ON-SITE VISUALIZATION USING BIM AND EXTENDED REALITY

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Abstract

The BIM approach is gaining significant attention in Slovenia's construction industry, soon becoming legally mandatory for publicly funded projects. Our study focuses on merging Building Information Modeling (BIM) and Extended Reality (XR), particularly Mixed Reality (MR), to improve construction processes. Focusing on the device Trimble XR10 with HoloLens 2, the visually compliance of the plans and the BIM model with the actual situation on the construction site was monitored. Additionally, a survey involving participants from local construction firms assessed user experiences with the device and contributed to analyzing advantages and disadvantages of traditional versus advanced approach (BIM and MR).

Introduction

Due to the increasing digitalization around the world, and consequently also in construction, there has been an heightened focus on advanced technologies such as BIM and XR. In Slovenia, the impending legal mandate for BIM implementation in publicly funded projects has spurred discussions on the industry's readiness and the potential benefits of integrating these technologies. The introduction of these technologies and devices faces many barriers, such as traditional mindsets, a culture of mistrust, limited knowledge of the workforce, low awareness of advanced technologies, complexity of the approach, the need to upgrade IT infrastructure, and it is therefore necessary to illustrate the benefits for construction companies. From the literature review (Alizadehsalehi et al., 2020; Safikhani et al., 2022; Sidani et al., 2021), research mainly conducted in the design and operational phase, off-site, by architects and real estate agents, and includes 3D models for visualization for owners, where VR and AR technologies predominating. AR is used during the construction phase to visualize and train workers. MR, which enables the merging of the virtual and real worlds and has the greatest potential for interactive collaboration between stakeholders on the construction sites is rather underrepresented. Our study delves into the practical implications of combining BIM and MR, specifically utilizing the Trimble XR10 helmet with the HoloLens 2 visor (*Trimble XR10 with HoloLens 2*, 2019), to enhance visualization on construction sites. Visualization is becoming a trend in the construction industry, as it enables easier understanding when monitoring construction projects and processes. With the help of advanced technologies such as AR (Augmented Reality) and MR (Mixed Reality), visualization on the construction site is more practical and efficient. An experiment was conducted on the construction site of the Retirement Home Šmarje pri Jelšah – dislocated unit Kozje, involving the creation and placement of a customized 3D BIM model with the advanced devise. The Trimble Connect AR + MR program ("Trimble Connect AR + MR," n.d.) was used for the experiment. Simultaneously, in order to compare the advanced and traditional approach in construction projects, a survey was conducted, involving 25 employees from local construction firms to capture user experiences with the advanced device and opinions on advanced approaches in construction, including the answer to the question of whether it makes sense to invest in advanced devices.

On-site visualization

Visualization

Visualization means creating a visual representation of information for easy understanding and interpretation. Visualization with the help of computer graphics and image processing enables the visual representation of forms and processes that we perceive and imagine more easily. With new technologies, immersive visualization has also appeared, which enables users to have an in-depth experience with the help of various interfaces, screens and devices. By combining enhanced sensory perception and tangible interaction, immersive visualization aims to reduce the user's perception of the real world so that their attention is focused solely on the immersive, non-real environment, thereby improving analytical and decision-making skills. This is where extended reality technologies come to the fore. By using immersive or advanced devices, it is possible to provide users with multi-sensory feedback that allows them to perceive experiences that closely resemble reality. Through sensory channels, the sense of control and realism increases for users, which usually improves the efficiency of users in obtaining data (Zhang et al., 2023).

BIM approach

Saving time, costs and improved collaboration between project participants can be achieved by collecting information about the project in one place, accessible anytime and anywhere. The above is a simplified definition of the BIM approach (Sacks et al., 2018). BIM stands for Building Information Modelling and it is a process supported by a number of tools and technologies that involve the creation and management of digital representations of the physical and functional properties of the built environment (Marc et al., 2018). In the research two dimensions of BIM, namely 3D and 4D BIM were used. 3D BIM is a geometric model of a building, which captures all the geometric data of the model and the individual building asset in an interconnected manner. The 4D BIM dimension is the 3D BIM model upgraded with a specific time dimension, with a time schedule for the construction of the building asset of the BIM model. For the purpose of the experiment, a basic 3D BIM model of the building was obtained and adapted to facilitate the treatment with the advanced device. In the practical part, a 3D BIM model over time (sequences) using MR, were presented, which already mainly belongs to the field of 4D BIM.

