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Collaborative Design in Virtual Environments

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1 Introduction

'Industry 4.0' represents an initiative and research platform of the German government and "aims to drive digital manufacturing forward by increasing digitisation and the interconnection of products, value chains and business models. It also aims to support research, the networking of industry partners and standardisation." (Klitou et al., 2017) In this context, architectural modelling and fabrication is changing dramatically and will change further due to computer and algorithm controlled and interconnected processes. Cross linking of software, plug-ins, scripts and apps – also originating from disparate fields such as product design, computer science, mathematics, mechanical engineering, civil engineering and media production – represents one of the major future tasks for architects, engineers and partners involved in the building sector. The interconnection and manipulation of software tools from various areas enables new opportunities and sets new standards for modelling, simulation, visualisation, operation of buildings and structures. Especially with this cross disciplinary tendencies in various technology driven and affected sectors, new potentials and opportunities open up in creative, social and organizational processes.

Today's teaching of CAD in architecture relies widely on the mediation of specific software in various aspects of design and production processes. Usually, it consists mostly of training courses and the interposition of applied examples. Within the context of computational tools, higher education must focus more on new working methods and processes and the independent acquisition of knowledge relevant to the advances of architecture in general. A particularly important aspect of teaching innovation is therefore the mediation of basic knowledge about functionalities, interfaces and adaptation possibilities of software used. In scientific and higher education, software and its functions must also be fundamentally questioned in order to generate an experimental environment in which new questions and solutions arise.

Taking this into consideration, the project "Industry 4.0 in Teaching" sought to impart and explore interactive, interconnected design processes with the use of virtual reality while stimulating a more collaborative design development and collaborative learning processes. The project has been divided into meshed phases. At first a comprehensive research on technical components, workshops and studies on Virtual Reality and related fields has been carried out. Then a basic technical infrastructure, such

as a mobile VR studio and a tutorial platform with software and research project documentations have been set up. Based on these foundations various student workshops, in which interactive virtual environments were developed with students have been hold. In addition and in relation to the project workshops a first prototype of a software tool for collaborative 3d-modeling in virtual environments has been developed.

In the workshops different methods of simultaneous, interactive and transdisciplinary project development, using Collaborative Virtual Environments (CVE's), have been explored, tested and applied within different tasks. CVE's are multi-user Virtual Realities, that actively support communication, collaboration, and coordination. The development of CVEs has lead to new ways for designers to collaborate and new kinds of places for designers to design (Maher, 2011). Throughout various workshops students developed interactive architectural models and simulations for VR and AR environments.

Figure 1: IVE for an immersive experience of a new lighting sytem for a historic room in Detmold developed and presented with the VR Studio of the Fellowship for Innovations in Teaching 2017/2018, student work by Eva Jörg

The project "Industry 4.0 in Teaching – Collaborative Design in Virtual and Networked Spaces" intended to seek and explore possible options of an integration of CVE's into architectural planning processes and their role in architectural teaching. At first the project range is limited to the Detmold School of Architecture and Interior Architecture and the focus lies especially on improving access to VR and AR technologies for students and providing them the necessary documentation and hardware setup to work with the respective tools. Hereby an additional focus lies on the possible distillation of alternative processes, referring to interdisciplinary exchange, networked modeling, automation and presentation of architecture through the use of VR and AR technologies.

2 Collaboration and Interaction in Architectural Design and Learning

Architecture is creation, and it is creative. But it is not only the process of envisioning space and use that needs to be of compelling spirit. The fantasy of creation does not end when the built form is finished. The user himself has a constant impact on his immediate environment, resulting in continuous transformation and interaction. This demands a process of participation and collaboration where the user is deliberately asked for input and engagement. Collaboration means here that in best case designers and users join forces in a playful act of creation.

