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Investigating the Use of VR Visualization to Help Students Gaining Understanding on Pull Planning

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This research focused on assessing the effectiveness of Virtual Reality (VR) as a tool for aiding students in grasping the concept of pull planning. In real-world scenarios, professionals from various trades contribute their expertise and project knowledge to establish commitments. Students, lacking substantial industry experience, face difficulties in comprehending pull planning without oversimplification. The proposed solution was an immersive VR visualization linked to the master schedule, allowing students to visualize site conditions during pull planning exercises. The study involved grouping students and equipping them with VR headsets, simulating different trade contractors engaged in pull planning overseen by a moderator. Findings suggest that VR enhances students' understanding of pull planning and also helps them identify additional issues like logistical challenges.

Key Words: Virtual Reality, Pull Planning, Construction Education

Introduction

In recent years, the Architecture, Engineering, and Construction (AEC) sector has incorporated practices and techniques drawn from disparate industries and disciplines. Lean construction, a methodology derived from the manufacturing sector, has demonstrated its potential to elevate productivity and minimize waste generation throughout the construction process. This approach also attenuates project uncertainties due to the efficient interchange of information among different disciplines. Pull Planning allows the project team to maintain waste at a minimal level whilst ensuring the punctual fulfillment of their responsibilities. It relies heavily on the visualization of activities that were brainstormed by other project stakeholders.

Literature Review

Pull Planning Practice

Pull planning is an approach in lean concept which fosters a sense of collaboration and aims to optimize resources while maintaining product quality. The primary focus of pull planning is to reduce inventory and minimize waste. Unlike conventional planning practices, pull planning involves key stakeholders in the decision-making process.

An observational study was conducted comparing pull planning practice to common planning practice, specifically Critical Path Method (CPM) planning (Ghosh, Reyes, Perrenoud, & Coetzee, 2017). The study involved general contractors who adopted visual schedules as an alternative to the traditional Bar Chart typically utilized in CPM planning.

4D BIM

4D model was developed as a BIM dimension that incorporates time into a 3D model. This method addressed the lack of visual representation of the CPM diagram as stated in a prior study (Collier & Fischer, 1996). The 4D model enhances construction planning by enabling visual execution of construction sequences and fostering collaboration through a unified 3D model. This approach reduces misinterpretations and redundant planning, creating a more interactive and communicative environment among designers, aiding in the early detection of potential issues often missed with traditional planning software (Fischer & Koo, 1998).

Implementation of BIM in the lean process has been proposed by scholars in prior studies (Eldeep, Farag, & Abd El-hafez, 2022). Past studies indicated that the addition of visual aids improves the participants' understanding of the construction work in the planning process. In addition, the use of 4D models enables the team to incorporate constraints into the model, thus furthering the effectiveness of the coordination (Toledo, Villegas, & Mourgues, 2014)

Prior Attempts at Incorporating VR into Construction

VR hardware development has reached a point that deploying a system using readily available consumer market components is feasible.This progress has opened doors for more research in various construction aspects. In a study involving industry professionals and students wearing VR devices to investigate construction schedules, it was discovered that the intervention of VR significantly enhanced users' ability to detect errors or omissions within the building's interior (Pratama & Dossick, 2018).

Incorporating Pull Planning and VR in Education

Given the more frequent uses of lean concepts in modern construction projects, it is important for universities to prepare their students so that they don't get overwhelmed by current industry demand. Since pull planning is a relatively new concept, a different approach should be used to enhance students' learning process. Studies have indicated that VR can be used to design an immersive learning environment (Cochrane, 2016). With the availability of mobile VR that are more affordable and more accessible, the medium became the starting point of this study.

Methodology

Approach

This study was conducted using experimental approaches. A number of students were recruited to participate in the study using a prototype that was developed earlier. The students were given a set of responsibilities and tasks that they can incorporate into the pull plan. During the study, they were allowed to discuss with other students to determine what they should do next.

Tools

Navisworks Manage was chosen to display a 4D simulation for the non-VR student groups. The students were given control of the simulation, and they were allowed to navigate through the model or play the construction sequence.

For the VR intervention, standalone VR headsets were chosen. They eliminate the need for a desktop PC connection, reducing costs and setup time. Creating a prototype with Unreal Engine was preferred to avoid paid platforms, as it allows customization. This prototype also holds potential for broader applications due to retained source code.

A digital whiteboard was chosen in place of pull plan board and sticky notes. This decision was taken to make it more efficient to track the development of the pull plan. Students were provided with individual accounts that allowed them to collaborate in the shared virtual whiteboard.

