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Using Immersive Technologies and Digital Twins for Interdisciplinary Teamwork in Architecture, Engineering and Construction

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Abstract. Immersive technologies have a very large potential to enhance the interdisciplinary teamwork in engineering teams, because they provide a way to visualize geometry data of products, technical systems, and buildings in their natural perspective. The visualization helps the teams to communicate in a better way and find errors in the data, even before any physical object was built. Industries like Automotive are already widely adapting these technologies to enable close collaboration between the departments of design, engineering, and production to reduce error rate in their projects. This article describes the possibilities of integrated immersive technologies and the using of digital twins in Architecture, Engineering, and Construction (AEC). These possibilities are the first results of a research project that aims to look at the entire life cycle of a building and identify potential use cases for digital twins and technologies like virtual reality and augmented reality throughout all stages of the life cycle. The goal is to integrate all participants of the construction process in one communication platform. One focus of research are the immersive assistance systems for construction workers and how working instructions can be generated for example to locate drilling positions automatically for various installation tasks as 3D Data. The aim of the project is to support the employees digitally in their tasks and to reduce the errors due to the 2D drawings traditionally used in the construction industry.

Keywords. Virtual Reality, Augmented Reality, Digital Twin, Transdisciplinary Collaboration, Assistance System

Introduction

As building projects are becoming more complex, there is a rising number of experts within the life cycle of a building from planning to demolition [1]. Especially the need for more sustainable buildings is a driver of complexity, since the buildings need more technology like intelligent building equipment to balance energy consumption and still provide a comfortable surrounding for their users [2]. Especially the German Construction industry is known for the division of labor as well as the associated strong competences in all subareas of expertise [3]. However, the strong fragmentation of competences leads to an increasing number of difficulties, as the complexity of a project increases [4].

Immersive technologies are already widely adapted within the automotive and manufacturing industries and have proven to lower the barriers for interdisciplinary collaboration, because they provide a very natural perspective for their users, what enables an efficient way to convey technical information across a diverse group of people [5]. This article is meant to present the first results of a new public founded research project in Germany, that started in January 2023. The project is meant to explore the usage of Extended Reality (XR) technologies and Digital Twins within the construction industry to enable a more efficient way of collaboration between all stakeholders of a building project. In the first step, the researchers decided to analyze the entire lifecycle of a building and come up with ideas how XR technologies could support and improve the processes. Then, taking into consideration what kinds of use cases are already widely explored, the goal is to identify new use cases of digital twins and immersive technologies in the construction industry. This paper will also describe the first experiment within this new research project to use a modern Augmented Reality Headset (Microsoft Hololens2) to support construction workers on site. It marks the beginning of a 4-year research project with more developments and experiments to integrate immersive technologies into the construction workflow.

1. Relevant work

Using Extended Reality (XR) technologies for Engineering purposes is an already widely researched project. However, as stated previously, the usage within the automotive and manufacturing industry is already more prevalent then in the construction industry. Nevertheless, there have also been several research projects to explore use cases within Architecture, Engineering and Construction in the past years. In [5] there is a study on how Virtual Reality compares to traditional BIM (Building Information Modeling) for AEC (Architecture Engineering and Construction) Team collaboration using a markup tool. The authors state, that the immersive experience and VR do support the team communication, however the participants using VR needed to be guided more carefully by their team members and some users were not able to follow the conversations. [6] reviews possible use cases of extended reality in building operation & maintenance, stating that these technologies can enhance human productivity in understanding the modern building infrastructure and decision making for the future smart city. An interesting comprehensive review of Augmented Reality (AR) and Virtual Reality (VR) technologies is given in [7]. According to this study, AR is successfully used in construction project scheduling, progress tracking, worker training, safety management, time and cost management, and quality and defect management. VR has proven to be an effective visualization tool, worker training technology, safety management tool, and quality and defect management tool.