Extended Reality

XR is a technology that combines both the digital and the real world. It augments the physical world with digital/computational elements using advanced devices. It is divided into three types: VR - virtual reality, AR - augmented reality and MR - mixed reality. VR is a technology that creates a virtual, digital environment. AR allows digital elements such as graphics, sound to be added to the real world. Virtual elements are placed in the real environment through interfaces, enriching it, while the user still maintains contact with the physical environment. MR is a combination of VR and AR, combining the real and virtual worlds. It allows the integration of virtual elements into the real environment. This technology allows the user to interact with digital elements in a real environment while maintaining awareness and contact with the real world. MR is a great tool for good on-site visualization in combination with the BIM approach, which will be presented in the next section.

Experiment

The case

The building under consideration, the Retirement Home Šmarje pri Jelšah – dislocated unit Kozje, is designed in a semicircular form, with three floors and comprises 2555.47 m^2 of net usable floor area. The foundation slab, the intermediate floor slabs and external walls are of reinforced concrete. The internal walls are of brick construction. All partition walls in the building are dry-walled - a system of two-layer plasterboard panels in a metal substructure with mineral wool insulation. The roof structure is a reinforced concrete panel. The building is designed to accommodate 49 residents. It is designed as a zero-energy building according to the Design&Build principle. The 3D BIM model of the building is presented in Fig. 1.

Figure 1: 3D BIM model of the building

3D BIM model preparation

The 3D BIM model of the building in question contains only the structural elements and interior fittings, without the necessary installations, with the focus on the individual structural elements when monitoring the progress of the work on site with the advanced device. For further consideration of the building model and placement in the space, the model was scaled down as the full model file was too large to export and use on an advanced device. For the purpose of this paper, the limitation is given to the first floor and therefore all unnecessary elements have been deleted in the 3D BIM model. The ArchiCAD program was used to edit the model. For greater visualization or transparency of the layout of the 3D BIM model on the location in a 1:1 scale, the mezzanine panels with the terrace were also removed. The other elements on the first floor were preserved. The lift shafts are visible in their entirety, as they were created individually as one element. Fig. 2 shows the adjusted 3D BIM model of the building's first floor displayed in the Trimble Connect program.

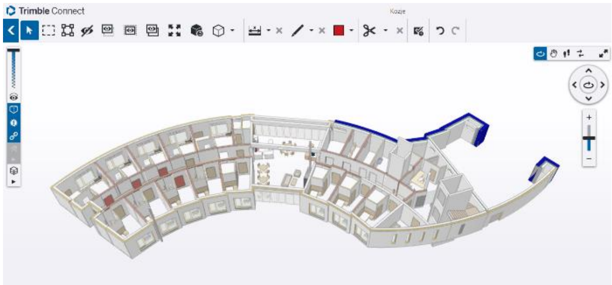

Figure 2: Customized 3D BIM model of the first floor

Equipping a 3D BIM model with a QR code

To facilitate the placement of the 3D BIM model in the real environment, a QR code or marker needed to be generated using the Trimble Connect software tool. The software generates a unique QR code, which connects to the advanced device while using the application Trimble Connect MR+AR. One or more QR codes can be generated for a single 3D BIM model of a set of elements or an object. For an easier determination of the location of the sheet with the QR code on the construction site a starting point on the 3D BIM model was chosen (presented in Fig. 3).

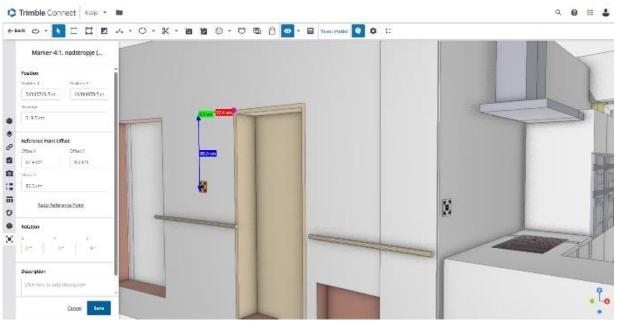

Figure 3: QR code locations and determining the starting point

The QR codes were printed in 100 % custom ratio and attached to selected locations on the object (see Figure 4). When placing the QR code on real elements, it is important to correctly determine the starting point, which was predetermined in the software, and place the lower left edge of the QR code exactly at this point. This requires a flat and clean surface to attach the QR code, taking into account orthogonality and using a quality mounting agent.

Figure 4: Attached QR codes on the building

Model placement in a real environment

An advanced device to carry out the experiment on site was used. The Trimble XR10 with HoloLens 2 is an advanced device that uses extended reality technology to bring digital elements from the screen into the physical world and clearly present the work of all participants, allowing projects to be completed on time and at no extra cost. It is the product of a successful collaboration between Microsoft Corporation and Trimble Inc. The device consists of two parts (see Figure 5) the Trimble XR10 protective work helmet and the HoloLens 2 visor.