2.1 Collaborative Design

Collaborative design follows the surging movement of more inclusive approaches to the design process. Related methods and techniques include participatory design, co-creation and open design processes. These approaches seek to bring together a wide range of people to contribute creatively in the development of solutions to design challenges. Chisholm (2016) points out that by engaging users as central actors in the design process, both short and long-term benefits arise such as: generation of better ideas (in terms of originality and user value), immediate validation of concepts, better cooperation between different people and across disciplines and increased levels of support for innovation and change.

Virtual environments and immersive technology thus serve as an additional tool to promote collaborative design by providing common ground for the visualization and manipulation of concepts in three dimensions. According to M. L. Maher (2011) "CVEs do not replace sketching on paper while co-located; they provide a different kind of environment for collaborating. Since the tools for expressing and sharing ideas are so different, we would expect that the collaboration is different". In the Fellowship for teaching innovation the aspect of collaborative development and design of spaces and objects in Virtual Environments was strongly related to the principles of collaborative learning.

2.2 Collaborative Learning

Collaborative learning is an educational approach to teaching and learning that involves groups of students working together to solve a problem, complete a task, or create a product. According to Gerlach, "Collaborative learning is based on the idea that learning is a naturally social act in which the participants talk among themselves (Gerlach, 1994). It is through talking that learning occurs."

There are many approaches to collaborative learning. Underlying these are assumptions identified by Smith and MacGregor (1992) when they state that learning is an active process which requires a challenge for learner to actively engage. Learners also benefit when exposed to diverse points of view and social environments; especially collaborative learning environments where they are challenged socially and

emotionally when engaging with peers. The fundamental goal of this teaching approach is to "shift learning from a teacher-centered to a student-centered model".

2.3 Collaborative Virtual Environments (CVEs)

The application possibilities of Virtual Reality (VR) and Augmented Reality technologies in industry, trade and the private sector is constantly expanding. There is continuous improvement of hardware technology happening at the same time that software applications and interfaces open up new possibilities for the immersive spatial experience of environments and objects in addition to the networking of different actors and processes.

VR and AR give users the opportunity to interact with pictorial, model-based information and to put themselves emotionally into places and situations through highly immersive representations. This can be applied in the final presentation and communication of a design or concept, but also already in various stages of a design process.

The rapidly advancing capabilities of software and hardware to transmit and link (visual) information in "real time" expands the applications of VR and AR beyond that of mere representation to also connect places and people more directly and make it possible to intuitively exchange ideas and experiences even over great distances.

Finally, similarly to Alan B. Craig's (2009) perspective that "Virtual reality is a medium, a means by which humans can share ideas and experiences", the capabilities of AR and VR can be harnessed for the specific objective of supporting collaborative design processes. Environments designed for this purpose are designated as Collaborative Virtual Environments (CVEs) and have been summarized by Nobuyoshi Yabuki (2011) as "a form of environments where multiple users, whether remote or not, can collaboratively develop and control virtual 3D models, using advanced information and communication technology (ICT).

2.4 Interaction and play in learning and design

> "The act of playing is a process of learning, of taking over responsibility while being inherently creative and joyful. Playing means direct interaction with the environment, personal engagement and building knowledge. While playing children learn and develop social and emotional behavior it also empowers them to express themselves and their unique identity." (Dattner, 1974)

A basic foundation for learning is interaction. User Interaction (UI) plays an increasingly strong role in the development of industrial, product design and many other technology affected or driven disciplines. Today Information Technologies offer a wide range of networking possibilities and direct access to technologies that partly have been exclusive (e. g. CNC production / 3D printing etc.). Ralf Reichwald (TU Munich) and Frank Piller (RWTH, MIT, Innovationsforschung) write in their book "interactive value creation: Open Innovation [...]" about development potentials through the "inter-

active integration of customers into the value creation process of a product". The comprehensive application of digital technologies plays a key role here.

But digital interfaces and software tools will not only set new standards to work. Learning will be an increasingly constant part of professional careers in the context of rapidly developing and changing technologies. Hereby, networked, easily and quickly accessible digital learning environments for education and training, experimentation, documentation and exchange of knowledge and, in particular, collaboration play a key role (Borrmann, 2015).