2. Lifecycle of a building and use cases for immersive technologies.

As stated earlier, the first step was to analyze the entire life cycle of a building. Since there isn't a standardized model of a building life cycle, it was defined for this research project as shown in Figure 1. The lifecycle was subdivided into the six phases planning, construction, installation, Maintenance/Modernization, Demolition and Recycling. The planning phase describes the process from the idea to the finished plans. In Phase "Planning", the building owner collaborates with architects, structure engineers and other specialist planners (e.g. Electrical, HVAC, Plumbing etc.) to plan the entire building, clarify interfaces between the trades and set up a project plan for the building process. In this phase, it is important to include all participants (also users, maintenance staff etc.) of the life cycle into the process, so mistakes that normally would show up later, can be eliminated at the very beginning. After the planning phase is finished, the construction phase begins. The “construction” phase is meant to describe the time span from the beginning of the earthworks to the finished construction of the building shell. This is followed by the installation shell, where all technical building equipment (sanitary, electrical and HVAC) as well as things like kitchen appliances, floorings and wallpapers are being installed by the according trades.

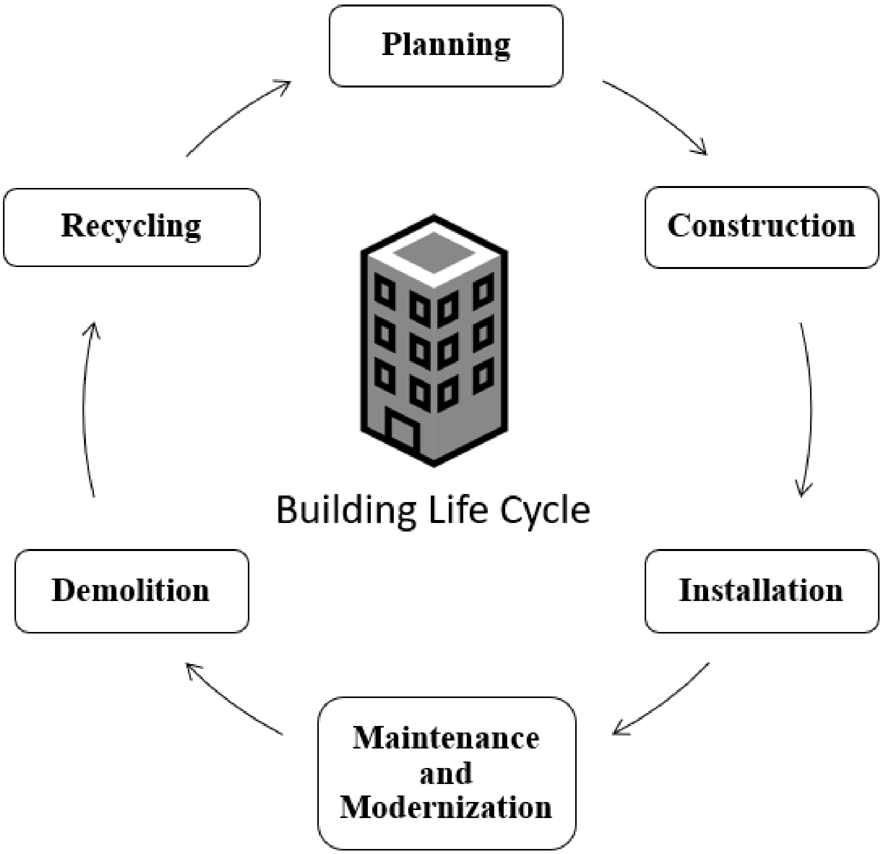

Figure 1. Building Life Cycle.

When the building is finished, it will be used and therefore needs maintenance and modernization. During this phase, basically all participants of the life cycle need to collaborate, depending on what tasks need to be completed. It is important that a building is maintained well since it should last over several decades. As time goes by, the requirements towards the building might change and so the building will need some modernization after a certain amount of time. This could be to enable more technologies to be used within the building or to make it more energy efficient, secure or user friendly. As soon as the further modernization or maintenance of a building is not economic or possible anymore, it reaches its end of life and needs to be deconstructed and recycled as good as possible, so a new building can be built. After clarification of the phases that need to be looked at, an overview of the phases, the stakeholders of each phase as well as the potential practical use cases of AR/VR and how they can improve collaboration and reduce errors of each process is given in Table 1.

