge size have a dramatic impact on the performance as they determine the number of fragments to be processed. For the measurements reasonable settings creating a valuable visualization were chosen.

Table 6. Render times for different scenarios using the graph and perspective seen in Figure 37.

scenario	frame-time (ms)
halos	10,0
solid	9,5
solid & AO	21,7
additive	8,6

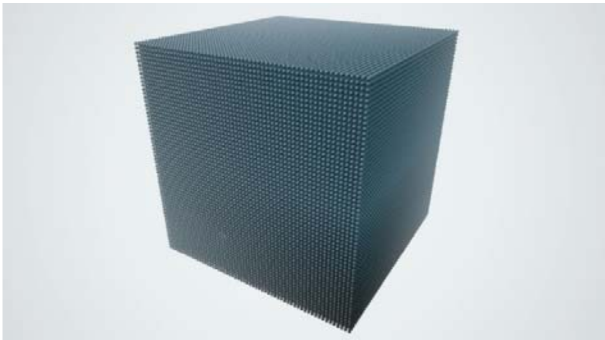

Figure 37. Synthetic grid network with 216000 nodes and 637200 edges, used to measure the timings in Table 6.

Discussion

In this work we presented three scenarios to visually represent graphs in an immersive virtual reality environment. We summarize our experience concerning the three visualization scenarios implemented as follows:

- rendering network data with halos is better suited to enhance depth cues on planar 2D screens (Figure 32). However, halos are not intuitive for human stereo vision because they have no physical equivalent. Therefore, we discourage applying them to VR.
- the rendering scenario corresponding to additive, that implements transparency, allows users to visualize large graphs due to its stable real-time performance. Furthermore, this rendering technique enables users to discern global aspects of the graph structure easily and fast (Figure 34 and Figure 35).
- the third scenario, solid & AO, implementing for example shadowing and ambient occlusion,offers the best depth cues and is therefore well suited to analyze local structure or proximity (Figure 29, Figure 30 and Figure 31). Despite being slow for larger graphs, this scenario is the most suitable for graphs in combination with the VR setup.

We showed that interactive rates for considerable large graphs can be achieved for several different visualization methods in a VR environment, which is an essential aspect for graph exploration and analysis. We put considerable effort in reducing aliasing effects, which are otherwise very disturbing especially in virtual reality. Furthermore, different intuitive interaction techniques were realized to facilitate users to explore the network data.

It would be interesting to explore how edge or node clustering can be used to combine geometry and therefore reduce the currently limiting fragment-shading bottleneck, while still providing high quality shading and enough cues to the depth and geometry perception. Furthermore, improving the performance of interactive semi-global illumination methods like the ambient occlusion presented in this work still is an important and promising research area.

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Movin(g) Reality

Noël Keijsers[1], Cheriel Hofstad[1], Rene van Ee[1], Bart van Oosteren[1], Carmen Ensink[1],

Theo Theunissen[2], David van Dommelen[2] and Jille Treffers[2]

[1]*Sint Maartenskliniek, Nijmegen, The Netherlands*
[2]*HAN University of Applied Science Arnhem & Nijmegen (HAN), The Netherlands*

Corresponding author: c.hofstad@maartenskliniek.nl

Keywords: VR, Rehabilitation, Stroke, Gait, Home-based training, Feedback

Many patients surviving a stroke suffer from gait and balance problem (Jørgensen et al., 1995; Beyaert et al., 2015), which can have an large impact on their daily functioning. During hospital training, patients receive individual training from physiotherapists often in combination with technological rehabilitation devices to improve their gait capacity. Important in this individual training, is that patients receive feedback on their performance. After discharged from the hospital or rehabilitation clinic, however, we observe that stroke patients would like to keep training at the same level as they did with the multidisciplinary team to maintain or retain their perceived activity level.

Problem

Patient

When stroke patients return to their homes, they experience less motivation to train because they don't receive any feedback regarding training and progress. Furthermore, most patients have no knowledge on how to execute specific exercises and no appropriate feedback how they have performed the exercise because of sensorimotor deficits. One common problem in stroke patients underlying their poor quality of gait is reduced foot elevation (drop foot) and/or reduced hip and knee flexion. For these patients it is important that they train these functions in their home situation and receive feedback on their performance.

Treatment team

The training performance and progress is not only important for the patient, but also for the multidisciplinary team. After the patient is being discharged from the rehabilitation clinic, the multidisciplinary rehabilitation team does not receive any feedback of the quality, quantity and progress of the home-based training of stroke patients. Information of the training is important for optimizing the training program. Moreover, it can be used to monitor the patient and indicate deterioration in their daily life functioning.

Solution

In first instance, we wanted to integrate challenging walking games in an augmented reality. However, current technology is hard to integrate in daily life (e.g. too large unusable glasses). Therefore, we came up with the following two solutions for stroke patients:

1. Train2Go: The stroke patient wears two movement sensors on the leg, which measure the position of the 1) foot and lower leg for foot and ankle problems or 2) upper leg and lower leg for hip and knee problems. These sensors provide feedback on foot elevation and ankle angle or hip and knee angle during walking. When certain predetermined limits are exceeded or not reached, the patient receives feedback by a vibration sensor. A vibration indicates that the patient has to adjust his walking pattern. The Train2Go application can be used outside or in a home setting.

2. Train@Home: For this application, we developed an app in which the stroke patient kicks a virtual ball. The app uses the camera of the mobile phone to define the real foot in the real environment. The display of the mobile phone shows the real (movement of the) foot in the real environment and a virtual ball. While viewing the display, the patient can move his foot and kick the virtual ball, which results in the virtual ball moving towards a virtual object (goal or pins). In this way, the patient can perform an exercise with important features of walking, which is fun and safe and in which he receives feedback of his leg movements. The Train@home application is used in a home setting.

After realization of these two applications, Virtual Reality can be integrated later, when virtual and augmented reality techniques are developed further and are less expensive.

The ultimate aim of our solutions is that stroke patients will improve their gait and balance and daily functioning. By providing feedback on their performance and progress, patients will be kept motivated and train more intensively. Finally, the multidisciplinary rehabilitation team will be able to optimize the training.

Figure 38. Schematic representationof the Movin(g) Reality applications

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Posters

Augmented Reality Verification of Building Deviations for Parametric Building Information Models

Michael Jenewein and Peter Ferschin,

Vienna University of Technology, Austria

Corresponding author: michael.jenewein@aon.at

Keywords: Augmented Reality, On-site AR, Parametric BIM

This paper presents a method for on-site adjustment of constructional deviations using Augmented Reality (AR) and parametric Building Information Modeling (BIM). The construction of industrial facilities often deviates from the original planning model due to changes during construction phase. These changes have to be updated to maintain a consistent as-built BIM as digital twin of a physical facility (Tao et al., 2018).

Surveying for building reconstruction is normally done using total stations, laser scanners or photogrammetry (Mill et al., 2013). Updating of existing BIMs is then performed later, in office. Possible errors in this process can be introduced during data acquisition, data transfer and 3D modeling.

To streamline this process, we propose a new real-time method based on AR (Wang et al., 2013). The basic approach is that recognizable geometric differences in AR view will indicate potential constructional deviations from the original BIM. Required AR corrections of the planning model to the existing constructional structure are performed using a wireless connected handheld tablet.

Conventional BIM software is not adequate for AR. The prototype implementation was therefore created using Unity as parametric developer environment and Vuforia as AR extension. Tracking is enabled through a cuboid multi target with QR code images.

The method is validated through a scale model and an industrial use case in the environment of a cement loading facility. The on-site AR view showed significant geometric changes in height and construction of the upper filter. These dimensional discrepancies could be updated directly in AR.

The results show that on-site AR is sensitive to subtle changes of environmental conditions such as lighting, viewing angles and positioning of targets but the proposed method also demonstrates that AR adjustment of constructional deviations is possible.

Parametric BIM-AR Method

The fundamental idea in the integrated BIM-AR method is to update BIMs after construction phase using AR technology directly on-site with rapid verification of building deviations (Figure 39).

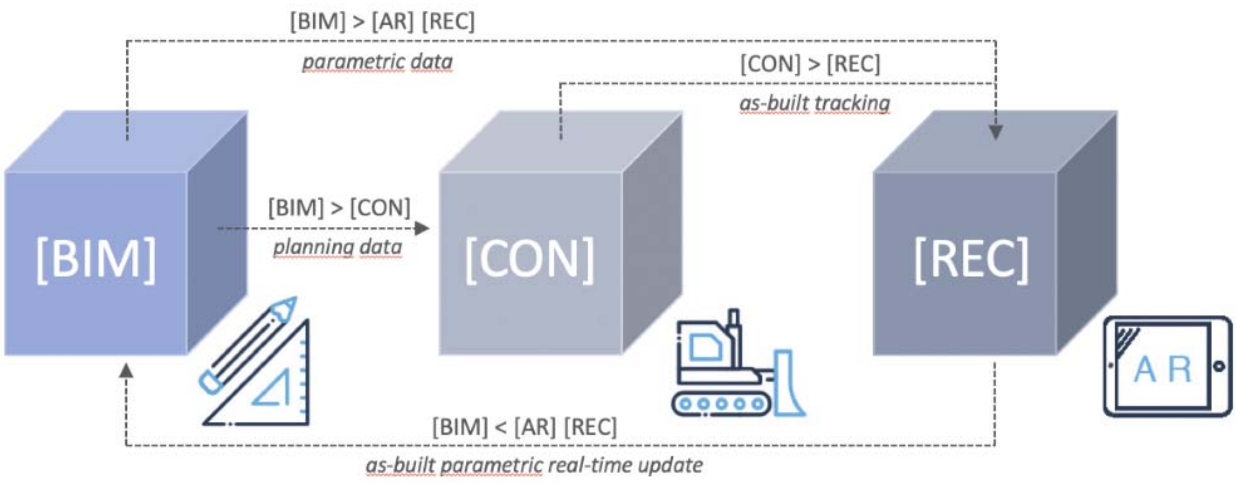

Figure 39. BIM-AR method for real-time updating of parametric as-built BIMs using on-site AR

There are three basic preconditions for developing an effective system for on-site AR reconstruction of BIMs: (1) a data source that can provide parametric BIM information; (2) a tracking method that can provide on-site information of physical facilities for real-time tracing of parametric BIM data; (3) a user-friendly interface that enables on-site interaction for BIM updating. At the moment standard BIM software is not adequate for parametric data export and further use with interactive AR systems. Therefore, additional software tools have to be used for the methodical development of parametric BIM and AR (Figure 40).

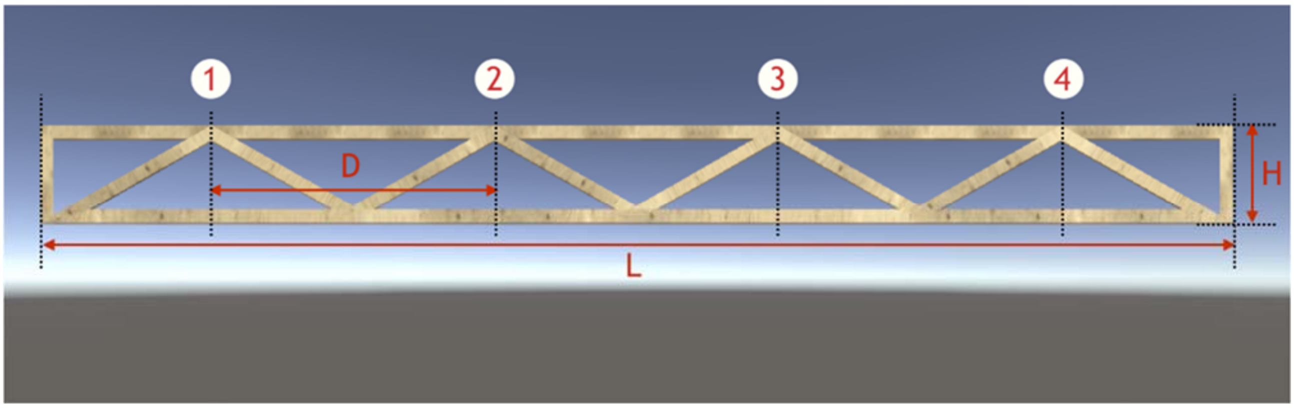

Figure 40. Parametric truss in Unity with length (L), height (H) and isosceles triangles with distance (D).

In order to achieve accurate tracking, it is fundamental to have clearly identifiable high contrasted image targets or multi targets as trackable objects. Environmental conditions have to be considered very carefully because lighting, wind, fog or dust can interfere the function of AR tracking. The correct position and orientation of both trackable targets and AR camera are essential for accurate tracking between physical world and virtual reality.

Parametric BIM-AR Implementation

The proposed parametric BIM-AR method for real-time updating of BIMs has been developed and implemented using a prototype scale model use case, and an industrial use case application. The BIM-

AR process is based on Unity for parametric modeling, Archimatix as node-based programming tool and Vuforia as AR extension.

ShapeThe individual steps of the parametric BIM-AR method have been implemented using a prototype model in scale 1:331/3. The model with dimensions of 36.0 x 36.0 x 13.5 cm enables to explore simulated constructive errors in an experimental parametric BIM and AR environment. Numeric measurements can be performed by using a virtual ruler based on a distance script. The node-based parametric modeling of the truss girders by using Unity and Archimatix is based on isosceles triangles and a 2D linear repeater. The rectangle 3D profile of the parametric truss girder components is generated by using a node-based plan sweep extruder tool in Archimatix (Figure 41) and linear repeated isosceles triangles (Figure 42).

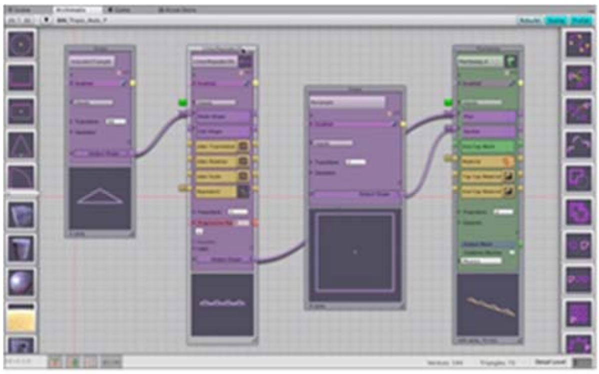

Figure 41. Parametric modelling in Unity/archimatic.

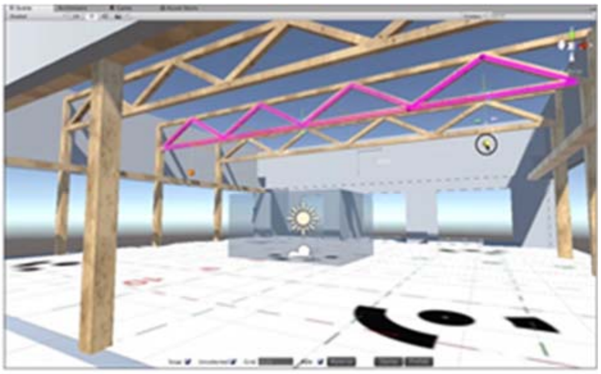

Figure 42. Parameters: triangles 4; distance 8.59 m.

ShapeThe used plain image target as trackable object is based on the ground plan view of the model´s base plate. To achieve a high contrast target, the ground plan layout of the scale model was generated by using colors for lettering and axes, and additional 12-bit markers (Figure 43).

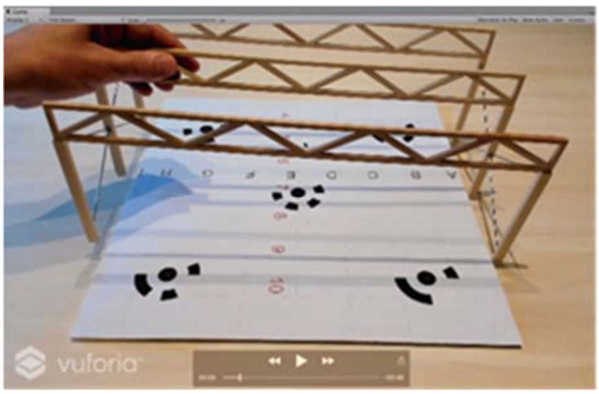

Figure 43. Merging of scale model in Vuforia AR

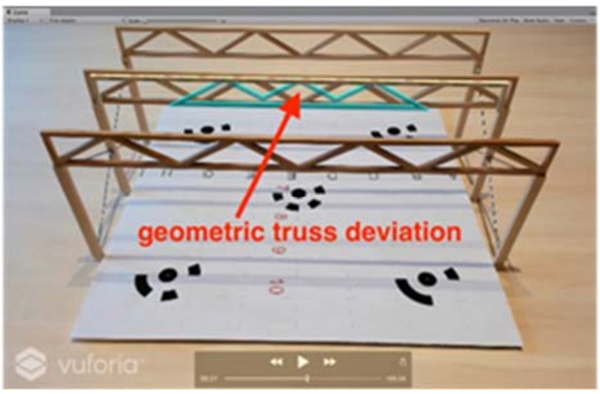

Figure 44. Updating of truss girder parameters in AR.