In this context the Fellowship project focused on collaborative design and learning, a form of interaction in which the people involved acquire knowledge and skills jointly and in mutual exchange. Ideally in this process all members of a group are equally involved in the learning process and share responsibility. These aspects must be promoted by digital learning environments such as virtual spaces, intuitive user interfaces and the simultaneous processing of digital objects and models. The main focus of the Fellowship project lies on collaborative 3D modeling in virtual and immersive environments.

3 Fellowship Project "Industry 4.0 in Teaching – Collaborative Design in Virtual Spaces"

Building on experiences already garnered in various collaborative learning and teaching projects (Sachs, 2019) the Fellowship project explored the application of VR and AR technologies in design development and modeling environments in an educational context. The teaching innovation had to be developed by the transfer of previous strategies of collaborative design and learning into digital and virtual environments. The main focus was, in addition to imparting and deepening knowledge of the applied technologies, to develop technical and methodological foundations for cooperative, simultaneous 3D modelling in virtual spaces and to use these in teaching. Furthermore, the project aimed to intensify the interdisciplinary exchange between people and institutions at the Ostwestfalen-Lippe University of Applied Sciences (TH-OWL).

3.1 Infrastructure and project setup

Several workshops in various elective modules in the international Master programs "Master of Integrated Architectural Design" (MIAD) and "Master of Integrated Design" (MID) at the Detmold School of Architecture and Interior Architecture represent the key part of the project. Alongside these and the infrastructure described below, various introduction courses and events with the corresponding virtual projection methods (VR/AR) have been held to successfully integrate these technologies in various study programs at the school. Furthermore the teaching innovation project provided technical and academic support in order to enable knowledge transfer initiatives with other departments and institutes of the University.

To provide students direct and easy access to the mentioned technologies, a strategy was developed for the acquisition and use of the technical equipment. Two mobile VR/AR studios were realized, each with a broad set of VR- and AR-equipment. In addition a project related youtube channel with several software tutorials (channel 'CAAD TH OWL' @ youtube), examples and video documentations of workshop and related events has been set up.

Software: Video Tutorials

Extensive video tutorials were produced as a result of software research and tests, which are available on the Youtube platform "VR HS OWL". The experiences with the use of the game engine Unity3D, the modeling program Rhinoceros and/or SketchUp as well as with the linking of different programs were passed on directly to students by the project tutors.

Hardware: Mobile VR/AR Studio

In order to simplify access to the technology, mobile VR studios have been developed and manufactured in the school's wood workshop. These consist of lockable boxes on wheels containingVR and AR glasses with various additional functions, corresponding PCs with high-performance graphics cards, fold-out screens, various control elements and user interfaces for VR applications (e. g. interactive gloves, etc.).

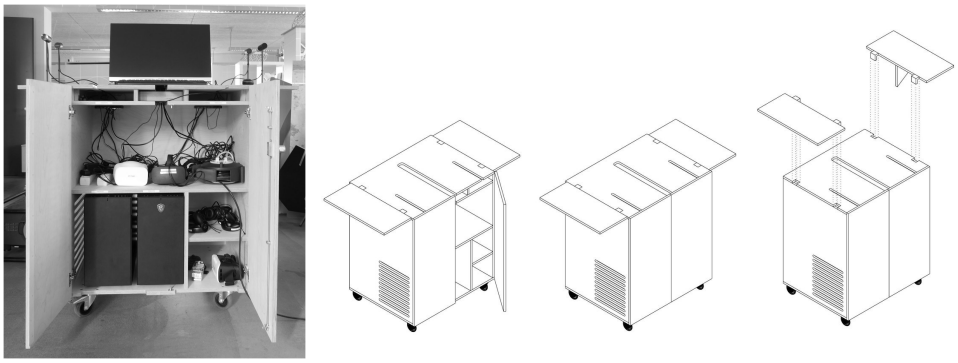

Figure 2/3: One of two mobile VR-Studios for Fellowship project for workshops and project presentations in exhibitions