Figure 5: Trimble XR10 with HoloLens 2

The Trimble Connect AR+MR application allows you to place a 3D BIM model into any environment in several different ways, in different sizes and views. It can simply open the model in the application and place it in any place, in any scale. Figure 7 illustrates the basic display of the entire 3D BIM model of the building on the construction site. For better accuracy and faster placement of the model on the construction site, the "Marker" subcommand was used, to scan the previously prepared and pasted QR code on the building. The model placement process is shown in Figure 6.

Figure 7: Display of the entire 3D BIM model of the building with its surroundings on the construction site

The first step was choosing the subcommand “Marker” in the menu of the advanced device. Then, with the help of the camera integrated in the advanced device, the QR code was scanned and uploaded a digital 3D BIM model using MR technology and projected it in a real environment. This allowed us to place the model on a real object at 1:1 scale. In the process of integrating the 3D BIM model at the construction site, occasional inaccuracies arose in projecting and aligning the model with the real structure, resulting in maximum deviations of 10 cm, when aligning along a non-straight wall. The minimal misalignment was observed when positioning the model using a QR code.

Preparation of the Sequence

Sequences in the Trimble Connect desktop application were created to show the construction phases of each structural element on the first floor of the building. One sequence will be presented in more detail in a selected room on the ground floor of the building in question (presented in Fig. 8). The sequence consists of seven steps (Fig. 9-15) and shows the construction of the vertical structural elements of the room in question according to the prepared 3D BIM model. The first step is the construction of the external walls, the second step is the construction of the internal brick walls, followed by the third step of the plastering. The fourth step is the installation of the internal panels of the internal drywall for the bathroom, the fifth step is the installation of the insulation on the drywall, the sixth step is the construction

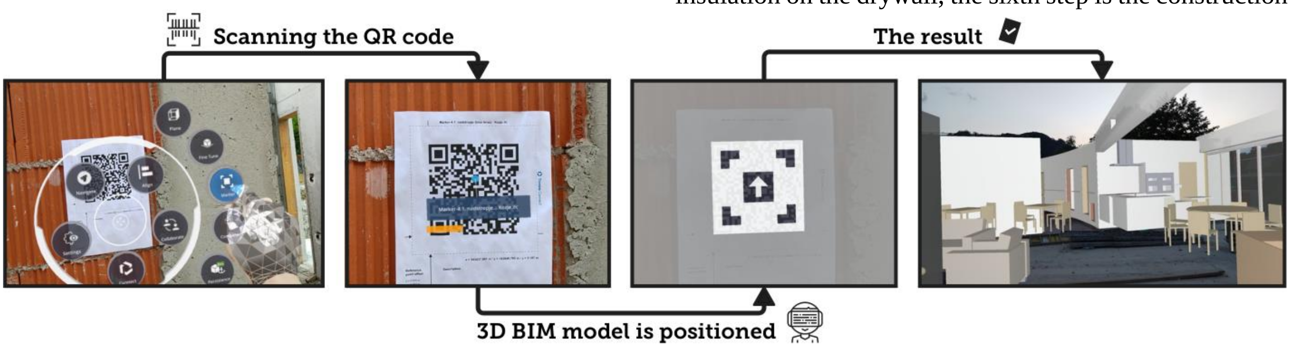

Figure 6: The process of placing a 3D BIM model with a QR code in a real environment

of the external panels of the internal drywall and the last step is the fixing of the tiles on the drywall in the bathroom. The sequence does not take into account the additional steps in the construction of the external wall (formwork, concreting, dismantling formwork), but is shown in one step, as "the construction of the external walls" (Fig. 9). The selected elements are shown and labelled individually in the figures, step by step, while the remaining elements are hidden. If a sequence were to be played, each previous element would remain displayed. For better understanding, each step and its corresponding element has been marked with a specific color, e.g. walls are marked in green.