The simulated incorrect position and geometry of the truss girder on axis 7 could be validated in AR view with an accuracy of 1.0 mm, equivalent to 3.33 cm in real-world scale (Figure 44).

To verify the findings of the model phase, an industrial use case in the environment of a cement loading facility has been performed (Figure 45). According to the planning BIM, the new loading facility on the right side should have the same size as the existing one. But because of technical requirements during construction, the shape of the roof has been modified from a flat roof to a pitched roof.

The parametric BIM for the industrial use case (Figure 46) has been generated in three steps: (1) model import from the original BIM to Unity; (2) further processing of the import data using node-based parametric modeling in Archimatix; (3) adaption of the generated parametric BIM for use in the Vuforia AR environment.

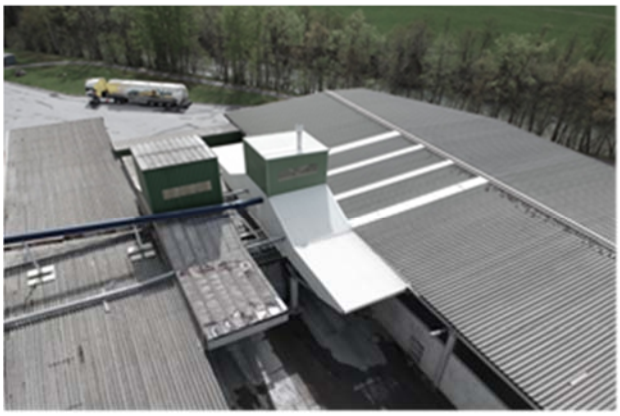

Figure 45. Aerial photo of cement loading facility

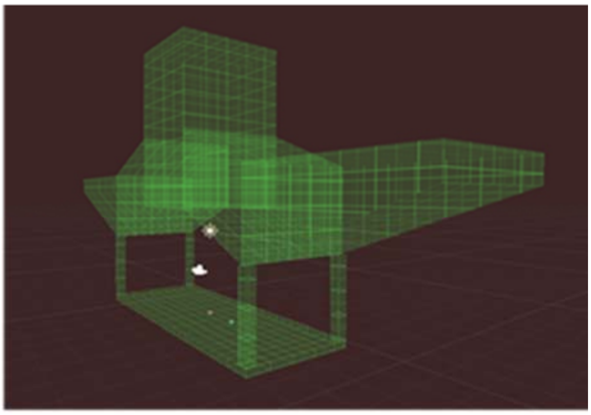

Figure 46. Parametric BIM of loading facility

Figure 47. Aerial photo of cement loading facility

Figure 48. Parametric BIM of loading facility.

The eave of the pitched roof has been measured in AR view with 12.26 m. The height of the planned flat roof was 12.54 m. So, the height deviation is 0.28 m, and the angle of the pitched roof could be calculated with 3,50°. The AR measurements have been verified with a total station.

Using the BIM-AR equipment (Figure 47), the height deviation of the roof could be updated in the parametric BIM with a validated accuracy of 3.0 cm (Figure 48).

Conclusion

The results show that the parametric BIM-AR method is sensitive to subtle changes in surrounding conditions but demonstrates also that parametric AR updating of construction deviations is possible with relatively high precision. It has also been shown that it is essential to have a well calibrated AR setup for accurate on-site tracking.

Lighting conditions and viewing angles have to be watched carefully, and the function of AR tracking can be influenced by dust, fog or wind. The remote control of the integrated BIM-AR database has been carried out using a wireless connected handheld tablet that enables location independent on-site interaction for updating of construction deviations.

Regarding the results of the industrial use case, the deviating roof construction of the cement loading facility could be corrected in the parametric BIM, using the proposed BIM-AR method. Numeric measurements of dimensional deviations could be performed directly in AR by using the integrated virtual ruler. Because standard BIM software is not adequate for parametric data export and use with interactive AR environments, additional software has been used as developer environment.

Improvements in the field of trackable objects and parametric interfaces for use in industrial BIM-AR context will help to derive a robust and reliable method for rapid on-site updating of construction deviations after construction phase with the advantage of saving effort, time and costs.

Acknowledgment

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Tao, F., Sui, F., Liu, A., Qi, Q., Zhang, M., Song, B., Guo, Z., Lu, S.C.Y. and Nee, A.Y.C., 2019. Digital twin-driven product design framework. International Journal of Production Research, 57(12), 3935-3953

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Buildings modeling: from the shape grammar specification to the IFC model

Tiavina Tantely Nivolala[1,2], Cédric Sanza[1], Véronique Gaildrat[1],

Princy Randriambololondrantomalala[2] and Jean-Pierre Jessel[1]

[1]IRIT, Université Toulouse 3 Paul Sabatier, Toulouse, France
[2]Université d'Antananarivo, Antananarivo, Madagascar

Corresponding authors: tiavina.tantely@gmail.com, cedric.sanza@irit.fr, veronique.gaildrat@irit.fr, princypcpc@yahoo.fr, jean-pierre.jessel@irit.fr

Keywords: Shape Grammars, Procedural modeling, City generation, Architecture, Virtual Reality

Virtual worlds creation has always been a challenge. Among all the procedural methods that have been used for tackling the issue, shape grammars are especially effective when faced with the problem of encoding knowledge about shapes and their reproduction. This paper proposes a system consisting of a shape grammar interpreter and a dataset of geographic and appearance information for quickly modeling architecture. It can automatically generate IFC (Industry Foundation Classes) files that can be used in many CAD (Computer Aided Design) applications. As a case study, we perform the process of specification and generation of some real and non-real buildings.

Introduction

The increasing expenses of manual content design of virtual worlds are at the emergence of new challenges, and the potential of procedural creation can't be disregarded as it is an effective method to make three-dimensional models in a quick and versatile way. Urban environments are filled with man-made objects. A distinctive characteristic that they share is that they can be coherently divided into clear regular structures from which we can extract the underlying hierarchies. Such structures are mostly composed of parts described by some observable geometrical patterns, and in order to create similar shapes, the knowledge of those structures is essential.

Architectural styles can be described by how their elements are composed, which in turn can be defined by a set of rules. Grammars have been successfully used before to model vegetation, buildings, interiors, streets, sculptures, furniture, etc. They provide a formalism to create new designs, but are also valuable in the analysis of a style by decomposition, since grammars clarify the criteria necessary to determine if a design belongs to a certain style, and they provide the necessary components to build new instances of it. This makes the use of shape grammars a suitable method to encode knowledge about architecture and generate a wide variety of similar models. As the creation of rulesets is a non-trivial task, during this process, allowing some guidelines and some additional information to be provided by the user to best capture some of their external knowledge and stay accurate to what they wish to re-create is an advantage.

This paper introduces an implementation of our system, which consists of a geographical knowledge base to store data about the appearance of buildings in a hierarchical way and a grammar interpreter and modelisation module, we then explore its application to real and non-real cities. In order to take full advantage of the generated shapes, and thus gear the models towards a large range of possible uses, we chose the export towards an inter-operable model in the building construction industry. The use of IFC will ensure this, by offering the possibility to share and extend the models between different softwares that can be used all along the building construction cycle.

The paper is structured as follows: in Section 2 we present some of the related works. In Section 3 we present an overview of our system, we introduce the grammar interpreter in section 4, and the creation of the knowledge base in section 5, in Section 6 we address how we export the resulting models to IFC, next we compare our system to existing engines and some significant examples will show the application of the system to small and larger scales. Lastly, conclusion and future works are given in section 9.

Related Works

Shape grammars were introduced by Stiny and Gips (1971) to design drawings in an initial work where all the generation was manual. They have ever since been studied in various fields, e.g. architecture design (Mitchell, 1990), design packaging while retaining the brand identity of the products (Chen et al., 2004) or even embroidery (Grow, 2017).

In 1978, Stiny and Mitchell introduced a parametric shape grammar that includes a set of rules to generate the ground plans of Palladio's villas (Stiny and Mitchell, 1978). The layout of the floors is created by applying different rules at each stage of the generation.

A generative grammar that explains the characteristics of the Casa Giuliani Frigerio (Flemming, 1981?) is proposed by Flemming in 1981. Following the general model given for parametric shape grammars by Stiny, Flemming designs layouts by assigning labels to the walls and then developing and connecting them accordingly.

Koning and Eizenberg proposed the application of the shape grammar formalism to three-dimensional material (Koning, 1981) or Frank Lloyd Wright's prairie-style houses. The balance, design and qualities prairie-style homes are known for, are embedded in the grammars. The fireplace is the key element of these houses and functional Froebelean type blocks are recursively arranged all around the fireplace.

Grasl and Economou proposed a grammatical approach to generate Palladian graphs by translating a shape grammar into its graph equivalent and then transforming the result into a plan by an interpreter module (Grasl, 2010).

In 2001, Parish and Mùller (2001) started modeling urban environments using shape grammars where each building consisted of mass models whose geometry and facade details was created by an L-system, Wonka et al. (2003) then demonstrated how to create more compelling details on the facades of each building by introducing the "Split Grammars", a new type of parametric set grammar with an attribute matching system oriented by a control grammar.

Müller et al. (2013) completed these concepts with the CGA (Computer Generated Architecture) Shape Grammar, which would be integrated in the CityEngine Framework.

Haegler et al. (2009) addressed the reconstruction of archaeological sites, which brings the issue of modeling unknown parts of their architecture by proposing several possible models for the same footprint, the reconstruction of several archaeological sites was made on CityEngine. Also using archaeological input data, Müller et al., 2005) goes through this process with the reconstruction of a quarter in Pompeii based on an extended version of CityEngine.

Biljecki et al. (2016) created an engine that generates buildings datasets and other urban features, their engine achieves multiple LOD (level of details) that will later be exported in CityGML format.

Nasri and Benslimane (2017) proposed an original generative method for Islamic Generative Patterns by using a symmetry based-approach and a shape gram- mar based on the analysis of Zellij patterns, to assist in the design of new forms of Moorish geometric patterns

Choosing the Pol house in Ahmedabad as a case study, Lambe and Dongre (2017) formulated an analysis of the style of Pol row houses, defined a language for them and used a grammatical approach to provide contextual alternatives for house plans.

Recently Yavuz and Sağıroğlu (2016) demonstrated how to recreate some well-known brick structures according to a few grammar rules.

System overview

The system is made of two modules: one for the generation of a geographically hierarchical dataset and corresponding rulesets, and the other for the interpretation of the grammar rulesets which encodes the basic information about how the buildings should be constructed and structured, and the modeling of the urban elements into IFC models. This process can go one of two ways, the user can either:

- Simply provide a rulefile and an axiom
- Though not required, the user can also give the path to the dataset and the axiom, and if the axiom was not retrieved from OpenStreetMap, the coordinates of the place they want to generate should also be provided.
- Optionally, they can also provide the desired level of detail.

The modules are therefore independent as the user does not need to use said dataset in the case they want to manually generate ruleset and use them directly in the second module. In the next sections we will go into more details about these modules.

Shape Grammar Interpreter

We propose to use a three-dimensional stochastic, context-free, attributed shape grammar for the modeling of the buildings. The generation first constructs the mass model, then continues to structure the facades and finally divides the facade to add details for windows, doors, etc.

A grammar is a tuple composed of an axiom, non-terminal shapes, terminal shapes, a set of rewriting rules and probabilities associated with those rules. The interpreter will start by parsing the ruleset into a map of rules and parsing the axiom into the first shape. By the end of the modeling process, we obtain a parse tree, an axiom-rooted tree with a terminal shape at every leaf. This parse tree will be provided as input, and the obtained data used to build the resulting IFC model. We will define some important terms relevant to the system below:

Shapes: Shapes are the building blocks of the grammar. Each shape consists of a geometry, a list of attributes, and a symbol from the set of non-terminal or terminal symbols.

The geometry requires the following elements:

- The footprint of the shape. When performing operations on a three-dimensional shape, most operations are achieved via modification of the footprint (scaling, splitting, etc.), whereas for a two-dimensional shape, operating on the starting point and the dimensions are sufficient for most of modifications.

- As defined in (Müller et al., 2006), the scope is the oriented bounding box associated with the geometry of the shape, and it is defined by three elements:
    - Its starting point which is the intersection of the leftmost and the lowermost edges of the footprint.
    - Its local coordinate system.
    - The three dimensions of the bounding box.

The axiom: All buildings footprints can be contained in a simple text file or specified using the shapefile format, which is a popular vector file format for exchanging GIS data. Each footprint is an axiom which will correspond to a building. The derivation begins with a vertical extrusion of edges. The side, top and bottom faces resulting from the extrusion are labeled accordingly. The grammar will be reused on each polygon (axiom) contained in the shapefile which allows us to operate on building footprints extracted from GIS databases.

The production rules: The rules are structured as follows:

```
predecessor → function(parameters) {successor1 : attr1 = val1, attr2 =
                 val2 | successor2} = prob
```

The probability to select a rule is determined by the prob variable, and the sum of the probabilities for all rules that have the same predecessor on the left side must be equal to 1.

Building-specific elements Unlike most shape grammars seen before, ours do not rely on external assets, instead every element is directly constructed into a 3D model. To make up for these external assets, we introduced stylistic choices into the grammar combined with the production rules, which give us enough flexibility to achieve interesting models. A particular focus has been put on the openings, where several possible configurations can be obtained from the available attributes as illustrated in Figure 49.

For example, the rightmost window (yellowwindow) in Figure 49 is obtained with the rules below:

```
yellowwindow → rsplit (Z,0.2 ,0.3 ,0.3){wall : color=indianred |
                 windowpart | upperwindowpart}

upperwindowpart → rsplit(X,0.4,0.6){windowpart|windowpart} windowpart →
      {window: style=framed , framecolor=gold , material=glass}
```

Figure 49. Examples of windows configurations

The grammar can produce models that are as specific or as generic as needed, on the same base. The user can choose to use some building specific elements and the way he makes use of them, or he can also operate on simple geometric shapes throughout the process. The resulting style of the model will vary along this choice.

This can be useful if the user chooses several shapefiles for different layers of the terrain. For example, they can assign an axiom symbol per shapefile (eg. "lot" for the shapefile with building footprints, "grass" for the shapefile with vegetation) and thus launch different derivations on them.

The terminals: We use three terminals: wall, window and door. Most stylistic choices applied to these terminals, except for the dimensions, are handled by the attributes explained below.

The attributes: Each shape can have an arbitrary number of attributes defined by a name and a value, which is how appearance information is handled. Attributes are used to define and propagate these stylistic informations down the shape hierarchy.

An attribute can define some of these informations: roof style, color of the walls, whether an opening is framed or not (and if so the color of the frames), opaque or transparent opening (glass) and its color.

Roofs: We included some common roof shapes in the grammar, which operate as building attributes. The roof type and color are specified in the attributes. The user can choose from: flat, shed, mansard, hip and gabled roofs.

As explained by (Laycoche and Day, 2017), the mansard roof is obtained simply by connecting the upper face of the building with the same polygon, reduced to 80 % of its size.

For the others, the calculation of the straight skeleton of the polygon is necessary. The hip roof is obtained directly by extracting each face of the roof from the straight skeleton.

We extract the faces by finding the shortest path between the vertices of each edge of the initial polygon (that is not the direct path). For this calculation we discard any other edge of the initial polygon and only keep the straight skeleton and the edge we operate on, as shown in Figure 50, since each face corresponds to only one edge of said polygon.

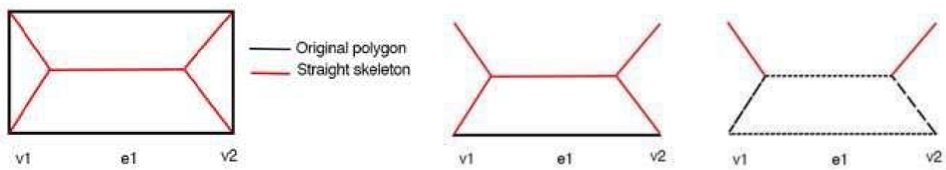

Figure 50. Face extraction: the edges with dashed lines on the bottom right image form the extracted face

For the gable roof, we start from the same skeleton and identify the vertices that have been created by the intersection of two bisectors, and move these vertices from their original position at the middle of the line that is incident to the two bisectors that created the intersection (Laycoche and Dongre, 2017).

Functions: The following functions can be used on each shape during the derivation:

Extrude: Performs a vertical extrusion on the footprint, usually called at the beginning of the modeling process to transform a 2D polygon into a 3D shape.