3.2 Workshops and independent student projects

The project workshops have been held in cooperation with other faculties at the TH OWL, the faculty for Electrical Engineering and Computer Engineering and the faculty for Media Production and external partner Universities. The first key workshop 'Maßlos Immersiv' in 2017 has been organized and held in cooperation with the chair of BIG at the Faculty of Architecture and the "Virtual Reality & Immersive Visualization Group" of the RWTH Aachen, represented by Hannah Groninger and Till Petersen-Krauß. In 2018 script writer and movie director Justin Koch acted as moderator and partner for the second workshop 'Forensic Spaces'. This VR related workshop

series has been even continued in 2019 with Justin Koch and Till Botterweck of Urbanscreen, Bremen.

In both workshops, in 2017 and 2018, the participating students already had a profound knowledge in the areas of 3D-modeling and programming, which simplified the entry into the software interfaces for the design of virtual, interactive models with the help of so-called "game engines" such as 'Unity 3D' or 'Unreal'. In both workshops, basics in handling game engines were imparted with the help of (video-) tutorials and examples developed and created especially for the project by the CAAD team.

The workshop 'Maßlos Immersiv' focused on experimental "3D modeling" and "sketching" in virtual spaces. The aim was to explore new ways of cooperation, interaction and presentation in an immersive environment and to explore and convey the modelling process in a group work. Hereby students developed various spatial VR games in which the user had to solve certain tasks conceived in interaction with the room and individual objects. For the individual projects the student teams made use of a variety of VR- and AR-Equipment (HTC Vive/Oculus Rift/ Microsoft Hololens etc). Depending on the group and the objectives of the respective group work, different software platforms such as Rhino, Unreal, Unity3D, Virtual Sketching (RWTH) and e. g. Tilt Brush have been used for the project.

Figure 4: Testing of a virtual, immersive and interactive game environment which has been developed and programmed by architecture students of the Detmold School of Architecture and Interior Architecture

For the second workshop "Forensic Spaces", students simulated crime scenes based on the idea of a fictitious or real crime. The goal of the project was to create a virtual, immersive VR experience in which the user/player takes on the role of a detective and solves the case in a three-dimensional space filled with all kinds of interactive information and clues. The students based their project scenes on so-called "Black Stories", a

cinematic crime scene or on the basis of investigations into a real crime to create the resulting immersive 3D games.

In addition to the workshops in the Master's programs, a cooperative learning project with first semester Architecture and Interior Design students has been visualized with the VR-Studio. In the bachelor first semester CAD-project the students developed a collectively modelled city on a provided, hilly landscape. The city consists of around 250 buildings on rectangular plots of land adapted to a grid. All project files have been linked and updated continuously for an even simultaneous modeling process and for VR-reviews, so that the development of the "city" with all its buildings could be viewed and presented to all students at certain schedules during the week.

Figure 5: With the introduced mobile VR-Studios students are able to walk through their collectively modeled 3D-model which has been simultaneously developed by 250 students in the first semester of Architecture and Interior Architecture (Bachelor)

3.3 Virtual Collaborative Design Tool

During the project and alongside the workshops a software tool for collaborative 3D modelling in virtual environments has been developed and tested. The prototype of the tool allows various users to enter an immersive three dimensional space where they can model primitive objects, manipulate and adapt them collaboratively. In the VR-tool various users can interact with each other and shape, scale, create three-dimensional geometries. The object physics (physical properties like gravity or ability to collide with other objects) can individually turned on or off by each user.

In the current development phase of the tool is in an iterative development process. One next major step will be the outsourcing of the internal physics engine to a host server. This might guarantee a smoother and more immersive experience for every user due to graphic speed.