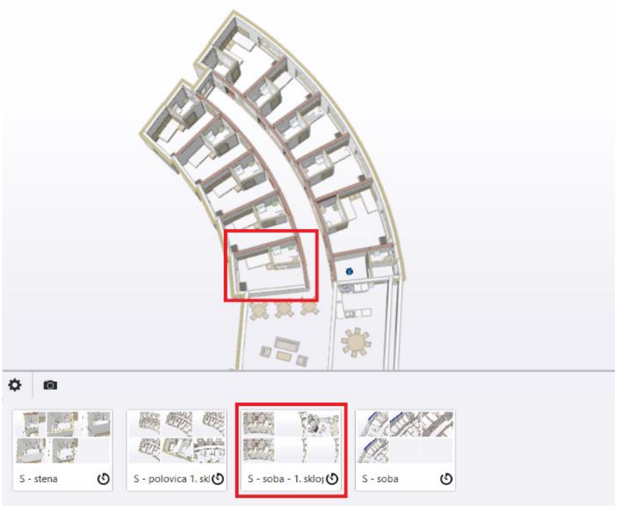

Figure 8: Selected room and sequence in the 3D BIM model

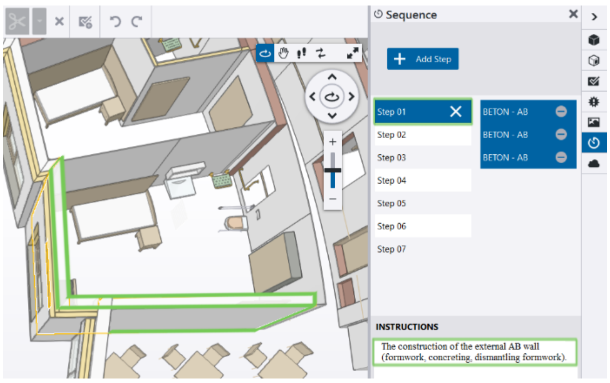

Figure 9: Step 1

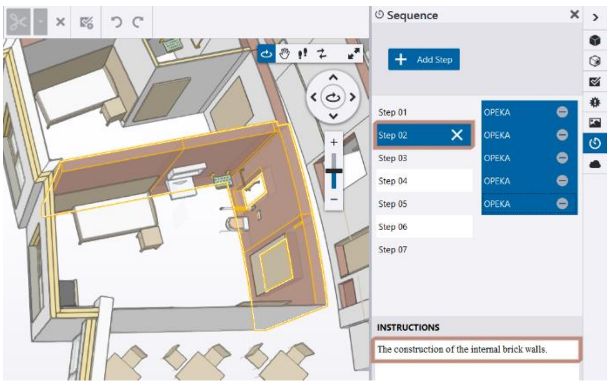

Figure 10: Step 2

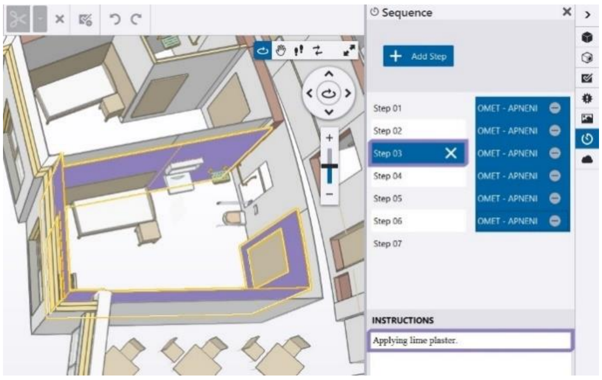

Figure 11: Step 3

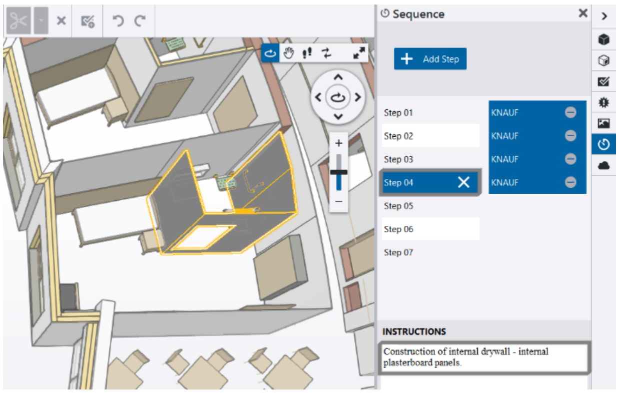

Figure 12: Step 4

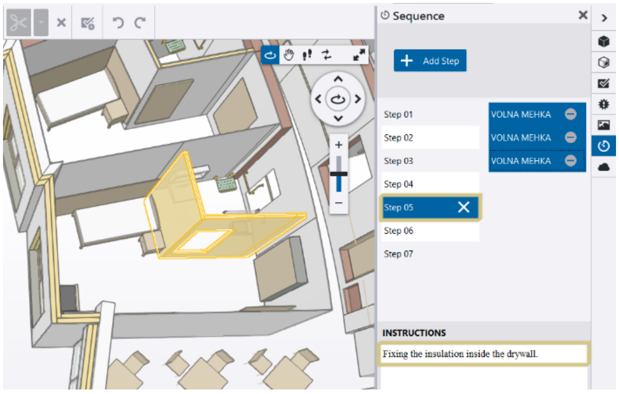

Figure 13: Step 5

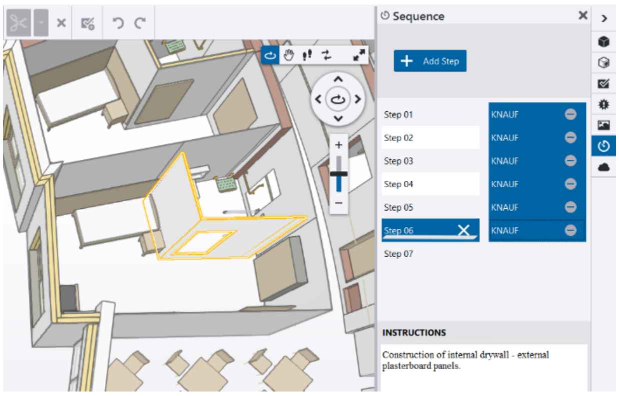

Figure 14: Step 6

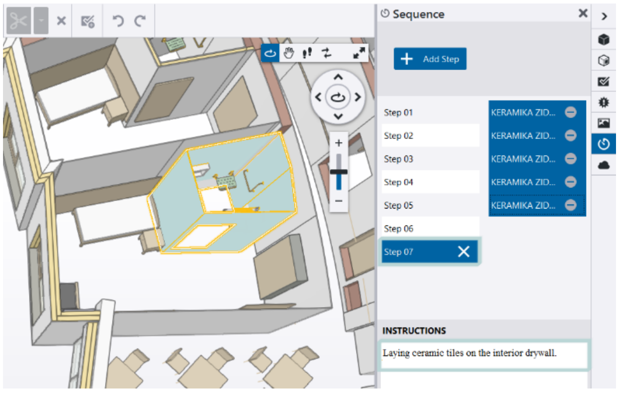

Figure 15: Step 7

On-site sequence display

In the previous subsection Preparation of the Sequence, the construction sequence of vertical construction elements of one room on the first floor of the building was demonstrated. In the following, the sequences will be shown on a 3D BIM model with the advanced device on the construction site.

The sequence is displayed in a real environment by selecting the command "Sequence" in the basic menu of the Trimble AR+MR application and then selecting the desired project, model. After the basic placement of the model, the "Collaborate" command and the "Sequence" subcommand were selected. A window appeared showing the steps of the selected sequence. You can move the steps manually or play the sequence. Visualization of the individual steps of the sequence on the construction site is shown in Figures 16-22 below. Each displayed 3D element of the sequence step is colored with a specific color, as in the previous subsection. On the model, a hole in the bathroom is present where the purpose is to show the area where the installation will take place and be kept. This hole was subsequently made on the building, but in a smaller size. It is also visible that the balcony and entrance doors in the model are placed higher than the actual floor, as the remaining materials and elements on the floor have not yet been installed.