Component Split: Introduced by Müller et al. (2006), this function is used to decompose a 3D shape into facades. The successors go from three to two dimensions in order to simplify the next operations performed on them, by setting one dimension of the bounding box to zero. The X axis is computed using the bottom edge of the polygon. These facades can be selected with the following selectors:

- front, back, left, right
- sides for all the facades
- others for the facades not yet selected

The front, back, sides are defined in reference to the parent shape, if no parent shape is present, then it is defined in reference to an (X,Y,Z) pivot where Y points to the back, -Y to the front, X points to Right and -X points to left. At first, each face is labelled as a side face. We consider the parent shape's X axis and its centroid. and calculate the dot product of said axis and the current shape's axis to define the orientation.

Split: Cuts a shape into several other shapes along the selected axis and with the dimensions specified in the parameters.

Rsplit: The same operation as split with values relative to the parent shape.

Repeat: Repeats the successors along the parent shape for the specified axis and dimensions, as long as there is still free space on the parent shape.

Translate: Translates the shape by moving the start point and the points of the footprint

Rotate: Rotates the axes and points of the footprint Resize: Resize the scope and points of the footprint.

The shape tree: Shapes are structured in a shape tree and categorized by their symbol and tags which indicates their place in the spatial hierarchy. There are six types of tags: building, building-part, storey, room, facade and facade-part.

Three-dimensional mass models are labeled buildings, unless specified otherwise when providing the axiom file, in which case they may be treated as other urban elements such as vegetation. Any subdivision of an element labeled building (excluding the component split) creates either building parts in the case of a vertical cut or floors in the case of an horizontal cut as long as the resulting shapes are also three-dimensional. A split operation on a storey will create room elements as children, finally the component split function binds the facade tag to the successor shapes so all elements resulting of subdivisions on these facades are also set with the facade-part tag.

The level of details: The needed level of details can be passed as an argument during the generation process. We can generate four different LODs, which are achieved by retrieving and modeling a subset of the shape tree for each level of detail, and going deeper the more details are required.

For the realization of each different LOD, the generation module traverses the tree up to a certain point. For LOD1, the module doesn't search farther that at the building parts-tagged shapes, LOD2 adds the roof element into the generation, LOD3 generates the exteriors of the buildings storeys shapes, LOD4 considers every leaf from the shape tree, interiors included.

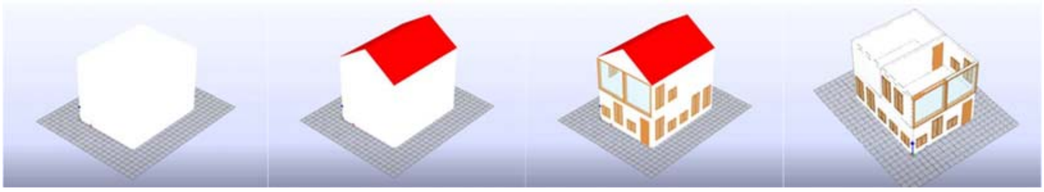

Figure 51. Different level of details obtained with our system

Knowledge Base

To facilitate the process, and reduce the time required for ruleset generation, the user can rely on a knowledge base. They can create this dataset consisting of hierarchically organized geographic areas and the corresponding information, as well as rulesets, and populate it all the way through, with new areas, and/or rulesets from a graphic interface.

When using shapefiles from OpenStreetMap, we have the option of automatically retrieving the corresponding rules (based on the location) from this knowledge base, where appearance information is organized in hierarchy, from the widest entity which includes all the other locations: the earth, to information that is typical to a certain zone, such as a neighborhood. After choosing an area of OpenStreetMap, the distance of its center will be used to find the nearest zone in the dataset, trying to locate the smallest closest area. If information is lacking for the specific area we're looking for, the system will then fetch the attributes by widening the search distance and going up the hierarchy until it finds non-null elements.

The graphic interface

A graphic interface is provided to aid into the construction of the dataset, as well as the generation of more generic rulesets, in said interface, the appearance information as well as some basic geometric information can be provided. To keep things simpler, the generated buildings follow a generic template, but a number of parameters can be tweaked to give personalized results, hence giving a considerable number of variations.

The process begins with selecting or creating the area the user wishes to populate in the left pane of the interface, they will provide the coordinates and the radius of the area. Once this is done, they will go ahead and click the 'Edit Rules' button where they can select a number of geometric and aesthetic parameters, such as the colors of the building, the minimum and maximum height of a building, the appearance of openings, … Several appearance information can be added to the same place with varying probabilities defined for the building elements.

The user can edit openings with more control, as they can be separately drawn in another interface (accessed by clicking the 'Detail Edit Window' but- ton) with a provided panel representing the opening to draw lines on and subdivide into rectangular parts. Each division is translated into a split rule, the percentage is taken from the line position relatively to the position of the whole width or height of the rectangle and provided as arguments to a rsplit rule.

All this information will be stored in the dataset and can later be retrieved and translated into rulesets.

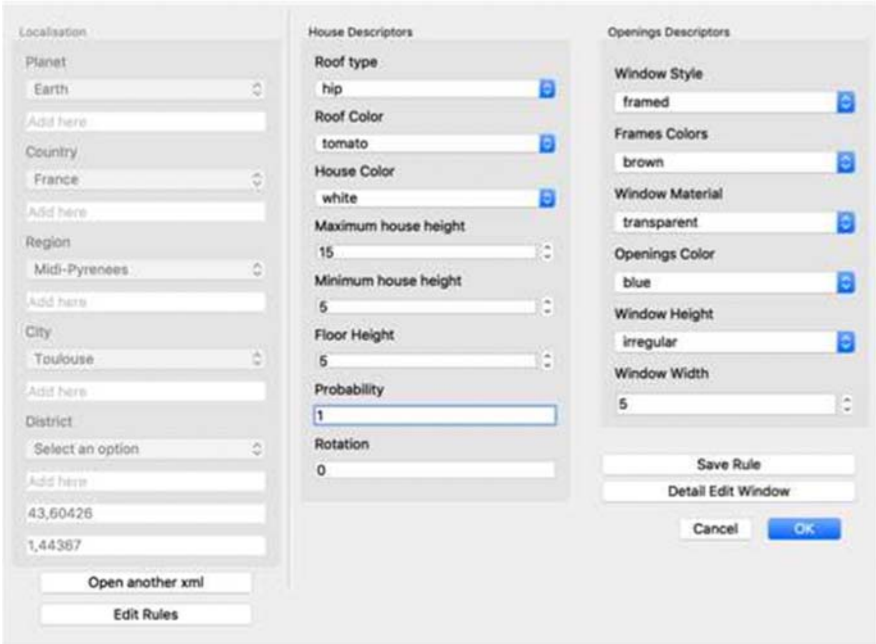

Figure 52. The graphic interface

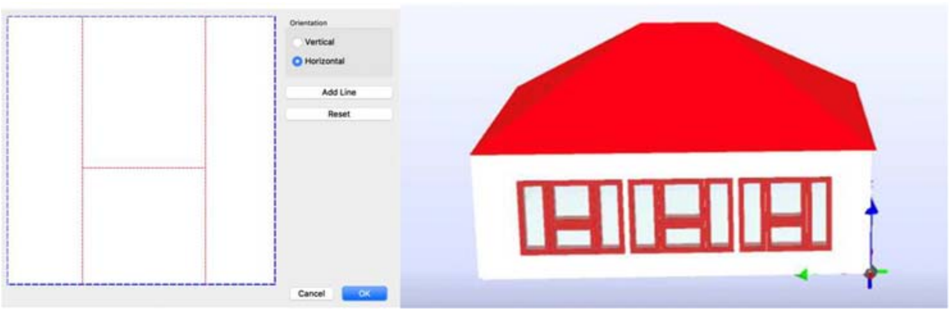

Figure 53. Detail editing of an opening and resulting opening

Designing semantic components

While the modeling process creates shapes without semantic, we are going to use the parse tree to build architecturally significant elements, such as building parts, roofs, doors or windows.

We can extract some semantic information from the geometry, by way of the functions used on the shapes and their terminal symbols.

For this part, we made the choice to use the IFC file format, an unified building model to keep the semantic information.

IFC (2018) is a standardized file format that represents a specification for Building Information Modeling (BIM) data that are exchanged and shared among different people involved in a building construction process or in building management. IFC is the international standard of openBIM. Rather than opt for simple visualization, the choice of IFC was made because while there definitely is a setback in the generation time, it is one of the most expressive standards out there, and is a full model with spatio-semantic coherence, especially useful in building construction, but also city planning, and it can easily be converted into other less expressive formats and refined if need be, however, there aren't much engines taking advantage of IFC.

An IFC model contains the building's geometry and construction data. The fact that the model contains both geometric and non-geometric data on the construction project makes it extremely complete. It also defines the relationships between building elements, how they are connected, structured in space or grouped.

A model of area is organized as a hierarchical set of IFC class instances: The process starts with a project that contains all the areas, an area contains buildings given by their footprint, a building is composed of several storeys, a storey contains rooms, walls, etc. and finally the walls can have openings that contain doors, windows, decorative elements, etc.

From the parse tree to the IFC hierarchy

In order to respect the way elements are built, following some standard architectural design in IFC, a tag has been attached to each shape after any operation to simplify the transition as we have seen before. As the hierarchies are different between the resulting tree and the model required by the IFC format, some indicators must be attached to the shapes in the derivation tree.

We will describe the generation of a fully detailed building below:

- The generation process consists of queueing through the shapes of the shape tree and generating an IFC element for each relevant shape part that needs to be instantiated.
- At first a site element is created, next the engine retrieves all the elements tagged building part that do not contain any building parts themselves (not as direct children) but may contain storeys. Each building is given an IfcPlacement relative to the site, stored as an IfcBuilding and related to said site.
- For all the building parts, the child elements tagged storey are retrieved and a ceiling shape is made from its footprint, and the roof is constructed for the highest storey, according to the corresponding, closing a full interior with indoor geometry.
- For each storey is created an IfcWallStandardCase, and it is given a placement relative to its parent shape, the storey, associated with a swept solid representation, and given an axis representation defined by the wall's start point and end point.
- The construction of solid elements really begins with the walls. From each shape's geometry from the shape tree is extracted a list of points: the starting point, size and direction give us the set of points needed to create a ground projection, which is the necessary data for creating an IfcExtrudedAreaSolid, which is how we construct the walls. Roofs are created by directly retrieving the coordinates of the faces, calculated by the different algorithms explained before, and instanciating an IfcFacetedBrep above the highest storeys for each building part.
- Finally, the creation of openings is basically the same as above but first to create the hole, an IfcRelVoidsElement is created between the wall and the opening element, before extruding the actual opening in the same place.

Basically, the IFC export happens as follows:

- All building-parts instantiate IfcBuildings
- These buildings contain the IfcStorey defined by the elements labeled floors, and roofs.
- The elements labeled facade are used to instantiate the walls for each floor.
- Openings are created where the doors and windows are supposed to be by making a hole of the expected shape on walls, before inserting the actual shapes there.
- If there is further division on a facade which is not an opening, each facade part instantiates a decorative wall curtain.

Comparison with other engines

Our approach can be related to two methods mentioned in the related works, and is more or less a link between (Bilecki et al., 2016) and (Müller et al., 2006): we keep the expressiveness of rulesets and store the information in a dataset file with possible multi-LOD representation.

We, however use a different approach and different datasets. Our engine generates geographical knowledge data from an user interface, along with a corresponding ruleset, and another module generates the corresponding model, we chose to use the IFC standard, which comes with full spatio-semantic coherence as well. Though the dataset file can be used for purely fictions models, it can be directly linked with OSM datasets.

The graphic interface makes the ruleset generation quicker and easier for non-expert users, the rules and xml files are extensible, as well as the generated model.

Outdoors and full indoors can be generated, including rooms and openings that are constructed giving an additional level of granular detail, as opposed to the first approach in (Bilecki et al., 2016), the rules we use are more simplified compared to those of CityEngine (Müller et al., 2006), but as a consequence, we do not have the more complex resulting shapes, especially curved shapes, but the trade-off the interface offers is especially important for quick, personalized buildings.

Results

We have implemented our system in Python and created several rulesets for different cases. We used shapefiles from OpenStreetMap to illustrate some of our examples. The rules were modeled according to different resources and our own analysis of the architecture of some buildings to recreate them. The resulting models can be imported and further modified into most CAD viewers.

An example of a building

This section introduces modeling with our system. For the Figure 54, which is followed by the corresponding ruleset, the initial mass model is split into two new buildings with hip roof styles, the second building is shrunk by a random value and becomes the shape b3, then both buildings are divided into five floors of height 4 each, with the split operation (they end up with respectively two and four floors due to size limitations), the ground floor (gfloor) of b3 is set to be different from all the other floors. Each floor is divided into facades that contain a repeat of yellow glass windows. The yellow window's heights are set to be random.

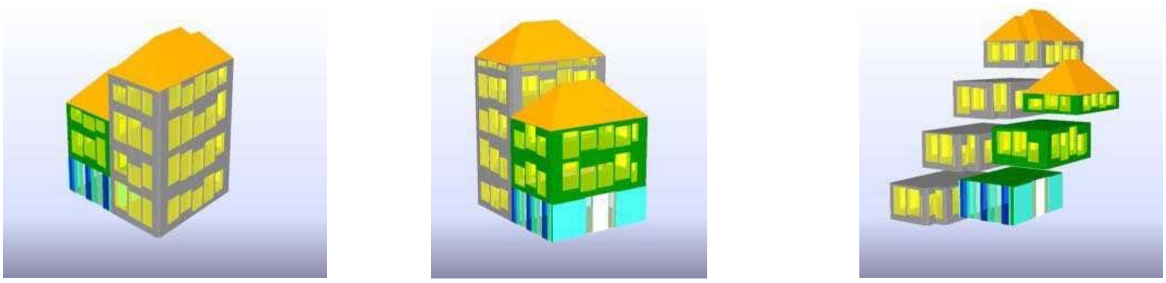

Figure 54. Example of a bulding

```
lot → extrude(20){building:roof=hip,roofcolor=sandybrown} building →
split(Y,sy/2,sy/2){b1|b2:color=grey} b1->S(sx, sy,
sz*rand(0.6,0.8)){b3:color=green}

b2 → repeat(Z,4){floor}

b3 → split (Z,4 ,4 ,4 ,4 ,4){gfloor | floor | floor | floor | floor}
floor → comp(){side : face}

gfloor → comp(){left:gleftfacade|front:gfront|right:grightfacade | back
: gback}

face → rsplit(X,0.1,0.8,0.1){wall|windowarea|wall} windowarea →
repeat(X,2 ,0.2){vwindow| wall}

vwindow → rsplit(Z,rand(0.1,0.3),rand(0.5,0.8) ,0.5){wall|window:
color=yellow , material=glass | wall}

gfront → split(X,5,2,5){wall:color=turquoise|door:color=white

| wall: color=turquoise}=0.4

gfront → split (X,4 ,1 ,2 ,1 ,4){wall : color=turquoise |window: color

=pink, material=glass | door: color=white |window: color=pink,
material=glass | wall: color=turquoise}=0.6

grightfacade → repeat(X,1,1,1){window:color=blue|window: color=turquoise
, material=glass |window: color=lightblue , material=glass}

gleftfacade → repeat(X,1,1,1){window:color=blue|window:color =turquoise
, material=glass |window: color=lightblue, material=glass}

gback → wall
```

Example with the dataset

Below is an example that was created entirely from the user interface, without manually writing any ruleset. The openings were hand-drawn as well. The following excerpt from the dataset corresponds to one of the two house styles illustrated in the later figure, the appearance information can be found as attributes to the values element, the appearance of the window is encoded in the opening tag:

```
<town designation=”Antananarivo”>

<location lat=”-18,9333” lon=47,5167”” dist=”0,3”/> <appearance>

<values proba=”0,5” bdRooftype=”gabled” color=”peru” doorCol=”ivory”
floorsize=”5” maxHeight=”20” maxrotation=”0” minHeight=”5”
openingCol=”paleturquoise” roofColor=”darkred” windowfcolor=”ivory”
windowheight=”tall” windowmaterial=”glass” windowstyle=”framed”
windowwidth=”2” / >

<opening>

<split axis=”X” children=”nt4582467848 | nt4582467288” parent=”

nt4582467064” splitvalues =”0.5023809523809524 ,0.4976190476190476” />

<split axis=”Z” children=”nt4582467512|nt4582468296” parent=”
nt4582467848” splitvalues=”0.4595238095238095 ,0.5404761904761906” />

<split axis=”Z” children=”nt4582467736|nt4582468856” parent=”
nt4582467288” splitvalues

=”0.4595238095238095 ,0.5404761904761906” />

<elements parent=”nt4582467064” terms=”nt4582468856, nt4582467736,
nt4582467512, nt4582468296” />

</opening> </appearance>
```

Figure 55. Buildings generated from the dataset

In contrast, in Figure 56, are simple examples generated from arbitrary footprints and two different rulesets which were manually generated.