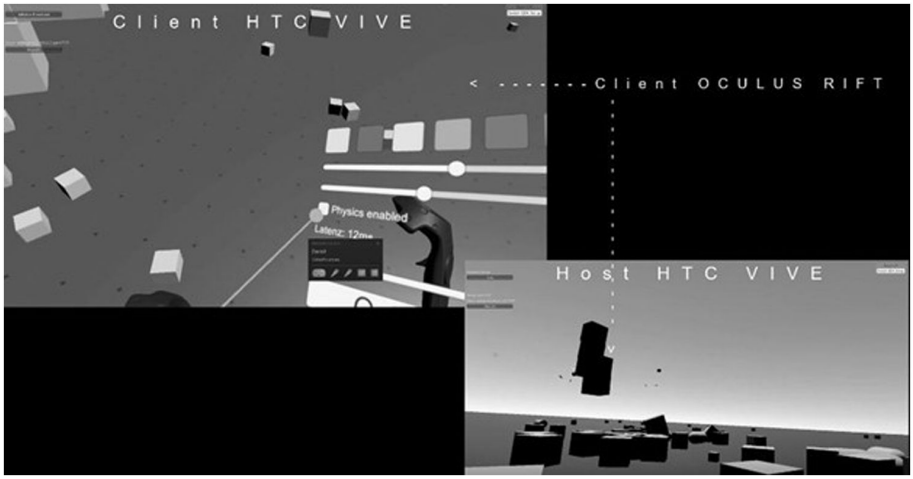

Figure 6: Screenshot of testing a two user collaborative modeling process with the self-made VR-Collaborative Modeling Tool developed within the Fellowship project

4 Review and Evaluation

By experimenting with the possibilities of 3D-modeling and virtual environments, our students learned to use various digital technologies, such as 3D-modeling, game design, rendering, animation and virtual presentation and projection in a targeted, reflective and project-related way. Hereby one essential goal was to intensify the interdisciplinary exchange between students and teachers at the OWL University of Applied Sciences which continues to happen with the VR and AR equipment that is now available to interested students, teaching associates and professors. Today the equipment can be tested and borrowed in "Fablab OWL" at the Detmold School of Architecture and Interior Architecture.

4.1 Achieved Goals

The focus of the project "Industrie 4.0" was, in addition to the implementation and deepening knowledge of the applied technologies, to develop a technical and methodological foundation for cooperative, simultaneous 3D-modeling in virtual spaces and to apply these in teaching.

The original goals of the teaching innovation can be shortly summarized as follows:

1. Sensitizing the students to VR and AR technology, the associated innovation possibilities, and appropriate working methods
2. Integration of Virtual Environments (AR/VR/MR) in design development, simulation and presentation.
3. Development of technical and methodological foundations for cooperative 3D modelling in virtual spaces

The goals set in the area of sensitization to new technologies and methods as well as the imparting of important basic knowledge for the use and handling of VR and AR technology were achieved to a high degree and even exceeded in some parts. Numerous students used the technologies independently in their own projects or final thesis projects.

The development of technical principles and methods of simultaneous and cooperative modelling in virtual spaces is still in progress. The concrete interactive and cooperative 3D modelling in immersive, virtual environments have so far only been implemented in the workshops in basic outlines or in initial conceptual approaches. Individualized software tailored to the project and data networks necessary for technical implementation are currently being developed in cooperation with an external IT specialist.

The most important step for the further development of the Fellowship project is the platform-based documentation of the work developed and a targeted combination of different competencies of partners. Here one important key point is the direct access to the documentation of the technical equipment used, including software, methods and objectives of individual projects according to the "Open Source" principle.

In a cooperation of the project 'Industry 4.0' with the project "Deeter", led by Constantin von der Mülbe, collaborative modelling in virtual spaces is prototypically tested. This development and further use of the hardware, software and knowledge is highly appreciated and should be intensified.