Figure 16: Step 1 of the on-site sequence

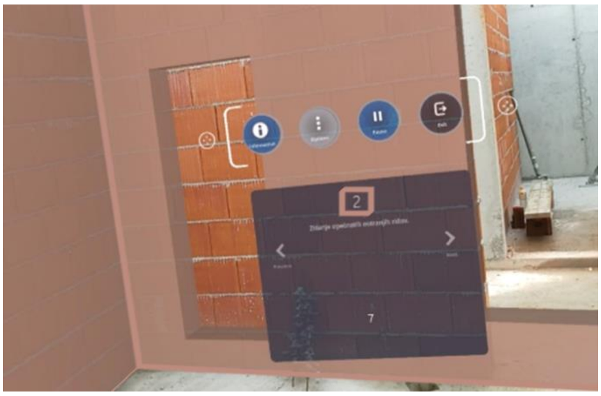

Figure 17: Step 2 of the on-site sequence

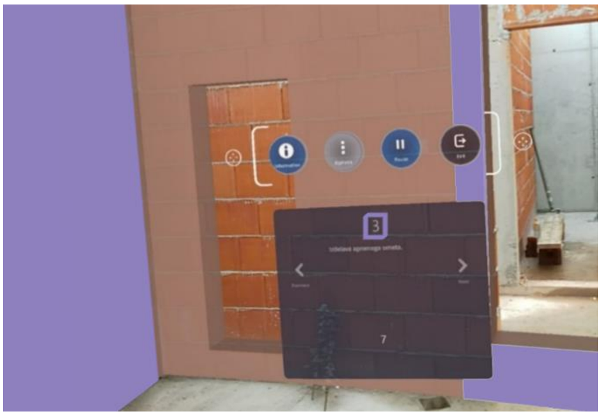

Figure 18: Step 3 of the on-site sequence

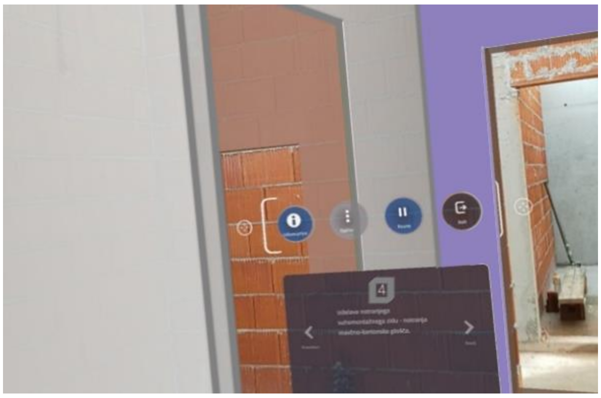

Figure 19: Step 4 of the on-site sequence

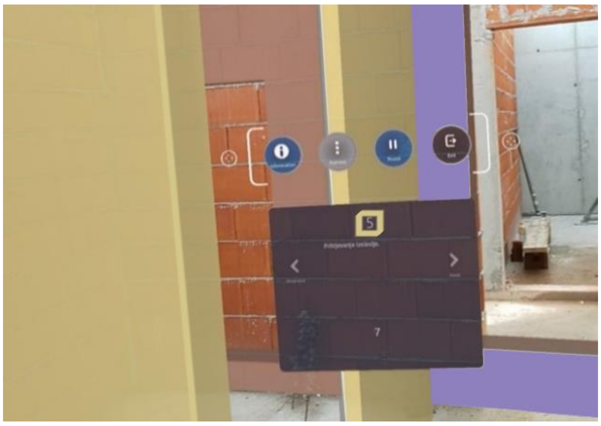

Figure 20: Step 5 of the on-site sequence

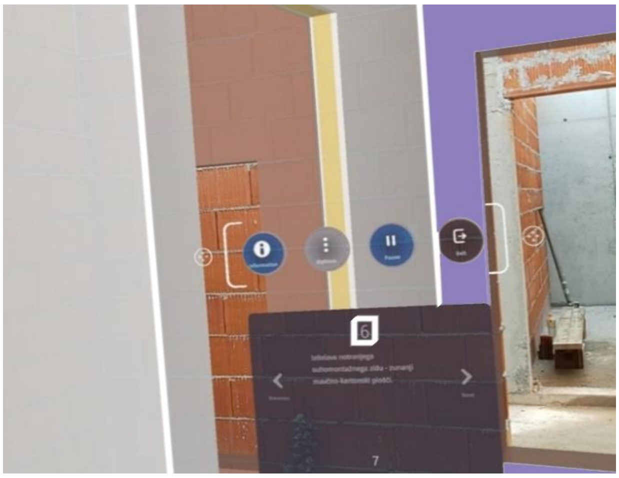

Figure 21: Step 6 of the on-site sequence

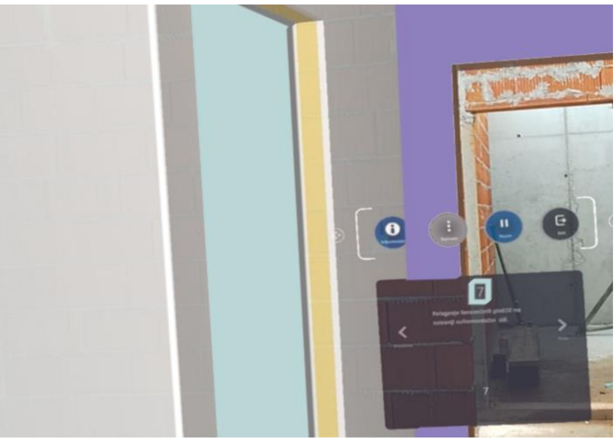

Figure 22: Step 7 of the on-site sequence

For an easier presentation and understanding of the sequence in a real environment, some steps of the sequence (steps of construction elements, without final cladding), through the construction process of the actual building, on the construction site are presented in Figure 23. These steps are: construction of the RC external walls (1), internal brick walls (2) and internal drywalls (4&6).
After the first two steps, work on the construction site continued on the second section of the first floor, where the vertical structural elements were constructed. Then the work for the installation of the slab between the floors was carried out. The next step of the sequence started after the construction of the external and internal walls on the second floor has been completed.

Figure 23: Steps 1, 2, 4 and 6 of the sequence shown with the actual object (Source: Josip Pongračić)