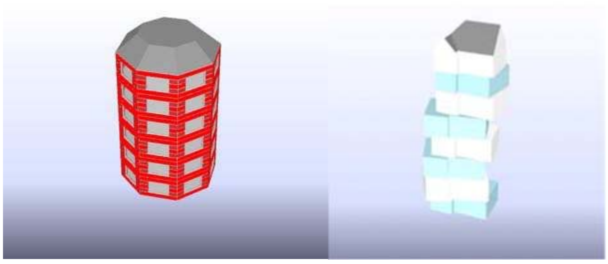

Figure 56. Examples of houses

Examples with real-world buildings

For the next results, we created our rulesets based on real-world buildings. In this case, Toulouse's downtown area (Figure 57) and buildings from an university (Figure 58). Their floor plans were extracted from OpenStreetMap, and for the later, we generated the grass from a separate shapefile by simple extrusion with the grammar. The university buildings add up to 87145 polygons that were generated under 142.03 seconds, the downtown area has 119448 polygons and the generation ran for 200.1 seconds. We ran our tests on an Intel(R) Core i5-4690 CPU @ 3.50GHz computer with 8Go RAM.

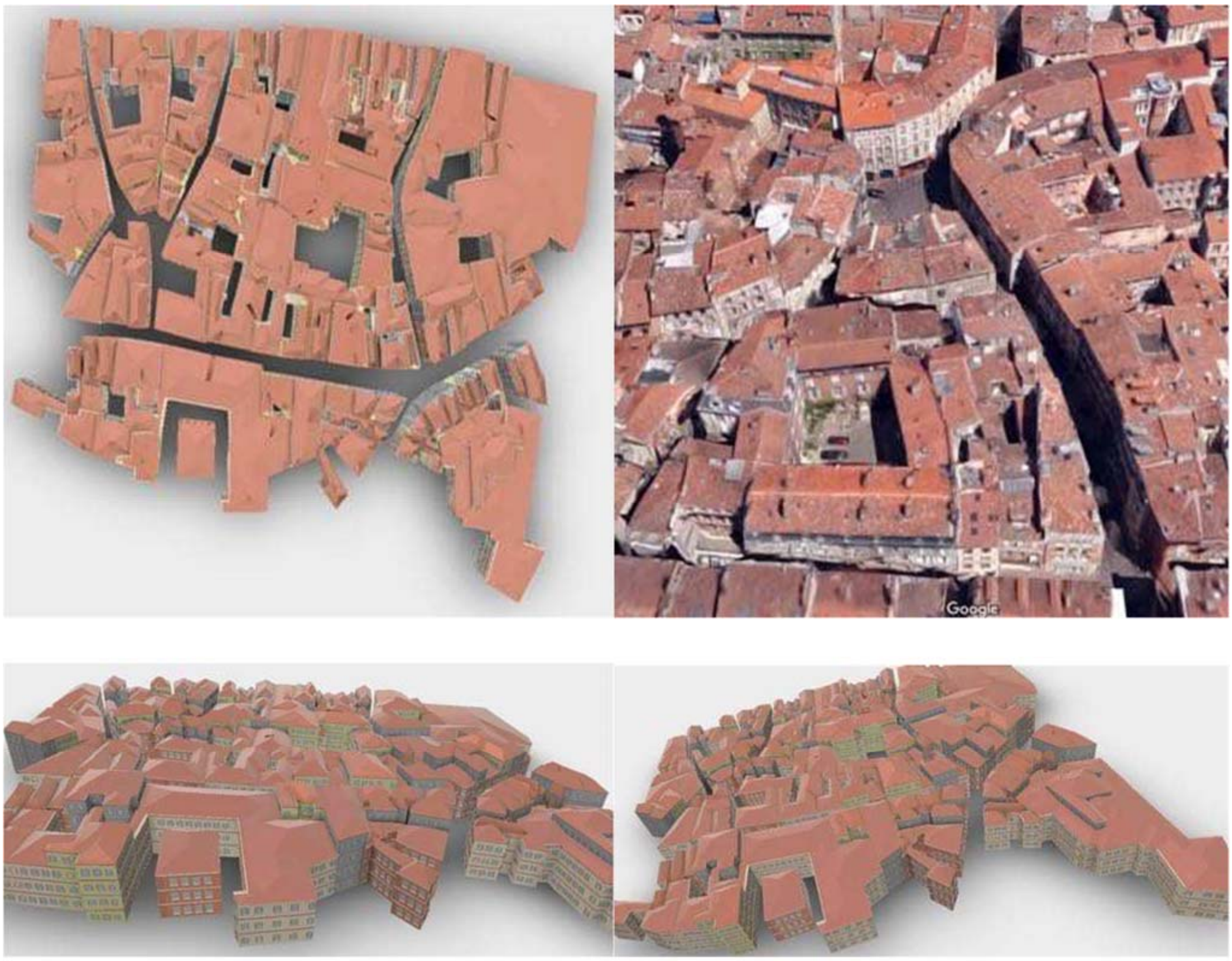

Figure 57. Downtown area of a city (Google Maps image for reference on the top right)

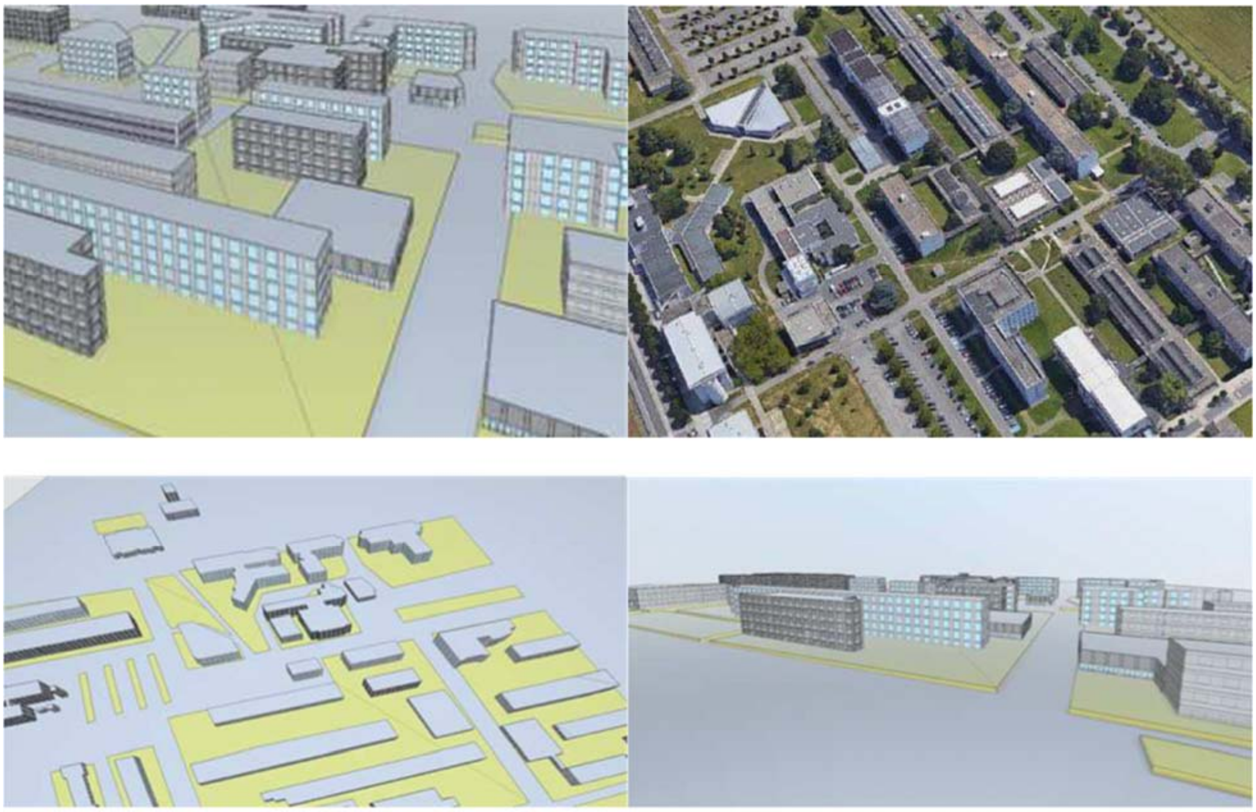

Figure 58. University Buildings (Google Maps image for reference on the top right)

Below is the Toulouse Downtown ruleset:

```
lot → extrude(15){building:color=blanchedalmond,roof=hip,
roofcolor=darksalmon}=0.4

lot → extrude(20){building:color=silver ,roof=hip,roofcolor= darksalmon
}=0.2

lot → extrude(15){building2 : color=lightsalmon , roof=hip ,
roofcolor=darksalmon}=0.2

lot → extrude(20){building : color=palegoldenrod , roof=hip ,
roofcolor=lightsalmon}=0.2 building -> repeat(Z,5){floor}

building2 → repeat(Z,5){floor}

floor → comp(){side : face}

floor2 → comp(){side : face2}

face → rsplit (Z,0.9 ,0.1){upper face | wall : color=darksalmon} face2
→ rsplit (Z,0.9 ,0.1){upper face2 | wall : color=white} upper face →
rsplit(X,0.1,0.8,0.1){wall|windowarea|wall} upper face2 →
rsplit(X,0.1,0.1,0.8,0.1,0.1){wall:color= darksalmon | wall | windowarea2
| wall | wall : color=darksalmon} windowarea → repeat(X,2 ,1){vwindow|
wall}
```

```
windowarea2 → repeat(X,2 ,1){vwindow2| wall}

vwindow → rsplit (Z,0.25 ,0.5 ,0.25){wall |bwindow| wall} vwindow2 →
rsplit(Z,0.2,0.6,0.2){wall|bwindow2|wall} bwindow→
rsplit(Z,0.1,0.8,0.1){wall:color=darksalmon| bwindow | wall :
color=darksalmon}

bwindow2→ rsplit(Z,0.3,0.7){wall:color=white|window:color= lightgrey}

bwindow → rsplit(X,0.1,0.8,0.1){wall:color=darksalmon|window | wall :
color=darksalmon}
```

Conclusion

When buildings share an architectural style, re-creating their similarity resides in finding their underlying basic characteristics. Shape grammars accomplish this by clarifying the common structure and depicting all of the hierarchical divisions this structure can go through. In the process of city construction in particular, a problem arises in the storage of huge datasets, we offer a relatively small alternative, as a single, lightweight ruleset can generate multiple variations of the urban styles, with some more complex details.

While it is still a work under progress, designing buildings with our system proves to be efficient and quick enough in most cases, as it is possible to observe the characteristics of a design, input the data into the system and even derive new designs with the same ruleset, providing a powerful language in which to express any architectural form.

The grammar is generic and simple enough for easy comprehension, but can be used to formulate meaningful rules to break simple shapes into more complex ones, and evolve the shape's design into more specific building styles, by possibly adding more and more details on the building mass model, down to the brick structure if necessary.

Tweaking a few parameters or adding a few details can shift the whole scene from one particular style to another, and the system gives a good trade-off between simplicity and visual quality.

While the various elements of a buildings can be modeled with detail, the more details are needed, the more production rules are required, which can turn out to be a tedious task in the long run. Thus for future improvements, one of the main issues to be addressed is the use of real-world pictures of buildings as training data for automatically populating our datasets and creating more style-specific rulesets.

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Into the Vitality: Responsive Modulation in Graphics

Han-Wei Kung

University of California at Santa Barbara, California, USA

Corresponding author: hkung@ucsb.edu

Keywords: virtual reality, organic shapes, audio-reactive interactivity, fluid flow

Many forms of life in the natural world have extraordinary capacities to sense their environments, to learn, and to remember, just as humans do, even though they are so unlike us. Into the Vitality is an interactive abstract virtual reality (VR) experience that invites viewers to see the natural world from a different perspective. The experience showcases organisms made by Perlin noise. Specifically, I developed a shader program that uses Perlin noise to displace the vertices of 3D geometric meshes and create organic shapes. The organisms can also modulate their shapes according to the volumes and frequencies of sound. Furthermore, the experience displays turbulent flow on the organisms' surface to demonstrate the concept of energy flow, or vitality, among everything in the natural world. I used curl noise to create animated textures that have naturally fluid-like movements. Participants can also interact with the surface colors through ray casting from a hand-held controller. In short, the VR experience attempts to awaken participants' imaginations and raise their awareness of the responsive natural world around them through animated shapes, motion, and textures.

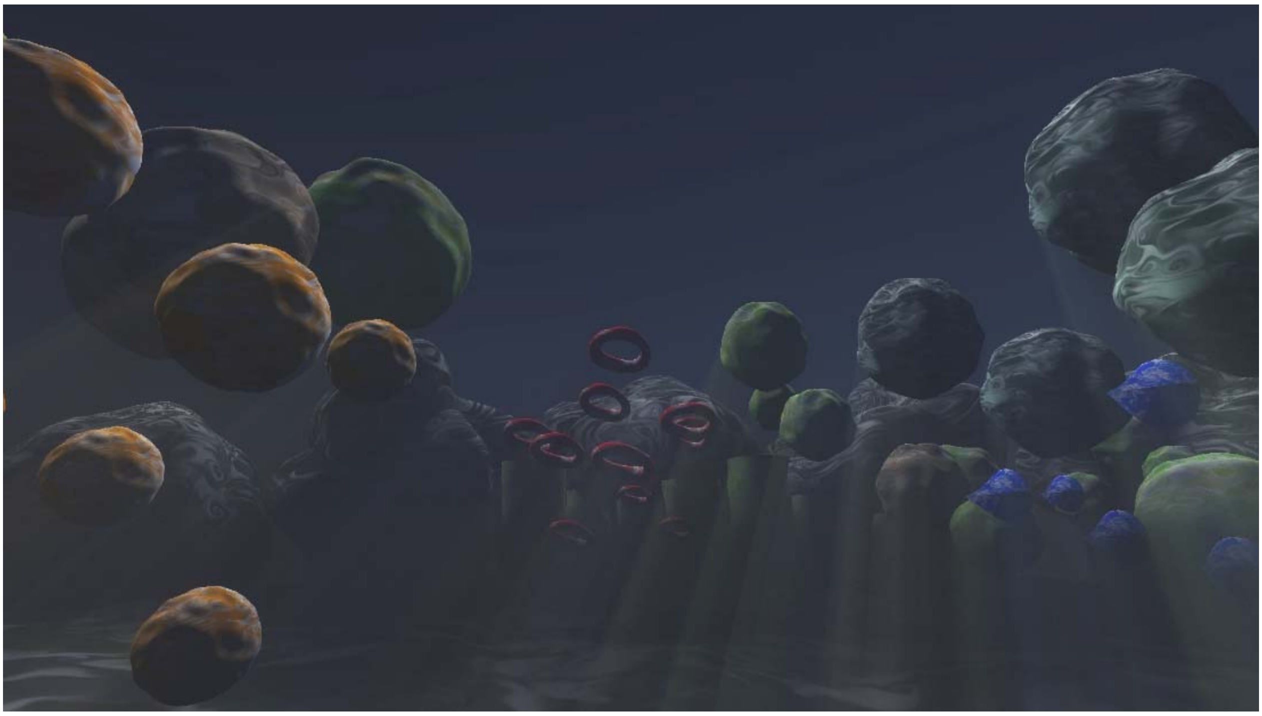

Figure 59. A screenshot from Into the Vitality

Introduction

As our knowledge of other living beings unfolds, we are revealing that they have intelligence and abilities that are so unlike our own. For example, mosses live in the interstices on rocks and logs, and they have thrived with limited resources for millions of years (Kimmerer, 2003). Whales and other marine species have evolved to depend on hearing as their primary sense to adapt to the perpetually dark world of the deep ocean. The life energy of plants and animals has inspired me to "re-visualize" the natural world in VR. I attempted to illustrate the flow of energy or vitality in the inhabitants or organisms of the virtual world. They can also modulate their shapes based on sound. This paper presents techniques that I developed to create this virtual world (Figure 59). To create this world, I used the Unity game engine and the Oculus Rift VR system.

The organization of this paper is as follows: First, I will explain why I used Perlin noise to create the shapes for the organisms. Then, I will describe how I made these organisms sound-reactive. Third, I will describe why I used curl noise to visualize the flow of energy. Each of these sections provide experimental results. Lastly, I will conclude this work.

Organic Shapes

To create organic shapes, one must generate a little bit of randomness that resembles the patterns found in nature. However, a purely random number generator produces numbers that are unrelated to each other and do not necessarily mimic natural shapes. In nature, most things are not purely random. For example, clouds and terrain seem to have elements of randomness, but there are a lot of complex interactions among the many tiny particles that compose these natural patterns. There is an algorithm that can create more natural results, and it is known as Perlin noise, developed by Ken Perlin [1985, 2002). The shapes generated by Perlin noise have a more organic appearance because Perlin noise generates a smooth sequence of pseudo-random numbers. Because Perlin noise generates coherent noise over a space, when we displace the vertices of a 3D mesh using Perlin noise, this results in a smooth appearance and an organic feeling (Figure 60). I implemented this technique through vertex shaders in the Unity game engine.