Table 1. Overview: Participants and use-cases for immersive technologies within the building life cycle.

Phase	Participants	Use Cases for AR/VR
Planning	Architect, Special Planner, Owner, Craftsmen	Virtual Reality: • Display and review of the BIM model in VR by the architect and client. • Validation of the design by all other project participants • Simulation of the environment of structures (lighting, vegetation, sun) • Simulation of interior lighting • Display of samples (tiles, laminate, roof tiles) • Electrician walks the VR model with the client and inserts sockets and switch positions. • Plumber walks the VR model with the customer and inserts plumbing positions. • Drywall builder walks the VR model with the customer and inserts walls. • Kitchen planner walks the VR model with the customer and inserts kitchen furniture Augmented Reality: • Representation of the finished building on the construction site
Construction	Architect, Special Planner, Owner, Craftsmen	Virtual Reality: • Quality control by overlaying 3D scans with BIM models • Coordinate design changes Augmented Reality: • Display walls/beams etc. • Information about cutouts for windows etc. • Verification of execution and positioning by superimposing the BIM model onto the real world • AR support for excavator operators during earthworks • Display of excavated volume and construction progress via augmented reality • Display of formwork/reinforcement and house connections

Phase	Participants	Use Cases for AR/VR
Installation	Owner, Craftsmen	Virtual Reality: • Planning of modernizations of existing buildings by the use of point clouds and VR Augmented Reality: • Walk-through of shell by owner and plumbing trades (plumbing/electrical) to view and confirm details of location of connections, switches in AR. • Display of machining positions (e.g. hole position with diameter, depth, tool type) in AR • Checking and warning in case of wrong poses of tools • Precise display of machining information
Maintenance & Modernization	Architect, Owner, Special Planner, Craftsmen	Virtual Reality: • Planning of modernizations of existing buildings by the use of point clouds and VR Augmented Reality • Use of AR to display existing flush-mounted pipes to prevent drilling. • Display of BIM data (wall thickness, texture, etc.) to facilitate planning (e.g. wall penetrations, etc.) • Electrician walks the AR model with the customer and inserts sockets and switch positions. • Plumber walks the AR model with the customer and inserts plumbing positions. • Drywall builder walks the AR model with the customer and inserts walls. • Kitchen planner walks the AR model with the customer and inserts kitchen furniture
Demolition	Owner, Demolition Experts	Virtual Reality: • Facilitated planning of the demolition by walking through the existing BIM model or the point cloud in VR Augmented Reality: • Displaying installations in the house for workers so that they can be more easily found and separated from the rest of the construction debris. • Determine dimensions and volumes of materials

After setting up this overview of possible use cases, the researchers collaborated with the industry partners of the research project to figure out what kind of use case might bring a big advantage to the process. The industry partners are manufacturers of measuring instruments and power tools located in Germany. As stated in chapter “relevant work” there have been a lot of attempts to use AR and VR for planning and design verification purposes and to enable engineers to collaborate. An attempt that is really missing is how those technologies enable better communication from engineers to workers. The chosen use case was “Display of machining positions (e.g. hole position with diameter, depth, tool type) in AR”. This use case might dramatically increase efficiency of installation workers, since it has the potential to eliminate the process of reading a plan and then finding the right spot and measure, where a hole should be drilled. Instead the information could be shown on an AR-Headset and the craftsman simply needs to follow the instructions on the headset. This could improve the communication from the planning engineers to the executive workers on site, what results in a lower error rate. The first task was therefore to find out if Augmented Reality Headsets are suitable at all for construction use. Especially the precision of the projected Holograms is a concern here, because it is critical to display the machining positions accurately to the worker.