Survey

The traditional approach of looking at plans and monitoring progress in the field has started to be replaced by a modern approach using advanced devices such as the Trimble XR10 with HoloLens 2, which allows the projection and interaction with digital models in real time, in a physical environment. In order to gain insight into the user experience of construction employees for this device, a survey was conducted to obtain relevant information on the pros and cons of the advanced device and to determine the rationale for use and investment. For the purpose of the research, a questionnaire was prepared, entitled "The use of advanced devices for extended reality in construction projects". At the time of the experiment, there were 40 workers at the construction site who were invited to try the Trimble XR10 with HoloLens 2. 15 individuals refused to participate, while 25 took part in the survey, representing 62,5 % of those invited. The questionnaire consisted of 14 closed-ended questions and one open-ended question. For the six questions on user experience, a 5-point descriptive scale, the Likert scale, was used to better analyze the responses. The results were then processed and displayed in Excel. In the following, the findings and the analysis of the respondents' answers will be presented.
The first four questions related to the general analysis of respondents' statistics: age, education, type of employment and workplace. 25 people took part in the questionnaire, 20 male and 5 female. This can be attributed to the fact that more male workers are employed in the construction sector due to the physical labor involved. Of all respondents, 10 have completed secondary school, 5 have completed a master's degree, 3 have completed a vocational or professional higher education, 2 have completed a bachelor's degree and 2 have completed primary school. None of the respondents had completed a PhD or other course. When asked about the type of employment, the majority of respondents answered that they were in regular employment, only 4 were in student services, 2 were self-employed and 1 answered contract work.
Since the paper focuses on visualization on the construction site, the type of employment of the respondents is also interesting. In order to get as diverse answers and opinions as possible, several different professions in the construction industry are covered in the survey. Most respondents (36 %) chose the answer "Other" to the question "Job" and gave the following answers: architectural engineer, mechanical engineer, mechanical development engineer, independent purchaser, electrician, IT technician (2 persons), blacksmith and project associate. 28% of all persons surveyed were site workers, followed by civil engineers or project managers with 12%. Two persons were foremen and one person was a supervisor.
The fifth question was: Have you had any experience with VR/AR/MR devices before using an advanced device? 72% of the respondents (18) had no previous experience

of using VR, AR or MR devices prior to using the Trimble XR10 with HoloLens 2. This was the first time that the majority of the respondents had seen and used an advanced device in person and were familiar with new technologies in construction.

Table 1 below shows the results of the level of agreement with the statements related to the respondents' user experience using the Trimble XR10 advanced device with HoloLens 2. The statements related to the ease of use of the advanced device, the comfort of wearing the advanced device, how satisfactory the display and sound is, whether the device responds well to commands, and the perception of the usefulness of using the device on the construction site. Each statement was rated on a 5-point descriptive scale, where I don't agree at all, 2 is I partially agree, 3 is I neither agree nor disagree, 4 is I agree and 5 is I strongly agree. The columns for each statement show the number of respondents and their proportion of each answer, the level of agreement.

Table 1: Respondents' user experience with the advanced device

5-point descriptive scale	1	2	3	4	5
	Number (%)	Number (%)	Number (%)	Number (%)	Number (%)
It is easy to use.	0 (0 %)	2 (8 %)	8 (32 %)	**10 (40 %)**	5 (20 %)
It is comfortable to wear.	0 (0 %)	1 (4 %)	5 (20 %)	**12 (48 %)**	7 (28 %)
The display is satisfactory.	0 (0 %)	2 (8 %)	5 (20 %)	8 (32 %)	**10 (40 %)**
The sound is satisfactory.	0 (0 %)	1 (4 %)	8 (32 %)	**12 (48 %)**	4 (16 %)
Good responsiveness to commands.	0 (0 %)	1 (4 %)	5 (20 %)	**13 (52 %)**	6 (24 %)
Use on the construction site is very useful, welcome.	0 (0 %)	0 (0 %)	7 (28 %)	7 (28 %)	**11 (44 %)**

The majority (40%) of respondents found the use of the advanced device to be straightforward, easy, with no respondents completely disagreeing.

Regarding comfort, over half of the participants (48%) agreed that wearing the advanced device was comfortable, and 28% fully agreed.

A significant factor in device usability is satisfactory content display. Eight percent disagreed with the display quality, while 40% expressed complete agreement, indicating a prevailing positive view.

Concerning sound quality, 48% agreed that the device provided satisfactory sound, while only one person disagreed, emphasizing the importance of clear and loud audio on construction sites.

Evaluating responsiveness to commands, the vast majority (76%) agreed that the advanced device responded well to both voice and gesture commands.

The final statement, "The use of the advanced device on the construction site is very beneficial and welcome," received overwhelming agreement, with 72% fully supporting its usefulness on construction sites. Respondents generally praised the advanced device for user-friendliness, comfort, display quality, sound clarity, responsiveness, and unanimously recognized its substantial benefits for construction site use.

It should be borne in mind that the respondents had only used the device for a short period of time.

The most important and the thirteenth question was: What do the respondents consider to be the biggest advantage of using an advanced device on site compared to the traditional approach? The vast majority of respondents (17), as much as 68%, answered that better visualization is the biggest advantage when using an advanced device on a construction site compared to a traditional approach. 4 people felt that the biggest benefit was better collaboration, and 2 people chose faster construction as the answer. 1 person answered that higher accuracy is the biggest advantage, while 1 person identified it as lower cost. No one recognized greater safety as a sufficiently important factor, nor did they highlight other examples.