Study Design

The university student tests were carried out in three stages, starting with pilot studies encompassing 22 senior students, 10 participants from overseas, and 6 graduate students. A series of simplified scenarios were created to streamline the pull planning process for university students. Students who participated gave their consent to be recorded and to provide responses to the questionnaires. Of the 36 participants, 24 responded to the questionnaires.

Study Limitations

The study tested a mobile VR prototype for pull planning, ensuring uniform experience by controlling scenario duration and role responsibilities. Students, inexperienced in pull planning, received pre-made commitments for guidance. Roles like drywall and wall finishes were chosen for their ease, avoiding overly specific ones like MEP, which had confused participants in a pilot study. VR was used for model inspections and limited collaboration, with pull planning mainly outside VR. The prototype operated on a local network due to technical constraints, preventing remote collaboration. Instead of a physical whiteboard, a digital one was used, facilitating the recording of sessions and allowing access from various devices.

Prototype Development

Software and Hardware Considerations

Previous research required VR equipment tethered to desktops, limiting participant numbers and financial viability due to hardware costs and constraints. The tethered setup also hindered multi-user interactions in one room. Recognizing these issues, researchers opted to develop a new prototype on mobile VR platforms, which were more affordable and available. These mobile devices supported native VR applications and screen mirroring, allowing non-VR users to participate through the mirrored display. For this study, Meta Quest 2 was chosen for its widespread availability and capability to display 3D models from Revit.

3D Model Development

The 3D models were acquired from an existing Navisworks project used in class exercise. The model was imported to Unreal Engine using Datasmith tool. Several optimizations had to be done on the model to make it possible to run the model in Quest 2. Proxy mesh feature in Unreal Engine was adopted to greatly reduce the number of polygon while maintaining the general shape of the model.

Study on Student Participants

The study utilized a VR prototype created in Unreal Engine 4.27 and Autodesk Navisworks 2023. Student participants were selected based on their construction scheduling knowledge, industry experience, and understanding of lean construction. Upon participation, the students were given pre- and post-experiment surveys assessing their psychological state and feedback on the tool's effectiveness in decision-making during pull planning. Participants were grouped into specialty contractor roles for a simulated commercial project, tasked with developing commitments. Uniform information was provided to all groups, with the option to create their own commitments. VR use was optional, allowing for construction sequence simulation, markups, and model navigation. The researcher led the pull planning session as a moderator.

Pilot Study

In the pilot study, twenty-two University of Washington senior students, unfamiliar with lean construction, participated in several VR tests. These students were assigned to trade contractor groups to conduct a pull plan and create commitments using their base knowledge. Without prior active involvement in pull planning, they relied on team discussions and online resources to determine potential commitments for each trade. Out of the twenty-two students who participated, ten returned their responses.

Questionnaires were distributed before and after the study to assess improvements in participants' conditions and understanding. The focus was on their physical condition, general scheduling process knowledge, and pull planning comprehension. In terms of comfort, five out of ten participants reported discomfort post-study (see Figure 1).

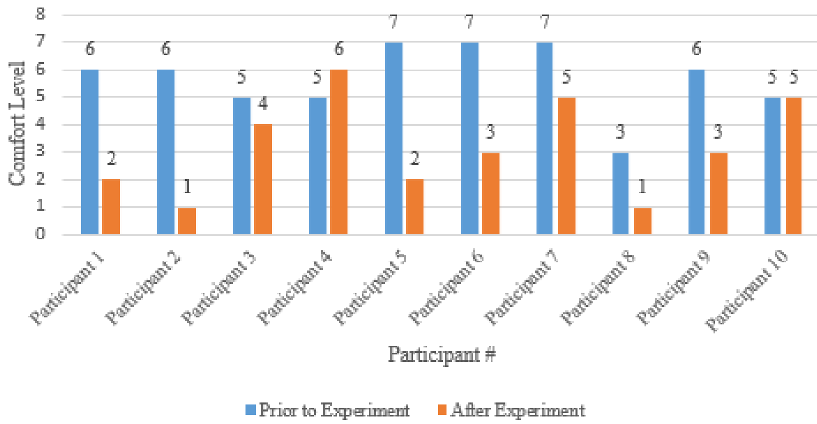

Figure 1. Comfort level Before and After Tests

Post-study responses indicated increased understanding of pull planning (See Figure 2), although their construction scheduling knowledge showed minimal improvement (See Figure 3).