Figure 60. Results of applying Perlin noise to different geometric 3D models.

Sound-reactive Modulation

Like an intelligent octopus, the organisms of the virtual world can modify their structure and appearance. Thus, their shapes can be modulated based on sound input from music or microphones through shader programs. In this sense, the organisms "respond to" sound. To have audio modulate the shapes through a shader, the first step is to interpret the audio with a meaningful representation that can provide useful information for the shader to process. One common way to represent audio is by showing how loud the audio is over time. This representation is called the time domain. However, this representation does not help us understand what we actually hear. Sound consists of different frequencies of sine waves. Therefore, alternatively, instead of representing audio in the time domain, we can represent it in the frequency domain by using the Fourier transform. The Fourier transform is a mathematical tool that converts a time-dependent signal into a frequency-dependent signal, revealing information about frequencies of the sine waves that make up the original signal. As a result, instead of looking at audio signals' loudness and time, we will be looking at its loudness and frequency. For my implementation, given an incoming audio stream, I calculated an array of magnitude values across the frequency spectrum using the Fourier transform. Each organism was then programmed to respond to a specific frequency range. The shader program attached to the organism displaces the vertices of the organism's 3D mesh according to the magnitude in that frequency range (Figure 61).

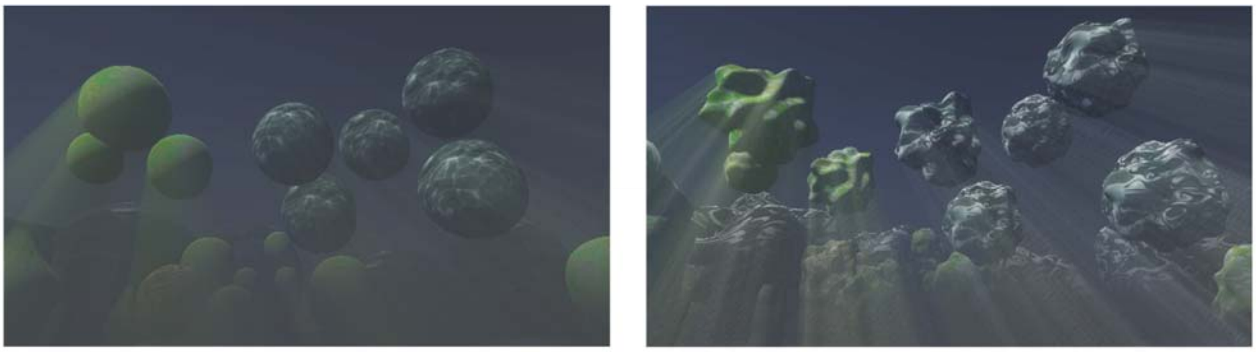

Figure 61. Screenshots showing that the organisms modulate their shapes by sound. Their shapes change as the volume of the sound goes from gentle (left) to loud (right)

Interactive Energy Flow

I represented the flow of life energy in the natural world by applying flow animation to 3D models' textures. I found my ideal candidate for flow animation in a method called curl noise, created by Robert Bridson (2007). A curl is a mathematical operator that measures the "rotation" in a vector field. Its input is a vector field, and its output is a divergence-free vector field, which means that it has neither sources nor sinks in the flow. Applying the curl operator to Perlin noise as an input generates curl noise. Curl noise contains varying vectors, which can be used to control the direction of the flow. Therefore, I developed shader programs that use curl noise as a flow map to distort and animate textures (Figure 62). In addition, the shader programs allow participants to interact with the textures by injecting colors into them (Figure 63).

Figure 62. Results of using curl noise to distort and animate textures.

Figure 63. Screenshots showing a participant changing the colors of the animated textures using a controller in VR.

Conclusions

This paper presents techniques to give 3D models an organic and flowing appearance based on a combination of two noise algorithms. With these techniques, models can also become audio reactive and interact with the audience in VR.

Because plants and wildlife are the inspiration for this work, I hope that the audience will relate the visual metaphors to lifeforms in the real world to better appreciate nature as a beautiful gift. Essentially, the work conveys a basic ethical attitude: respect for life—not only human life but all lifeforms.

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Designing an edutainment serious game for the Antikythera Mechanism in virtual reality

Eleftherios Anastasovitis and Manos Roumeliotis

University of Macedonia, Thessaloniki, Greece

Corresponding author: elanasta@uom.edu.gr

Keywords: Serious games, virtual reality, cultural heritage, immersion, Antikythera Mechanism, game-based learning, game analytics, edutainment, cultural application.

Gaming industry offers extraordinary experiences to users, maximizing their engagement to fulfill the objectives of each level of the game. In addition, enhancing the educational impact, games serve serious purposes and tends to be effective educational tools in sciences and in training (Susi et al., 2007). Furthermore, there are indications that Serious Games (SGs) for Cultural Heritage (CH) can effectively facilitate communication and understanding of cultural content, stimulate the interest of participants and enhance their motivation to further exploration (Anderson et al., 2010;Montara et al., 2014).

Virtual Reality (VR) reinforces some crucial factors, that increase the immersion in a virtual cosmos, such as a) feel of presence, b) interactions in physical way, and c) multi-sensory participation, increasing user's satisfaction (Anastasovits and Roumeliotis, 2018). Moreover, data derived from games, their use and players provide a new and complementary way of designing games, of affecting the game production and offer a better customer service [Drachen et al., 2013). Also, player experience can be improved and tailored to each player but also augmented via richer experience-based interaction (Yannakakis and Togelius, 2018).

The Antikythera Mechanism is the oldest known computer engineer developed around the end of the 2nd century BC (De Sol la Price, 1974; Seiradakis, 2018). The Antikythera Mechanism consists of many axes and gears, but is not a clock mechanism (Roumeliotis, 2018). It is known to have been a solar calendar, computing and displaying periodic celestial information, such as moon phases and lunar and solar eclipses (Freeth et al., 2006). It is one of the earliest known scientifically complex instruments (Wright, 2005), that is exposed in a fossilized state of 82 fragments at the National Archaeological Museum of Athens (Freeth et al., 2006).

In this contribution we present through a poster and a demo, the design of a 3D SG for the Antikythera Mechanism, extending our Virtual Museum (Anastasovits and Roumeliotis, 2018; Anastasovitis, 2017), that interconnects VR immersive technologies in the context of experiential game-based learning theories, for better communication of the artifact, assisted by Artificial Intelligence (AI) through game analytics.

Methodology

The main objective of this presentation is to design a model of emblematic CH objects to communicate more effectively with the public through full-immersive VR technologies and dynamic customization of user experience in assistance of AI, by studying the case of Antikythera Mechanism, for future SG development. In achieving our cardinal objective, we have set out the following objectives:

Obj. 1 – Strengthening experiential learning: Communicating the emblematic object by enhancing the sense of presence in its original context of use, through VR of a high degree of immersion, and supporting experiential learning by developing an SG for CH.

Obj. 2 – Embedding storytelling: Enhancing the effectiveness of learning and entertainment in SG for CH, using storytelling.

Obj.3 – Personalized content and usability adaptation (via AI and game analytics): Enhancing the effectiveness of learning and entertainment in SG for CH, using AI, utilizing data collection and analysis to adapt the experience, according to user behavior.

Obj. 4 – Evaluation: Evaluate the effectiveness of learning and entertainment in SG for CH, through pilot testing with groups of users and enhance the validity of results by collecting and analyzing data during the game.

The available information for the Antikythera Mechanism is combined with the storytelling technique and converted into scripts. Additional information for the season from other relevant sources, feeds the visualization of the virtual world as well as the rules that govern it. By integrating game mechanics, scenarios are transformed into quests with the appropriate play features (levels, rewards, etc.). Thus, the virtual world becomes a game (see Figure 64).

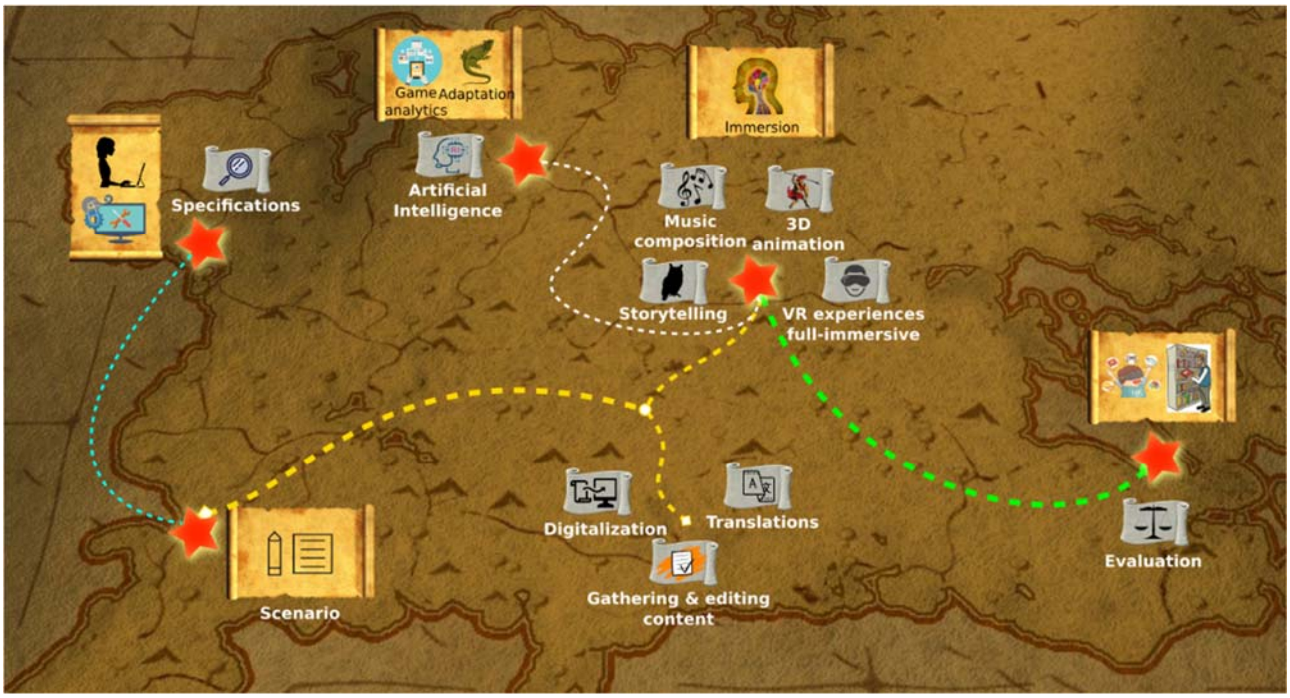

Figure 64. The methodology for the full-immersive SG for the Antikythera Mechanism.

Designing a VR serious game for the Antikythera Mechanism

The starting point for the 3D SG is the Virtual Museum for the Antikythera Mechanism, where the digital 3D reconstructed fragments of the artifact are being exposed. All functions will remain, and will be the place where the missions for the user will be in the current time-period. Since accepting the mission, the player will be transferred back in time and will try to gather all the necessary information through adventure games designed in Unity1 game-engine and interacting with Oculus Rift S2 head mounted display with the touch controllers.

Successful completion of the mission will bring the player back to the Virtual Museum, rewarding him/her with the necessary knowledge to build structural parts of the Antikythera Mechanism. In addition, when the player succeeds in all missions the full reconstruction of the Antikythera Mechanism functional model will be available. Below, the outline of the full-immersive 3D SG for the Antikythera Mechanism is being presented (see Table 7).

Table 7. Knowledge transfer for each thematic area of the SG for the Antikythera Mechanism.

Thematic	Knowledge transfer	Means of communication
Virtual Museum	fragments (external, internal), Antikythera Mechanism structure, historical context, research progress	3D-viewer, X-Ray viewer, VR experiential, 3D-animation
The cargo	shipwreck, treasures, ship, excavation, route (departure, destination)	VR experiential, 3D-animation, storytelling
The inscriptions	structure, periodical phenomena	VR experiential, storytelling
The astronomy lab	periodical phenomena (lunar and solar eclipses, celestial orbits, etc.)	VR experiential, 3D-animation, storytelling
The mechanology lab	structure (axes, gears, teeth)	VR experiential, 3D-animation, storytelling

Conclusion

In this application poster and demo, we presented the methodology and the design of a full-immersive VR SG, that is in progress, for the emblematic artifact of CH, the Antikythera Mechanism. Extending our Virtual Museum for the Antikythera Mechanism the user can act both in modern time and in 2nd century BC, the era of the Antikythera Mechanism and execute the designed missions in an edutainment way. Artificial Intelligence and game analytics will be used to overcome dynamically the gap between different level of user experience, regarding the usability and content adaptation.

Acknowledgements

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A VR serious game for understanding cultural heritage

Christina Tsita and Maya Satratzemi

Knowledge transfer for each thematic area of the SG for the Antikythera Mechanism.

Corresponding author: c.tsita@uom.edu.gr

Keywords: Virtual Reality, Serious Game, Cultural Heritage, 3D representation, Learning, Level of immersion

In recent years, various technologies are used for digitization of Cultural Heritage (CH), as well as for the development of augmented-, virtual- and mixed-reality (AR/VR/MR) gamified applications, that integrate digitized cultural content, with the aim to widen the CH audience and improve the experiences provided in CH context (Ioannides et al., 2017). More specifically, AR/VR/MR systems are applied in CH sector having education, exhibition enhancement, exploration, reconstruction or virtual museum intentions (Bekele et al., 2018). This trend is expanding as there are many benefits that the CH field and the visitors can have from such applications. Thus, efforts are being made to increase applications' effectiveness in attracting more visitors and enhancing visitors' experience. It is evident that the education, entertainment and escape factors delivered through VR & AR experience, have positive impact on visitor's overall experience. These three factors can also induce the public to revisit an attraction (Jung et al., 2016).

The VR Cultural Heritage Serious Game

This study aims at understanding of CH through a Serious Game (SG) which by definition indicates the balance between education and entertainment (Alvarez and Djaouti, 2011). The reconstruction of an archaeological site is intended, in order to be used as a 3D virtual world setting of the SG. The sense of presence in a different time and place is intended to be enhanced through rigorous 3D representation of the site and its related practices, as game activities, which are being executed by a first-person controller, through the use of high immersive VR system (headset). The CHSG will be developed for the Roman Agora of Thessaloniki (Greece), which is located in the centre of the city. The game is expected to enhance the experience of the visitors in the archaeological site, as well as in the Roman Forum Museum, which is located inside the aforementioned site. The goal is to enhance CH understanding by applying experimentation and exploration activities in an immersive virtual world setting and at the same time to find evidence on whether it is possible to bring balance between entertainment and learning in a CHSG, through the use of different levels of immersion.

The game is intended to contribute to the existing results regarding the potential of CHSGs in terms of entertainment and learning. Additionally, by using log data is intended to contribute with more rigorous results in the field, while it is evident that few of the existing CHSGs studies exploit that possibility. Moreover, the study aims to contribute in overall CHSGs efficiency in terms of learning and entertainment, which is also one of the latest discussions in the field (Tsita and Satratzemi, 2018; 2019). More specifically, the proposed game aims to a) increase SGs efficiency by design, b) contribute to the collection of more rigorous CHSGs research results, c) examine the CHSG's effectiveness on higher cognitive processes, and d) analyze log data and use artificial intelligence to increase SG efficiency in terms of user experience and learning. In more detail, it is suggested to define the targeted effectiveness goals, in early stages of SG design, in terms user experience (which includes entertainment) and learning. In this way, it will be possible to develop built-in mechanisms that will allow the targeted data collection during gameplay aligned with efficiency parameters. Thus, the log data together with the data from other evaluation tools (questionnaires, pre- and post-tests) can increase the validity of the results. To exploit the data collection even more, a part of the data will be used not only for the final evaluation, but also for the formative evaluation, during game session. Some of the data will be analysed and part of them will be the input to the artificial intelligence mechanism, which will configure part of the game. Consequently, the game will offer a more personalised experience, that is more satisfying in terms of entertainment and learning. However, this paper focuses on the CHSG's intention to facilitate higher cognitive processes, such us understanding in CH setting, according to the revised Bloom's taxonomy (Krathwwohl, 2002). This study aims to indicate the 3D virtual world setting and the adventure game genre as suitable for CH learning and more specifically for CH understanding. The combination of the experiential approach with the digital 3D representation in a virtual world can enhance the educational value of the experience, while the user is able not only to observe the environment but also to interact with its content. The explorative behaviour in the virtual world is being enhanced by transforming the interactive experience in a SG, by implementing game mechanics and pedagogical approaches (Bellotti et al., 2012).