Figure 7: Project Deeter – a research project on the CVE 'The Virtual Meeting Room' by Constantin von der Mülbe, which has been supported by the Fellowship-project

4.2 Integration in teaching and research

An important aspect of the project's continuity has been the connection of different departments and institutes of the university. Partnerships between individual laboratories and actors have been established, particularly through impulses from the teaching innovation. They are already bearing concrete fruit in current projects, such as the planning of a 'Centre for Virtual Spaces OWL' or further cooperation projects with the 3sixty Lab (Department of Media Production) and the Living Lab (Department of Electrical Engineering and Computer Science). Furthermore, a university-wide field of action "Virtual Spaces and Digital Construction" was initiated by the university board. The field of action is headed by Axel Häusler and Hans Sachs since October 2018.

By networking the Fellowship project with external lecturers and scientists teaching and researching VR/AR, the students were able to gain important experience in dealing with digital technologies in general. They were particularly motivated by the possibility to directly apply the first basics of immersive virtual projection methods, to experience them up close and to actively participate in shaping them with the introduced software tools and provided hardware infrastructure.

5 Conclusion

This article has described the main activities within the Fellowship project "Industry 4.0 in Teaching – Collaborative Design in Virtual and Networked Spaces" in the context of the Collaboration and Interaction in Design and Learning. It has been highlighted that the further development of CVE's and IVE's in an architectural context will play a significant role in the future development of design, development and fabrication processes. The direct interaction with and within virtual environments or objects, the simultaneous connection of design and development activities of different users is already uncovering new strategies, cognition and even aesthetics in architecture. Of course the impact of such development applies not in first place to architectural design and building practice. In general it reveals various new ways to mediate and interconnect information, processes, people, machines and things.

In architecture CVE's and IVE's need to be further explored, developed and integrated into software-based planning and modeling tools. The workshops of the Fellowship project have not only highlighted the high potential in the integration of Virtual Environments in the design process. They have also pointed out the importance of an intensified interconnection of disciplines. Especially in academic education and research various aspects and phases of planning processes must be explored, questioned and further developed. Emerging concepts, strategies and approaches on CVE or IVE integration should then ideally be documented and structured in exchange- or open databases or progressed as open source software. The software tools or at least parts of it should be easily applicable and exchangeable across creators, institutions, disciplines and platforms.

In the context of interaction, there are many possibilities for the design of new teaching concepts and strategies in the context of VR and AR. These need to be further developed in experimental research, directly integrated into teaching and tested iteratively.

The article and the referred project have not constituted an extensive software development, nor the workshops have led to a comprehensive teaching or modeling methodology that replaces current sequences in the development or education of architecture. The project rather intended to seek and explore possible options of an integration of CVE's into architectural planning processes and teaching methods.

In a next step, the project range needs to be extended regarding the interconnection of disciplines but also in terms of the technical infrastructure. As VR and AR technologies distillate as key interfaces and projection techniques in various fields this development must be institutionalized. The equipment, technical expertise and evolving methods also have to become accessible and well documented. The 'Centre for Virtual Spaces OWL' represents one key step in a row of developments where technological knowledge, conceptualization, design and IT skills will have to be intertwined in order to think, create and test new methods of realizing projects and things – not only in architecture.

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Figure 1: Joerg, Eva (student at TH OWL). (2017) *IVE-Schloss-Detmold*
Figure 2: Sachs, Hans (Professor for CAAD). (2017)_*VR-Studio-Detmold*
Figure 3: Mena, Tomas (CAAD assistant). (2017)_*VR-Studio-Detmold*
Figure 4: Karuzys, Mathias (CAAD tutor). (2017)_*Testing of a virtual immersive and interactive* game environment
Figure 5: Karuzys, Mathias (CAAD tutor). (2018) *CAD module Bachelor project: Resilient City in VR*
Figure 6: Karuzys, Mathias (CAAD tutor). (2018) *Screenshot prototype CVE software-tool*
Figure 7: Karuzys, Mathias (CAAD tutor). (2018) *Screenshot project Deeter*

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