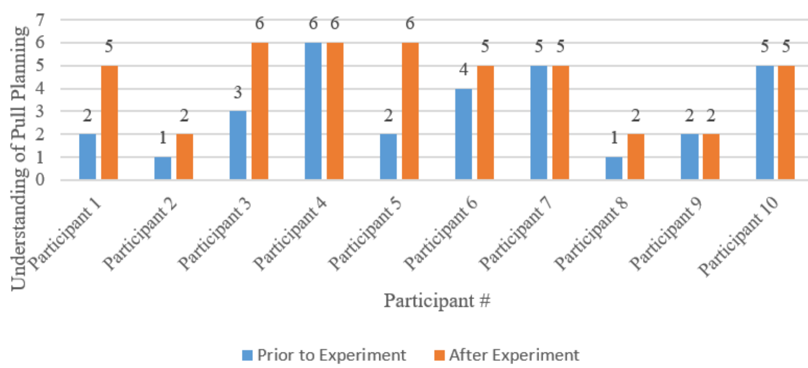

Figure 2. Participant Understanding of Pull Planning (Higher is Better)

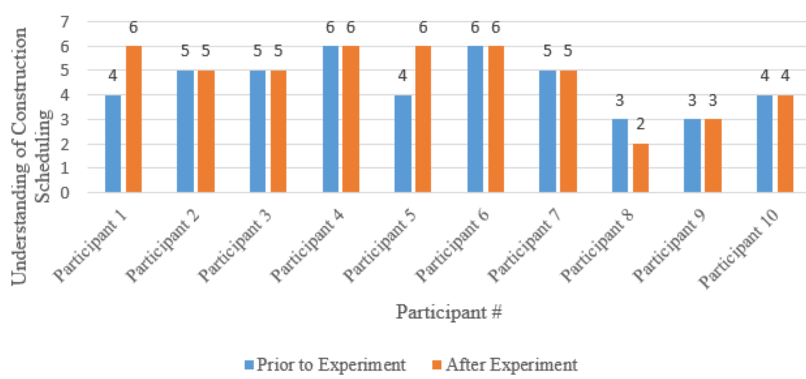

Figure 3. Participant Understanding of Construction Schedule (Higher is Better)

Second Round of Study

In the second test, third and fourth-year students from Andalas University, Indonesia, with no prior exposure to VR or lean construction, were chosen to assess VR's impact on understanding the pull planning process. Students could commit to suggested tasks or add activities as needed. Ten Civil Engineering students participated; only three experienced discomforts from VR use, indicating a minimal impact on comfort levels (See Figure 4).

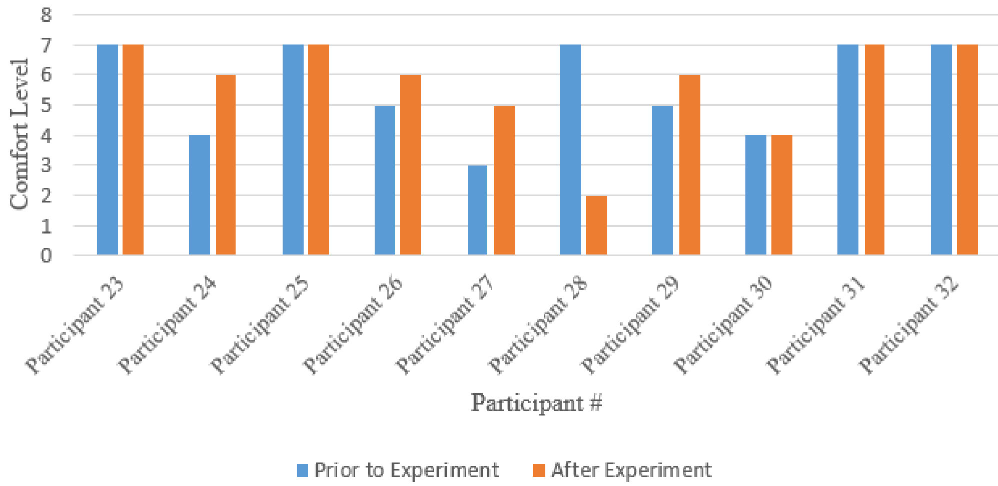

Figure 4. Second Round Participant Comfort Level on Round 2 (Higher is Better)

The participants, mainly student assistants/graders in a construction planning course at Andalas University, reported minimal improvement in understanding the scheduling process, possibly due to their background (See Figure 5). However, questionnaire results showed enhanced comprehension of pull planning, with nine out of ten participants reporting a better understanding after the study, a higher rate than in previous tests (See Figure 6).