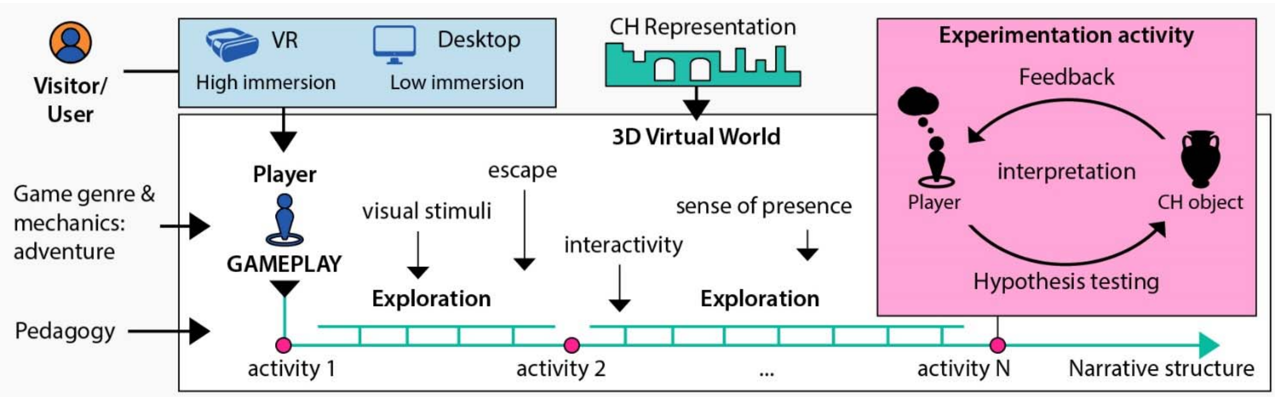

Figure 65. Visual representation of the immersive CHSG environment & user experience

During the design phase of this CHSG, some conceptual factors for the design of CHSGs have been considered. The intended level of immersion, when designing a game is not necessarily the highest, depending on learners' specifications. Although the high level of immersion brings great results on users' entertainment in CH context, may not be included in users' interest when they need to learn from a game (Tsita and Satratzemi, 2019). Subsequently, we will try to find evidence on whether it is possible to bring balance between entertainment and learning in a CH setting, through the use of different levels of immersion. The visual representation of the proposed 3D CHSG setting and user experience are presented in Figure 65. The user, visits the 3D virtual world, by using different input devices. The game genre and mechanics in our use case, is the adventure game, which supports both exploration and experimentation in the 3D representation of the archaeological site through the interaction with the space and the findings from the archaeological site (CH objects). Pedagogical approaches, such as experimentation Kolb, 2014), scaffolding (Vygotsky, 1978), revised Bloom's taxonomy (Krathwohl, 2002) etc. are being considered for the activities. The visitor transforms in a historical character, and plays at first person. The world setting is coherent with design consistency regarding rules and visuals, because of the rigorous 3D representation of the existing historical place. This setting offers the visual stimuli and interactivity opportunities, as well as increases the sense of presence, and the escape experience, while the user explores the virtual world, in order to complete the missions. During the exploration the user observes the environment, interacts with it (to the extent that the interactivity level has been defined by design), feels that is being inside the virtual world and that is someone else (the character/role) in a different place and time. During the exploration, the player executes some activities. The experimentation type of activities, are highly important for the cognitive participation of the player in the game. The player interacts with a CH object, which is part of the environment, and has to execute a task in order to progress in the game. The player forms a hypothesis on what he/she has to do to complete successfully the task. Then, the player tests the hypothesis, by interacting with the CH objects/ environment and receives the feedback from the environment in a natural way. According to the feedback the player, alters the previous hypothesis and tests something else, until the riddle is solved. This approach is aligned with Kolb's theory (Kolb, 2014) and it is inevitable to apply the experiential cycle of learning, where the user thinks about how to solve a task and experiments to the point that the approach tested, leads to the solution of the problem (Kolb, 2014). This approach is also aligned with modern museology, which encourages visitors to form their own interpretations about the museum objects (Mairesse and Desvallées, 2010).

The use of rigorous 3D representation as a virtual world setting for a 3D SG is suitable for increasing CH awareness, attract visitors and trigger visitors' interest on the CH content. The use of high level of immersion to enhance the sense of presence and escape, can increase users' satisfaction in terms of entertainment, while the use of adventure game mechanics can strengthen the CHSGs potential on enhancing higher cognitive processes, such us understanding. The understanding of CH is expected to be reinforced by implementing the game in a 3D virtual world, which offers proper visual stimuli during exploration. Moreover, understanding is being supported by the experimentation activities, which allow active cognitive participation of the player. Additionally, the game tasks are aligned with similar activities/practices of the past, which are being executed by the player, through role-playing, which increases the sense of presence and promotes the learning by doing (Hein, 2004). Therefore, the next steps are to develop the game and test it in order to study whether these elements do indeed enhance understanding of CH, and what are the effects of such game in user experience (including entertainment) and learning. It legitimate to compare the effects of using different input devices for the same game, meaning to compare the experience of a desktop application and the experience of a VR headset device, in order to extract the effects on a) learning and b) entertainment.

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AR-Pong: The Adaption of the Classic Pong Game to Multi-User Mobile Augmented Reality

Christoph Anders, Nico Möller, Nils Schlüter, Richard Schulz, Yavuz Uslubas, Ingo Börsting, Markus Heikamp, Ole Meyer and Volker Gruhn

University of Duisburg Essen, Germany

Corresponding authors: ingo.boersting@uni-due.de, markus.heikamp@uni-due.de and ole.meyer@uni-due.de

Keywords: Augmented Reality, Multi-User, Synchronization

Developing multi-user applications for Augmented Reality (AR) poses extensive challenges, such as synchronizing physical and virtual objects in real time. In order to explore these challenges, we implemented an AR adaption of the classic Pong game. In our application, any flat surface in the physical world can be used as a playing field (see Figure 66). The rackets with which both players have to defend the ball are controlled by moving smartphones back and forth. We use Google's ARCore to track the physical environment and the current users position. ARCore creates a coordinate system in the physical world that is relative to the position of a single phone, so that the opposite devices differ in coordinate systems. Within our application, ARCore's Cloud Anchors serve as reference points. When an anchor is set by one of the users, the origins of both devices are recalculated relative to the reference point, resulting in shared information about the physical environment. In order to exchange game objects between users, we implemented a network manager, using server-based commands on specific interactions. In addition, we implemented a network transform component to synchronize object's positions and physics. Since the rackets are controlled by the players and the synchronization is therefore triggered by the clients instead of the server, these objects are marked as variables that are synchronized on command. This also applies to variables like the game state and the score. Our current version still offers room for extensions such as a single player mode with an AI component. However, by now it enables users to play AR-Pong in a shared gaming experience.

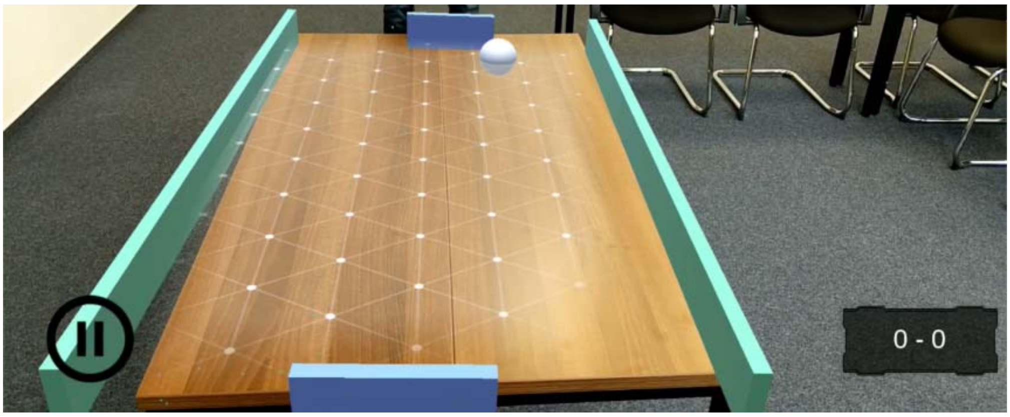

Figure 66. Virtual game field and elements in relation to the detected plane.

PLUGGY3D. Augmented Reality for cultural heritage

Arcadio Reyes-Lecuona, Daniel González-Toledo, María Cuevas-Rodríguez,

M. Luna Herruzo-Torrico, Ana García-Puyol and Luis Molina-Tanco

University of Malaga, Spain

Corresponding authors: areyes@uma.es, lmtanco@uma.es

Keywords: Augmented Reality, Cultural heritage, 3D models

The PLUGGY project aims to allow people to be actively involved in cultural heritage activities, not only as observers, but also as content creators (Lim, 2018). Within it, a suite of tools dedicated to create, share and experience 3D models has been developed. These tools use the web and portable devices that have support for virtual and augmented reality.

PLUGGY AR/VR tools

The PLUGGY3D suite is a set of applications that allow to import, curate and experience AR and VR content within the PLUGGY Social Platform and Curatorial Tools (Lim, 2018). The PLUGGY3D suite includes the following applications: PLUGGY3D Create, PLUGGY3D Curate, PLUGGY3D Experience Web and PLUGGY3D Experience Mobile. Together they manage the content and functionality required to create virtual exhibitions to enhance on-line and on-site visits to museums or other indoor cultural sites. Figure 1 shows a complete scenario of the PLUGGY3D suite of applications, from the modelling of a 3D object, which lies outside the scope of Pluggy, to the experience around the object.

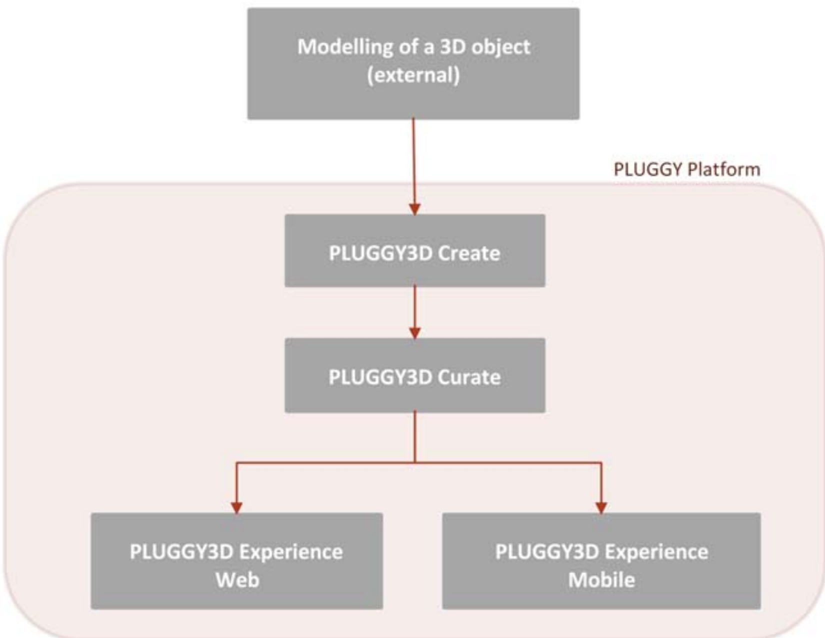

Figure 67. PLUGGY3D suite workflow

PLUGGY3D Create is a web application that allows to upload 3D models, to define the hierarchical structure of their geometrical objects in terms of their parts, and to utilize other basic editing options, such as choosing a main rotation axis to facilitate natural 3D navigation (González-Toledo, 2018). See Figure 68 for a screenshot of PLUGGY3D Create.

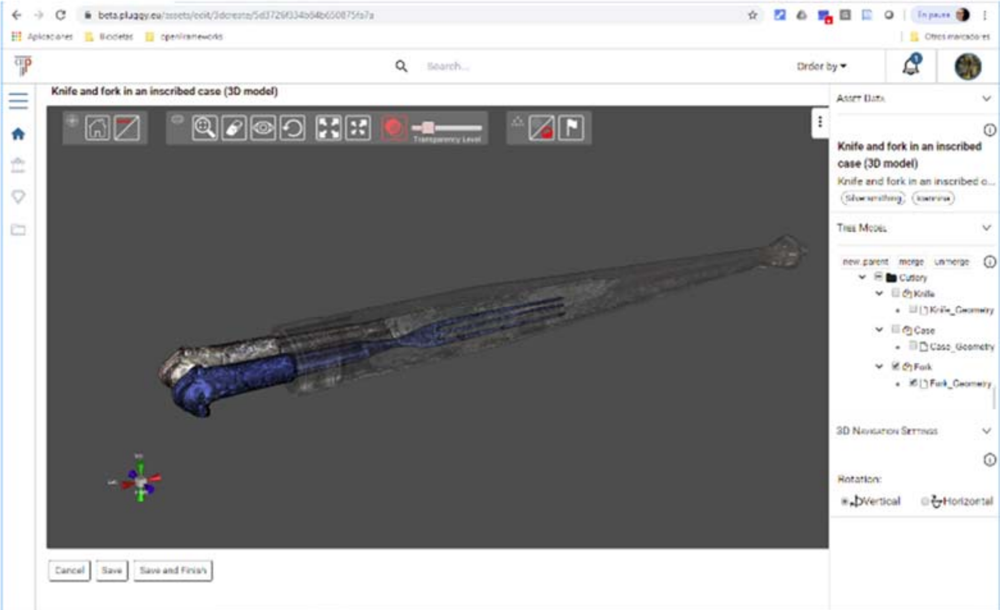

Figure 68. PLUGGY3D Create is a web application which allows basic edition of product tree and 3D navigation settings.

PLUGGY3D Curate allows to build digital exhibitions as a sequence of chapters using one or several of these 3D models. In each chapter, users can highlight specific parts of the model and attach customized labels, which can be located in 3D. Areas of the model can be made semi-transparent or can be hidden in their entirety, to better show other parts of the model from different points of view. While curating an exhibition, chapter titles, their description and annotations of elements can be added in several languages to make the exhibition accessible to a wide audience (Figure 69).

PLUGGY3D Experience Web allows to experience and navigate the exhibition created in any WebGL compatible web browser. If the exhibition is available in different languages, PLUGGY3D Experience Web allows the user to select a preferred language. In return, the browser will display the text information in labels and panels in said language. Users can explore the different chapters by means of enhanced interaction techniques for viewing objects (González Toledo, 2018).

PLUGGY3D Experience Mobile presents the curated virtual exhibitions in Augmented Reality using Google ARCore (ARCore, 2019), which has been proven to enhance the user experience and to increase the enjoyment of learning about cultural heritage (Voinea, 2019). For non ARCore compatible devices the exhibitions can still be experienced in Virtual Reality (Figure 70).

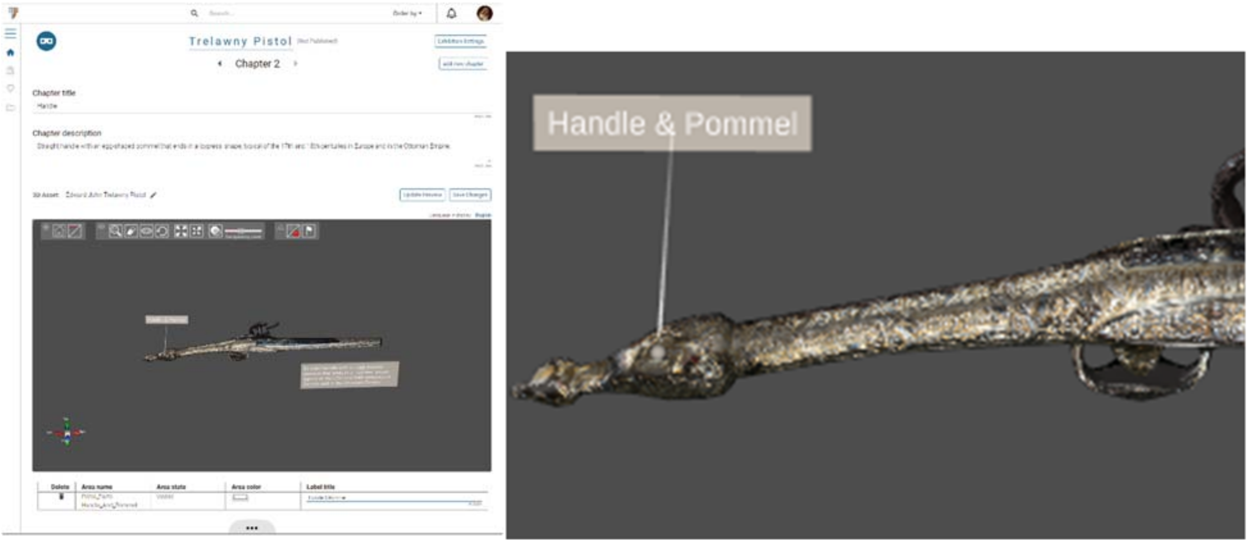

Figure 69. PLUGGY3D Curate is a web application that allows the curation of AR and VR exhibitions using 3D models and additional text content in several languages. The application offers various ways of highlighting or focusing specific areas of the models.