When asked whether they would like to use the advanced device they tested in their work, as many as 17 people out of 25 respondents expressed a desire to use the advanced device in their work. The remaining 8 people, which represents 32%, do not. It can be concluded that the advanced device left a good impression on the respondents and that they see sufficient advantages in its use.

The final open-ended question was: What is your opinion about the usefulness of an advanced device in an advanced approach in construction compared to a traditional approach? Respondents varied in their opinions on the utility of the advanced device. While some declined to respond, the majority viewed the device as highly beneficial for on-site visualization during construction, emphasizing its role in providing a clearer understanding of the project, facilitating control, and comparing the actual state with the planned one. Two respondents highlighted its usefulness in swiftly resolving issues on-site. Improved communication between clients and contractors emerged as a significant advantage, aiding those struggling with 3D visualization. One respondent favored the advanced approach, citing error reduction, cost savings, and increased profitability. However, concerns were raised about the limited presence of such devices in construction, undervaluing their potential. One respondent emphasized the device's usefulness only when all details in the model are precise; otherwise, it is deemed a waste of time. Ensuring adherence to plans and instructions was seen as crucial for successful implementation. Traditional approaches were criticized for deviations, causing delays, unforeseen costs, errors, and tensions among participants. Participants found it challenging to comment on the downsides of advanced technology due to limited experience, but highlighted high costs, potential discomfort during use, and the risk of damage as concerns. The unfamiliarity with advanced technology among participants raised questions about collaboration efficiency, potentially leading to conflicts and misinterpretations.

Result analysis

Visualization on construction sites brings numerous advantages, fostering better understanding of projects and facilitating coordinated workflow. The Trimble XR10 with HoloLens 2 proves invaluable in envisioning the final structure, understanding project elements, and determining necessary construction tasks. Its user-friendly interface and versatility contribute to its ease of adoption, with the Trimble Connect AR+MR application being central to the study. While highlighting the device's benefits, the text explores its applications, advantages, and its potential impact on the construction industry.

The advanced device offers several advantages, such as ease of use, good visualization, seamless integration of 3D BIM models into real environments, display of work sequences, improved communication, and quick access to data, and archives. The rising accessibility of such devices due to affordability and mass production signals a shift towards incorporating advanced technologies in construction, gradually replacing traditional methods.

The paper also discusses the intricacies of model placement using QR codes and acknowledges limitations, such as imprecise projections without QR codes. External factors, like weather conditions, impact the success of QR code applications, necessitating laminated codes for durability. Practical challenges include language barriers, as commands are predominantly in English, posing a hurdle for non-English-speaking construction workers.

The importance of sequences using the advanced device becomes evident for project supervisors, managers, and other participants. Creating sequences proves crucial for specific and intricate tasks, ensuring precision in the construction process. The ability to convey the work sequence aids in organizing diverse workgroups, clarifying task logistics, and addressing critical points. Adhering to established sequences promotes timeliness, well-organized workgroups, enhanced collaboration and better task comprehension.

However, challenges emerge, particularly related to the device's weight and discomfort during prolonged use. Issues arise in strong sunlight, impacting content visibility. The device's limited battery life, approximately 2 hours, poses a constraint but can be mitigated with additional batteries. Technical glitches, encountered during the application update process, temporarily interrupted the experiment, emphasizing the need for continuous software improvements and user support.

Despite initial skepticism and language barriers, worker feedback on the Trimble XR10 has been positive. The device's ability to bridge communication gaps between leaders and workers is seen as advantageous, with potential benefits outweighing drawbacks. The implementation of advanced technologies is seen as transformative, enhancing work conditions, reducing costs and expediting construction processes.

Conclusions

This paper explores the integration of BIM and XR for construction visualization, focusing on the significance of visualization, the BIM approach, XR technologies, and the device Trimble XR10 with HoloLens 2. An experiment conducted at a retirement home construction site, utilizing a customized 3D BIM model on the existing structure, provided valuable insights into the practicality of advanced technologies in construction. Despite some drawbacks, the Trimble XR10 showcased numerous advantages, emphasizing user-friendly operation, effective workflow and improved communication. The results highlighted positive responses from workers, acknowledging the benefits of advanced technology, particularly improved visualization using advanced devices over traditional approaches. The study suggests that investing in XR technologies yields significant benefits, improving productivity, communication, and project understanding in construction projects. Further research is recommended to analyze the use of XR devices under controlled laboratory conditions and to compare user experiences in ideal scenarios with actual building conditions. Validating investments in XR devices in combination with BIM approach would promote a deeper understanding of their impact on the construction industry.

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