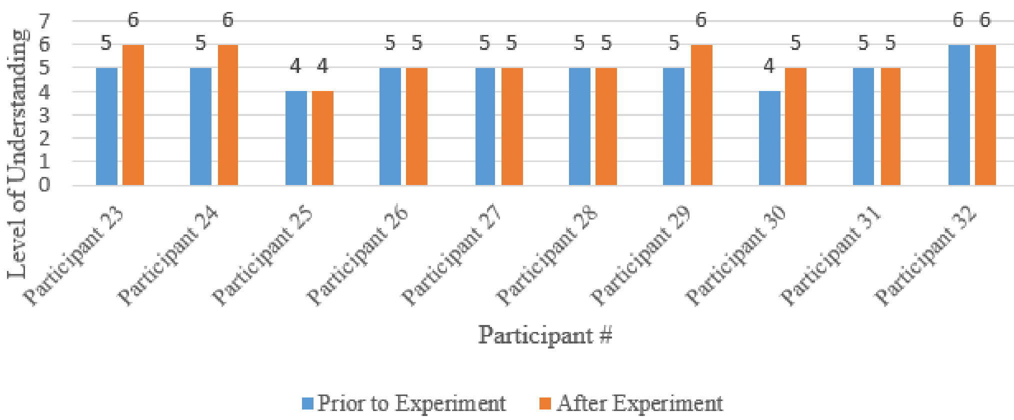

Figure 5. Second Round Participant Understanding of Scheduling (Higher is Better)

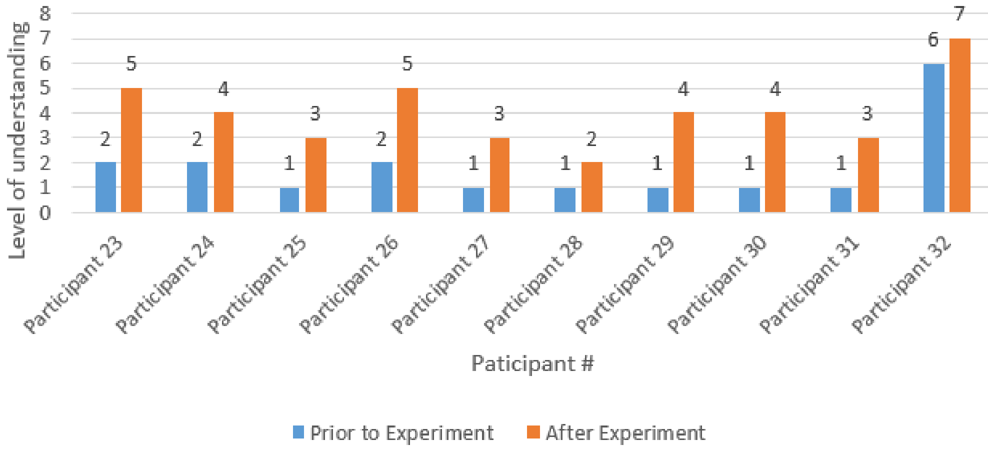

Figure 6. Second Round Participant Understanding of Pull Planning (Higher is Better)

Third Round of Study

In the third round, participants from the University of Washington's Construction Management master's program tested an optimized VR prototype, following feedback from earlier tests. Although half reported discomfort (See Figure 7), it was less significant than in previous studies, suggesting the updated prototype improved comfort. Most participants reported a better understanding of the scheduling process (See Figure 8), a more consistent response compared to earlier tests. Additionally, three out of four participants felt their knowledge of pull planning improved through participation (See Figure 9).

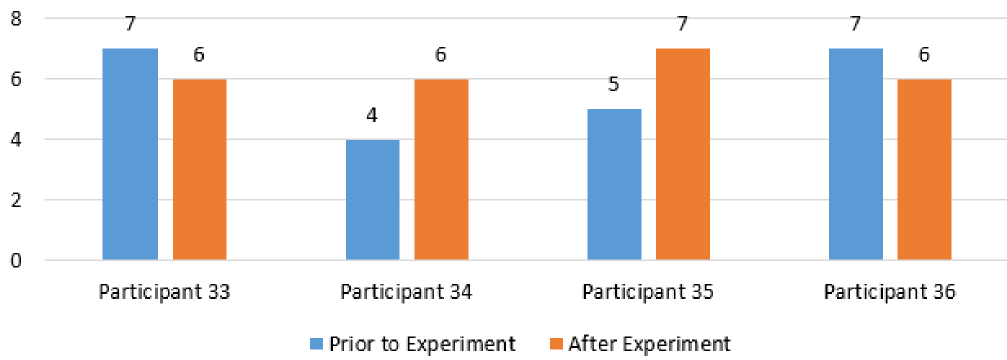

Figure 7. Third Round Participant Comfort Level (Higher is Better)