Figure 70. PLUGGY3D Experience Mobile is an Android application that allow to experience the exhibitions created with the web application PLUGGY3D Curate

The Palacio de la Aduana as an example of virtual exhibition

To showcase the capabilities of the curation tools of PLUGGY 3D, the historical building of the Museum of Malaga has been modeled in 3D and an exhibition has been created (Figure 71). The recently-remodeled neoclassic Palacio de la Aduana (Customs Palace, in English) is home to this new museum in the city of Malaga (Spain). This public building serves to show how cultural heritage can be made more accessible to the public by means of a social virtual platform. The model has been created using meshes that add up to 28.908 polygons, which is easily managed by both web browsers and Android devices compatible with ARCore. Here, the asset shown in the exhibition is a section of the building itself, and it has annotations about its history, construction, and remodeling process. This exhibition (Figure 72) can be experienced in both VR and AR at https://beta.pluggy.eu/exhibitions/5d48f98c68f9fe8622c8e2f1.

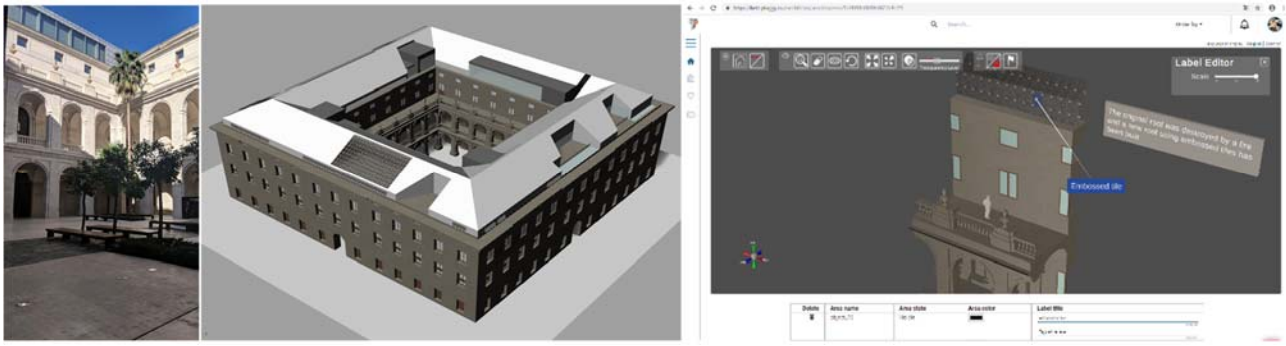

Figure 71. The Palacio de la Aduana building (left) has been fully modelled in 3D (centre) and can be annotated in a virtual exhibition using the PLUGGY 3D Curate tool (right).

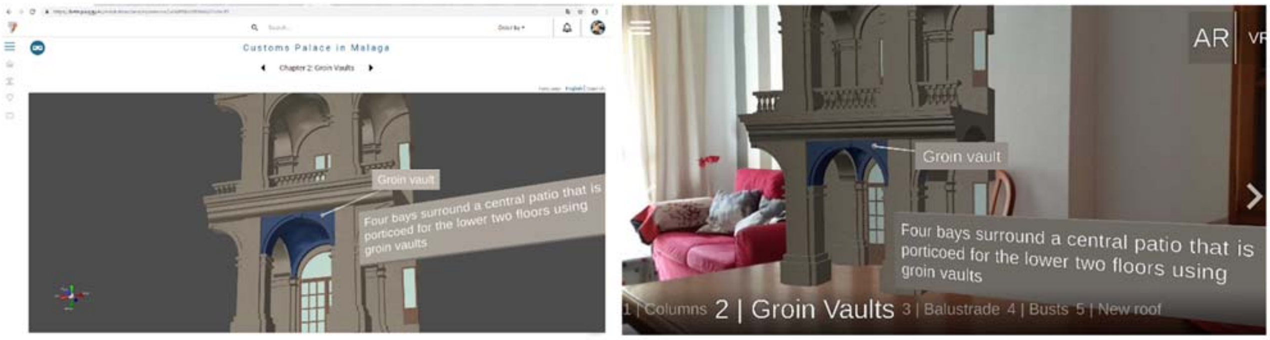

Figure 72. The virtual exhibition can be experienced using different versions of the PLUGGY 3D experience tool, in the web (left) or using Augmented Reality (Right).

Acknowledgements

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Explaining Principle Component Analysis in Virtual Reality

Reinier Zwart, Jarno Smit and Marie Postma

Tilburg University, The Netherlands

Corresponding author: Marie.Postma@uvt.nl

Keywords: STEM, Data Visualization, Principal Component Analysis, VR in Education, Mental Rotation, Engagement, Flow.

In our study, we developed and tested a VR environment designed to educate students of higher education (e.g., university students in social sciences) in the area of statistics, specifically, helping them grasp the statistical method of Principal Component Analysis. Principal Component Analysis (PCA) is a popular method employed both in behavioral sciences and in data science to reduce multidimensionality of data sets containing a high number of variables. Compared to feature reduction, i.e., the removal of certain variables, PCA minimizes any loss of information. Large datasets typically also contain variables that are highly correlated. The use of PCA ensures that the criterion of multicollinearity will not be violated. Even though PCA is a comparatively simple mathematical variable-building technique, many undergraduate students struggle to develop an intuition for its workings.

Explaining complex statistical subjects to students can be difficult, particularly when students do not possess the intuition to easily grasp the mathematical concepts underlying them (Lajoie, 2003; Suyatna et al., 2017; Arwanto, Budayasa, & Budiarto, 2019). However, creating 3D visualizations of these concepts may improve understanding, especially using dynamic visual representations (Suyatna et al., 2017). In order to develop an intuition for PCA, students need to be able to perform mental rotations of data points in 3D space and extrapolate to multidimensional spaces. This turns out to be challenging to many of them, arguably due to their limited spatial ability. Spatial ability is the extent to which one can employ given cognitive functions in activities requiring visual thinking. High spatial ability is shown to be strongly related to success in professions like engineering and architecture, which require adequate understanding of spatially complex concepts (Lajoie, 2003). Moreover, spatial ability has been positively linked to the completion of spatial complex tasks (Wenzel et al., 2002). Next to spatial ability, it is important that students are properly motivated to learn. Such motivation can be achieved through the use of technology-mediated learning (Chun, Kern, & Smith, 2016; Henrie et al., 2015; Santhanam, Liu, & Shen, 2016; Harandi, 2015).

To test whether understanding the technique of Principal Component Analysis can be improved by presenting it in 3D space, we developed a dynamic application in Unity 2018.3.2. that included limited possibilities of interaction, explanations of basic concepts, rotations of data points and an explicit presentation of dimensionality reduction in space. Next to the measurements of spatial abilities, we included the assessment of 'engagement' and 'flow' as two concepts expressing learner attitude towards the learning experience.

Student engagement, i.e., the active participation, effortful involvement or investment in learning (Henrie et al., 2015), has been linked to academic performance (Herman & Tucker, 2000; Carini, Kuh, & Klein, 2006). Based on the review of Freina and Ott (2015), we can expect that the of virtual reality for educational purposes will lead to an increase of student involvement and motivation, both of which are components of student engagement (Fredricks, Blumenfeld & Paris, 2004). Similarly, in a study comparing the learning gains of students in three different learning modalities (traditional, VR and video), the students in the VR condition reported higher engagement than the participants in the other two conditions (Allcoat & Mühlenen, 2018). We can thus expect students learning about PCA in the VR application to be more engaged, possibly resulting in better learning outcomes.

As defined by Csikszentmihalyi and Larson (2014, p. 136), "flow denotes the holistic sensation present when we act with total involvement". It is complex construct that consists of a number of dimensions, including, among others, concentration on the task at hand, the merging of action and awareness, sense of control, and an altered sense of time (time passing faster than normal). Flow only arises when we are actively engaged in an interaction with the environment, using some type of skill. Being "in the flow" is assumed to have a positive effect on learning (Choi, Kim, & Kim, 2007; Skadberg & Kimmel, 2004; Webster, Trevino, & Ryan, 1993).

In sum, we tested the impact of 3D interactive VR environment on the development of knowledge and understanding of a complex statistical concept, taking into consideration participants' spatial ability, as well as engagement and flow during the learning task. Below, we provide the details of the experiment and the experimental results in more detail.

Experiment

The application was tested with 40 Dutch university students who had little to no prior understanding of PCA. Their performance on a subsequent test was compared to the performance of other 40 Dutch university students from the same institution of higher learning who received an explanation about PCA on paper. The average age of the participatns was 22 years ($M = 21.88$, $SD = 4.08$); 37 of them were male and 43 were female. We measured the participants' spatial ability using the standard mental rotations test (Peter et al., 1995), their engagement (Wiebe et al., 2014) and flow, using an adapted version of the Flow State Scale (Jackson & Marsh, 1996).

The VR application created in Unity was presented in Oculus Rift. It contained the same explanation, provided by a voiceover (recording of a native male English speaker), as the paper version of the task. The VR environment was designed to minimize unnecessary distractions, yet still be visually appealing. It consisted of a plane surrounded by four walls with a star-filled sky above (see Figure 73 and Figure 74). In the environment, participants were at several moments given the task walk freely, for example, in order to investigate a dataset projected in the 3D space. The application was divided into five scenes. The first scene provided a general introduction to the VR application and the controls. In the second scene, the participants were presented with a data set (Figure 73). The same data set was described in the paper version of the task. The main goal of PCA, i.e., how to present the data in reduced dimensional space with minimal loss of information, was introduced in this scene.

In the third scene, participants were presented with the learning material. Subsequently, in the fourth scene, we used the well-known metaphor for PCA, showing a 3D teapot, for which the user was instructed to find an angle from which a 2D photograph of the teapot could be taken, showing as much visual variance as possible. In the final scene, the concept of dimensionality reduction was explained and applied, followed by a summary. After each scene, the participants were provided with the opportunity to replay and revise the scene.

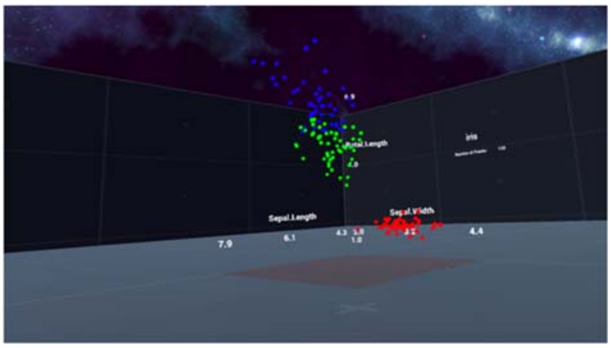

Figure 73. Presenting the data set

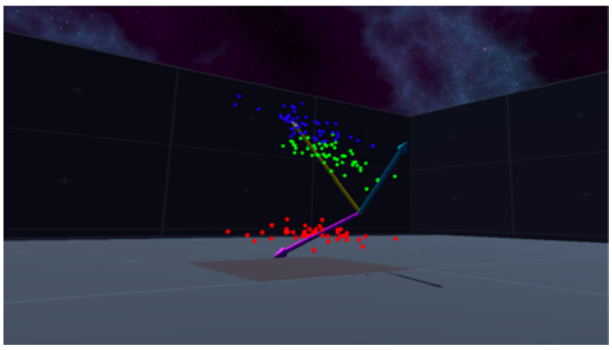

Figure 74. Demonstrating the dimensions.

All questionnaires were administered with the help of Qualtrics. Spatial ability was measured with a short version of the redrawn mental rotations test by Peters et al. (1995). In the test, participants were instructed to determine which two of four different figures were the rotated form of the example figure (see Figure 75) for a total of 12 questions. The engagement questionnaire consisted of 21 questions based the instrument developed by Wiebe et al. (2014). It had a high internal reliability (VR: Cronbach's a = .89; paper: Cronbach's a = .90). The measurement of PCA knowledge development and understanding consisted of a 8-item open-ended exam, developed with the help of the revised Bloom's taxonomy (focusing on the categories of 'remembering' and 'understanding'). An answer model was constructed with questions weighted according to their difficulty. The total amount of points that could be awarded was 10. The student responses were graded by two examiners, blind to condition, with a high inter-rater reliability (Cohen's k = .98). For further analysis, the total number of points was summed up ($M = 4.35$, $SD = 2.13$).

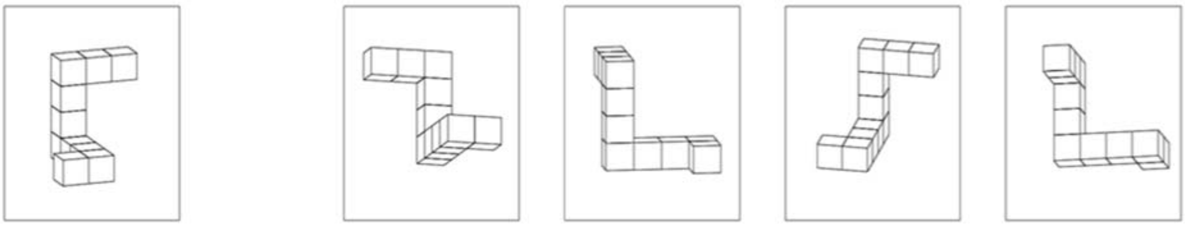

Figure 75. An example of a question in the Mental Rotations Test

Results

For the statistical analysis, we constructed a regression model using condition (VR vs. paper), engagement and spatial ability as predictors and learning outcomes as the dependent variable. Flow was excluded from the analysis due to its low correlation with the learning outcomes. Our results showed no effect of VR, compared to traditional paper-based instructions, on learning outcomes. There was also no effect of spatial ability. Engagement turned out to be the only significant predictor of the learning outcomes ($F(1,77) = 4.547$, $r^2 = 0.056$, $p = 0.036$, $b = 0.236$), and the participants in the VR condition reported a higher degree of engagement than in the paper condition ($M_{VR} = 79.15$, $SD_{VR} = 11.25$; $M_P = 69.95$, $SD_P = 13.84$; $t(78) = -3.263$, $p = .002$).

Table 1. Pearson's correlations between experimental variables.

Condition	Variable	1	2	3	4
Paper	1. Spatial Ability	-			
	2. Flow	0.093	-		
	3. Engagement	0.017	0.801**	-	
	4. Learning Outcomes	0.210	0.347*	0.362*	-
VR	1. Spatial Ability	-			
	2. Flow	0.077	-		
	3. Engagement	-0.048	0.652**	-	
	4. Learning Outcomes	0.010	-0.126	0.030	-
Total	1. Spatial Ability	-			
	2. Flow	0.093	-		
	3. Engagement	0.031	0.714**	-	
	4. Learning Outcomes	0.125	0.156	0.234*	-

Conclusion

In this study, we examined the possible effects of using VR learning for complex statistical concepts requiring spatial abilities. In our experiment, we also tested for possible effects of user engagement and flow. Although we did not observe any direct effects of VR on learning outcomes, the results show that the use of VR leads to a higher user engagement, thereby contributing to the learning experience. In a follow-up study, we will test the VR application in a real statistics classroom. Next to that, in our future research, we aim to explore the added value of increased interactivity in the VR environment. Furthermore, the use of VR learning methods versus traditional methods over a longer period of time can be investigated.

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An Augmented Reality Based Application with Haptic Feedback for Ventricular Puncture Procedures in Neurosurgery

Sergio Teodoro-Vite[1], Isaac Tello[2], César F. Domínguez-Velasco[1], Jessica Alatorre[1], Salvador Pérez-Lomelí[1], Víctor Alcocer-Barradas[2], Miguel A. Padilla-Castañeda[1],*

[1]National Autonomous University of Mexico, Mexico City, Mexico
[2]Mexican National Institute of Neurology and Neurosurgery, Mexico City, Mexico

Corresponding author: miguel.padilla@icat.unam.mx

Keywords: Augmented Reality in Neurosurgery, Medical Training, Surgery Planning

In modern medicine, training methods are changing due to ethical and legal concerns for patient safety, the difficulty of working with human cadavers, restrictions on practising time, the surgical complications of inexperienced residents and the cost related to operating room utilisation (Alaraj et al., 2011). These aspects have forced to medical residency programs to innovate and find new ways of teaching and in turn shorten learning curves. The new immersive technologies of virtual reality and augmented reality (AR), are allowing the training of surgical skills using simulated environments, which provides trainees with an internal view of the patient without the need for invasive procedures (Zhu et al., 2014).

Neurosurgery requires special skills and abilities, which involve subtle touch gestures as well as an accurate spatial perception in combination with adequate knowledge of the head anatomical structures, to be able to perform basic and complex surgical procedures (Hooten et al., 2014). Ventricular derivation procedure consists of the placement of an external catheter in the ventricles of the brain to drain excess fluid, reducing the intracranial pressure. It is usually used for the treatment of intracerebral haemorrhages with intraventricular extension, subarachnoid haemorrhages, traumatic brain injury, or bacterial meningitis. It is considered that the procedure was correctly done when there is spontaneous flow through the catheter (Schirmer et al., 2013).