3. Accuracy of an AR Device for work instructions

In order to test the suitability of augmented reality glasses for the visualization of machining positions, for example, an accuracy study was carried out to show how precisely defined points in space can be displayed on the glasses. For this purpose, a Unity3D application was developed for the Microsoft HoloLens2 (HL2), which recognizes a predefined QR code on a test sheet using PTC Vuforia and displays six offset points on the HL2 display (see fig. 2 left). The QR code used is relatively large at 8x8 cm and has good recognizability (rich in detail, high contrast, no pattern repetitions). The experiments were conducted in a bright, clean room without natural light. Although there won't be any comparable image targets on an actual construction site, this kind of target was chosen, because the goal was not to test how accurate the HoloLens2 can detect a target, but to test the accuracy and repeatability of the holographic projection.
The experiment was conducted with a total of five people, including two who wore glasses. Each person had the task of drawing the virtually displayed points on the paper on a total of 10 sheets (see fig. 2 right). The AR glasses were taken off and put on again after five runs to ensure that they were worn correctly. In addition, the glasses were individually adjusted to the user's eyes via the calibration integrated in the HL2 before the first and sixth sheets.

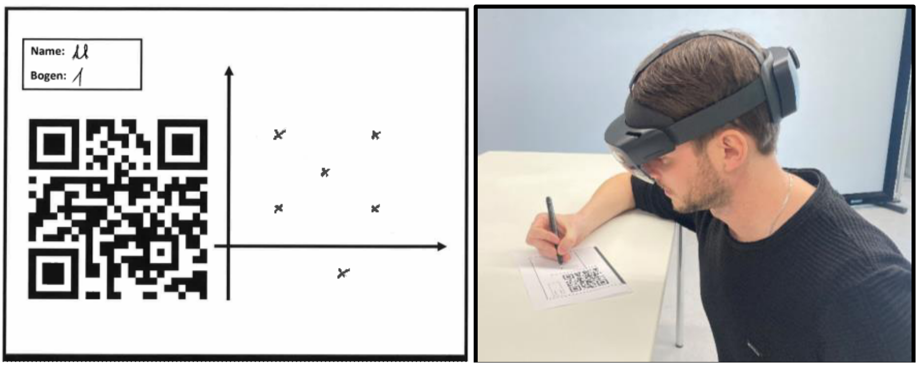

Figure 2. Accuracy study; Test sheet (left); test participant during processing (right).

The test sheets were digitally evaluated after the test to determine the distance of the plotted points to the target positions. Due to the way the test was carried out and the associated measurement accuracies, the results were divided into different, roughly defined categories, which can be taken from Table 2.

Table 2. Results of the accuracy investigation

Distance to target	0mm - 1mm	1mm - 2mm	2mm - 5mm	>5mm
Proportion of measuring points	18%	64%	17%	1%

The evaluation of the results of the accuracy investigation carried out shows that an accuracy of less than one millimeter can be achieved under ideal conditions using the hardware & software mentioned (18%). In particular, a good recognition of the image target and a good illumination of the room are important. A conclusion on differences in accuracy between glasses wearers and non-glasses wearers could not be determined.

4. Discussion

The analysis of possible use cases for the application of XR technologies over the entire life cycle of a building shows a number of different interesting areas of application for various potential users. The underlying technology differs fundamentally in some cases, which is why the use cases were discussed with industry partners. While Virtual Reality is more suitable for planning processes, assistive Augmented Reality applications have the greatest potential for the construction process itself. The biggest advantage could be the elimination of manual measuring work, as well as the elimination of mistakes caused by wrong 2D plan interpretation. The tests have shown that the HoloLens2 as a display device for machining points can achieve a precision of less than one millimeter under ideal conditions, which is defined as sufficient for the use cases mentioned above. However, the tests also show that the deviation in the system used (software & hardware) is at least 1-2 millimeters in 64% of the cases, and even more than two millimeters in 18%. In a practical use case, it can be assumed that the accuracies determined in the test cannot be achieved, since important factors such as lighting continue to worsen the result. In addition, a very good and easy-to-identify QR code was used here, which significantly improves the orientation of the ar-glasses in space. It must also be taken into account that in the experiment carried out, only the displacement of the target points in the paper-plane, i.e. in two directions, is taken into account. No statement can be made about the displacement in the third spatial direction on the basis of the test, but it is to be expected that the accuracy decreases further as a result. In summary, it can be said that the HoloLens2 can be used as a display device in a supportive manner or as a basis for the intended use described here. However, in order to achieve a sufficiently robust and high accuracy of less than one millimeter repeatability, an alternative measurement technology must be used or added.

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