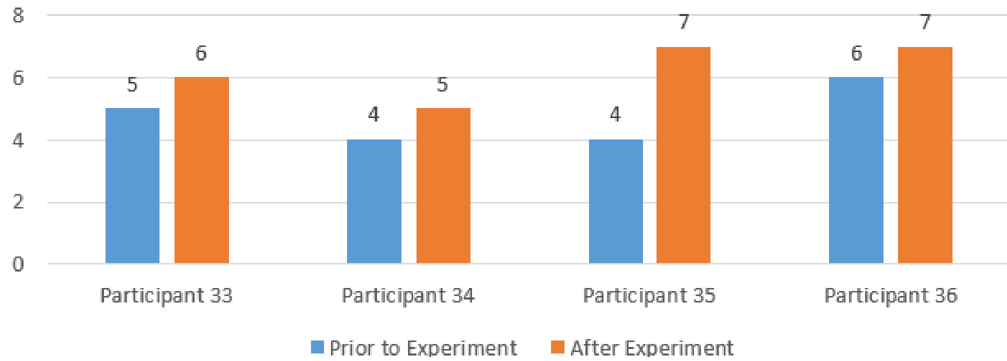

Figure 8. Third Round Participant Understanding of Scheduling (Higher is Better)

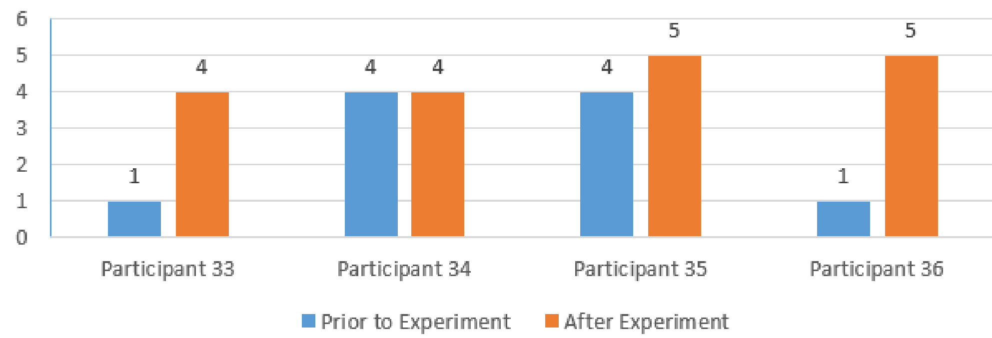

Figure 9. Third Round Participant Understanding of Pull Planning (Higher is Better)

Discussions and Conclusions

Individual/Personalized Point of View in Pull Planning

As demonstrated by the post-study questionnaire responses, having a personalized point of view on a model in the form of an immersive environment helped in enhancing the students' understanding of scheduling and pull planning.

In the studies, individual viewpoints had two main benefits. Firstly, they enhanced independent learning, as less experienced students could closely study building models and sequences during the pull planning process. Secondly, they supported communication within groups, facilitating discussions about activity sequences and building aspects in the VR simulation. However, this approach had limited impact on cross-disciplinary communication, with discussions mainly focused on tasks assigned to the students.

Challenges in Incorporating VR Devices for Education Purpose

VR devices are widely available and can be purchased on a relatively affordable price. However, the lack of productivity software that can be utilized as a medium for learning became a barrier in implementing them for construction education. Several tools that are available today are catered more towards enterprise use and are costly. This study developed an in-house prototype that can be customized, but it requires extensive amounts of time to develop and test the features.

Meanwhile, not all students might find VR intuitive. Based on the observations, some student participants were having a hard time simply trying to complete a task in VR. This limitation is not related to their actual experience or knowledge in the construction industry. Therefore, if such new technology is to be implemented, a training session should be made mandatory.

Conclusion

This study indicated that there is a potential of implementing a customized VR tool to help students with understanding the process pull planning. The availability of individualized point of view allows them to independently inspect the building and look for any errors or discrepancies, which should help them with decision making during the pull planning process.

Further studies could look into what kind of interactions that would potentially occur between student participants to help with the understanding how the students go through the problem solving process with the help of immersive environments.

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