This work presents the development of an AR-based system for ventricular catheter placing for training purposes. The general concept consists of the presentation of an augmented scene in which the resident can interact with a physical reference and be guided with a 3D view of the ventricles, reconstructed from computer tomography (CT) images.

Materials and Methods

AR-based application, shown in Figure 76, consists of a vision-based configuration composed by a camera sensor, a QR code target as a spatial reference, a 3D Systems TouchTM device for haptic feedback, a 3D printed cranium for physical reference and application software to display an augmented scene.

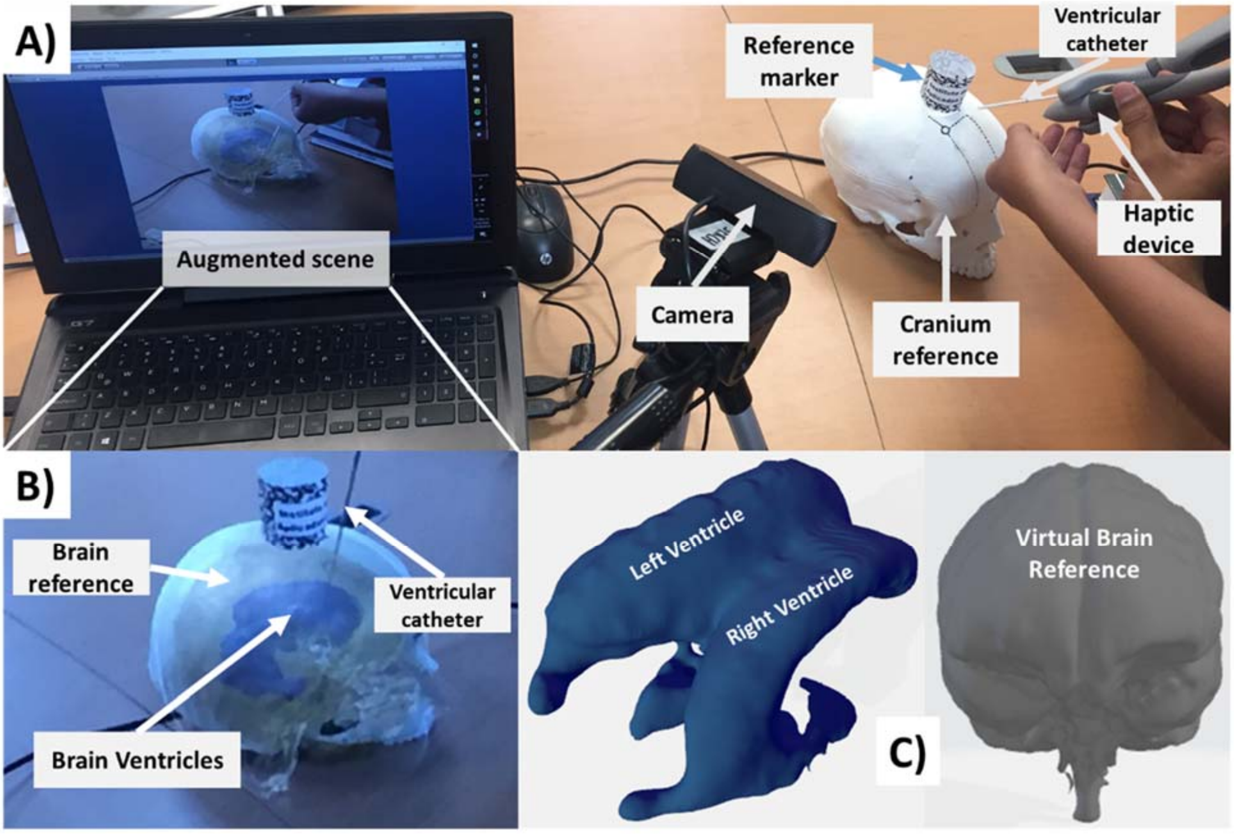

Figure 76. Ventricular Puncture AR-based setup. A) Vision-based configuration using a physical reference (3D printed cranium) with haptic feedback interaction. B) Augmented visualisation, virtual models, registered on the reference model. C) 3D virtual models from a patient-specific reconstruction.

AR architecture is composed of four main modules: sensing, registration, haptic interaction and visualisation. In sensing phase a standard webcam is used to obtain a view of the real world, which is pointed to a 3D printed model of the skull with a QR code attached on top. 3D virtual models of intracranial anatomical structures were performed in two steps, the segmentation of the CT datasets, followed by the reconstruction over the resulting contours of the region of interest. The resulting surfaces were submitted to post-processing using the MeshLab (Cignoni et al., 2008) software. 3D models were refined and placed in their final position in the scene using the Blender (Hess, 2010) software, where the experimental setup was built and later exported to Unity3D engine (U. Technologies, 2019).

In the registration phase, ventricles and brain reference are virtually matched within the 3D printed skull using Vuforia development kit. A 3D Systems Touch haptic device was used to simulate and monitoring the interaction of the puncture catheter, with the physical and virtual setup, the path and the forces interaction with the rigid structures defined as cerebral parenchyma, epidendum and septum. Finally, in visualisation phase the graphic rendering is performed, in which the digital information from the real and virtual scenes is fused in a single scene in Unity3D engine.

Experiments and results

The objective of the study focused on success to correctly place the ventricular catheter with and without the AR view. A trepan is showed at Kocher's point, located by performing the following measurements: 10cm from the Nasion reference following the midline, and 3cm lateral to the midline and 1-2cm prior to the coronal suture, as shown in Figure 77. The ventricular catheter is inserted, following the anatomical references to reach the Foramen of Monro.

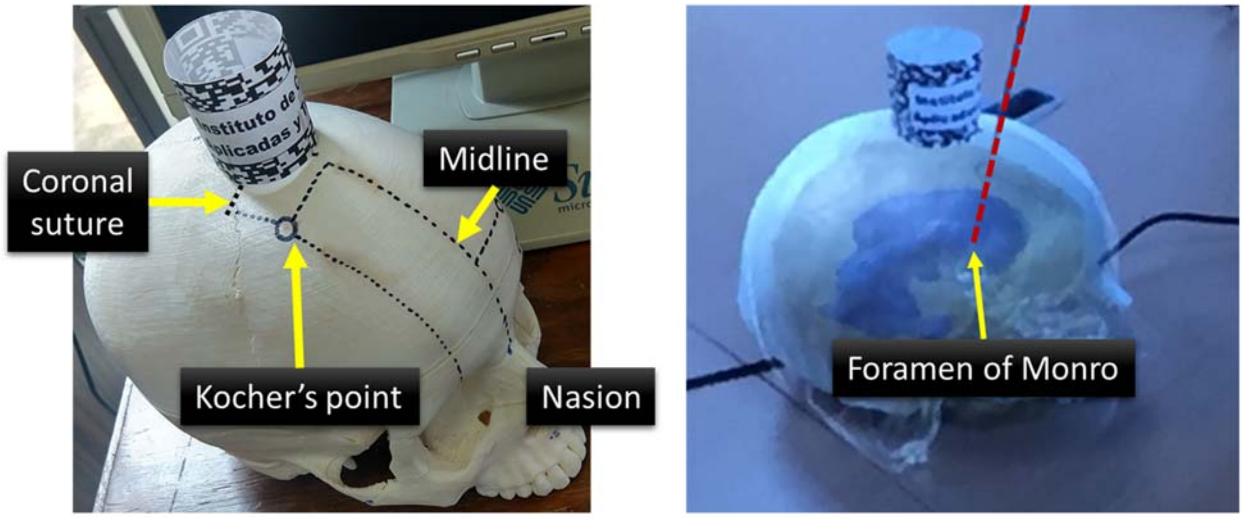

Figure 77. Physical references for experimental puncture setup.

Hydrocephalus case was tested. A series of four-stage experiments were programmed for each user: familiarisation, first tests, punction with AR view and punction without AR view, keeping the anatomical relationships.

Six first-year neurosurgery residents participated in preliminary tests. We measured the number of attempts to obtain a successful puncture by using the virtual ventricular model and the puncture guided only by anatomical references. The success rate using the AR view was 100% but removing the augmented view and directing the puncture guided by anatomical references, at the first and second attempt without this seen, 16.6% succeeded, on the third attempt 66.4% and on the fourth attempt 100% had a successful puncture.

Conclusions

The AR-based system presented for simulation of ventricular punctures has a great potential as a training tool. Furthermore, experimented neurosurgeons suggest that this kind of technologies can be used for surgery planning and even trans-operative stage. In the future, other procedures, like endoscopic cranial base surgery, craniotomy site marking, stereotactic and functional neurosurgery can be tested using the methodology described.

Acknowledgements

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Demos

Haptikfabriken Polhem – A New 3D Haptic Device

Jonas Forsslund

Haptikfabriken & Forsslund Systems AB

Corresbonding author: jonas@forsslundsystems.com

Keywords: Haptic device, force feedback, force-reflecting

In a public pre-view, a new spatial (3D) grounded haptic device named Polhem is introduced and demonstrated. With an all-metal structure it is equipped to compete with other high-quality devices while reducing cost, enabling customization and providing open source control.

Background

Spatial haptics, where the user can touch and bi-directionally interact with virtual environments with the sense of touch, has been known to the Virtual Reality community for over 20 years. The use of high-quality haptic devices has still been limited to certain applications e.g. interactive assembly (Perret et al, 2013) and surgery simulation where the relatively high cost of the hardware can be justified. However, to reach wider dissipation, the cost, especially of custom-made devices, need to be lowered. One initiative in that direction is the WoodenHaptics project (Forsslund et al, 2015), where a completely open-source haptic device can be fabricated in wood by the user and modified to explore the design space of various workspaces, force qualities and materials, and to tailor it to different applications. To create a professional, durable device suitable for end-users, significant redesign is however required.

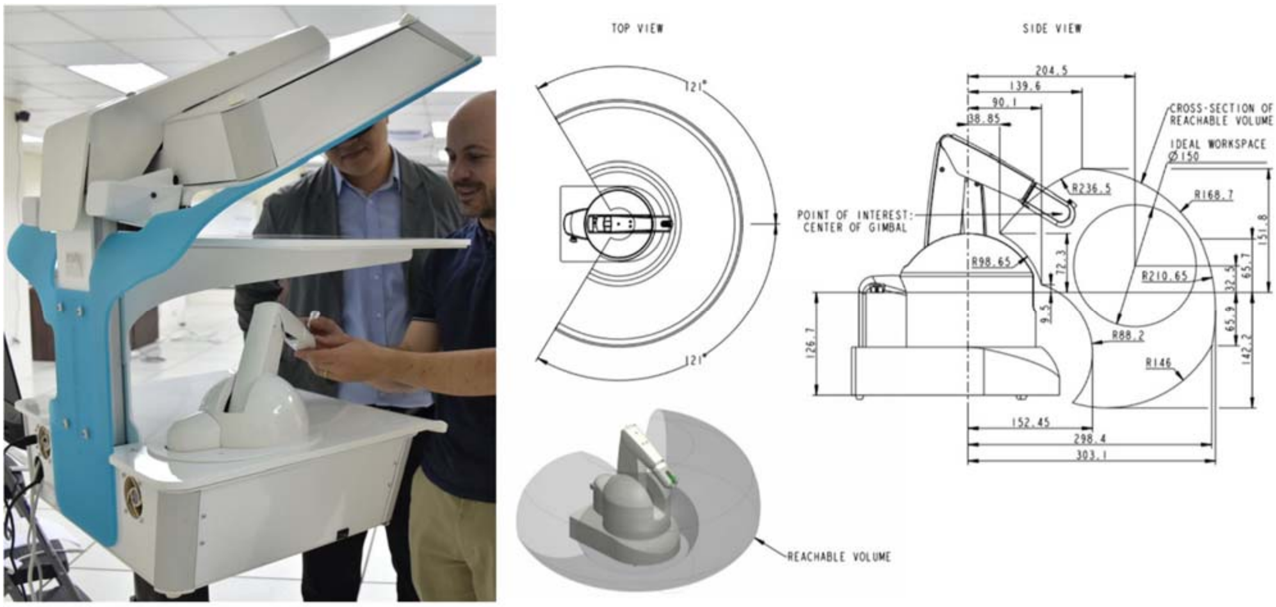

Figure 78. Left: Polhem haptic device used in the context of the oral surgery simulator Kobra.
Right: Workspace.

Introducing Polhem Haptic Device

Like some of its historical predecessors (see e.g. Salisbury & Srinivasan, 1997), Polhem is an under-actuated 6-DoF input and 3-DoF output force-reflecting device. It has been designed from scratch to have several benefits that could be useful to the community: It has an all-metal structure for rigidity and durability. The relatively large motors enable high continuous forces without risk of overheating, and it can be customized without significant redesign, allowing for tailored devices with different workspaces and force characteristics. From a computer perspective it supports a full-stack open-source API and firmware, allowing for user innovation in e.g. control theory. The device is connected through USB or a Digital Acquisition Card, the later offering higher update rates (5khz+) which allows for high-stiffness applications. Finally, it is priced to compete with more expensive all-metal devices and high-end plastic-based devices.

Polhem is structurally like other serially linked haptic devices, with three motors driving first, second and third linkages respectively. The second and third motors are however being placed off axis from each other, in such a way that inertia about the first axis is reduced compared to what had otherwise been required in order to accommodate the large motors. Incremental encoders are employed on all axes, including the manipulandum gimbal, enabling e.g. continuous rotation of the manipulandum (the user handle). The standard workspace is shown in figure 1 and consist of an ideal doughnut-shape of 150 mm diameter where maximum continuous force is guaranteed to be well over 5 N. The reachable workspace is however larger, as shown by the shape surrounding the circle in the top right corner.

Future Work and Acknowledgments

There are many possibilities for future iterations of the device, to name a few: wireless connectivity, improved USB control performance and faster and temperature-controlled overdrive of motors for increased peak forces. Eventually costs will be driven down with volume production and advances in digital fabrication methods and materials.

Haptikfabriken is an initiative from Forsslund Systems AB to design and produce affordable high-quality haptic devices for multiple applications. The Kobra oral surgery simulator is also developed by Forsslund Systems AB. The author is the founder of the company.

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Demonstration of HeloVis: a 3D Immersive Helical Visualization for SIGINT Analysis

Alma Cantu, Thierry Duval, Olivier Grisvard and Gilles Coppin

IMT Atlantique - Lab-STICC, UMR CNRS 6285 Brest, France

Corresponding author: thierry.duval@imt-atlantique.fr

Keywords: Immersive Analytics - Scientific Visualization - 3DUI - Virtual Reality

HeloVis is a typical contribution to Immersive Analytics, it is a 3D interactive visualization that relies on immersive properties to improve user performance during SIGnal INTelligence (SIGINT) analysis. HeloVis uses perceptive biases, highlighted by Gestalt laws, and depth perception to enhance the recurrence properties contained in the data. Each radar pulse is represented by an object positioned on a helical scale depending on its time value. The period value can be modified by the end-user and impact the helical scale by twisting or untwisting it (Cantu & al. 2018).

As SIGINT analysis requires a correlation on several dimensions, HeloVis encodes information thanks to the visual variables of color and third dimension: radius of the cylinder (see Figure 79). Being able to differentiate values of frequency or pulse width thanks to color strengthens the cluster detection provided by the helical representation and permits to identify outliers. Using the radius to represent information increases also the cluster detection and improves the selection of clusters (Brath 2014).

3D tools offer the user direct access to the numeric value of the data (Level, Frequency, Pulse Width ...) or differences between two pulses.

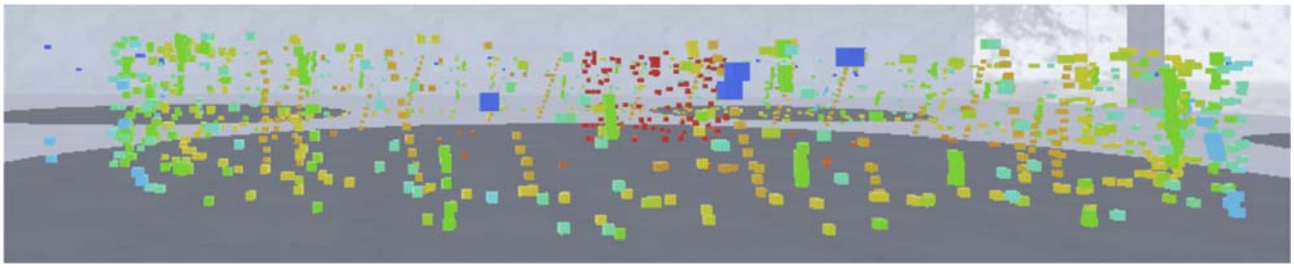

Figure 79. View encoding frequency on both the color of the pulses and the radius of HeloVis.

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The application track, posters and demos of EuroVR

Proceedings of the 16th Annual EuroVR Conference - 2019

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