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Real-Time Construction Progress Visualization for Enhancing Transparency and Decision-Making in Stakeholder Communication

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Abstract

This paper explores the benefits of real-time construction progress visualization technologies for enhancing communication and decision-making in the AEC industry and on construction projects. Traditional communication methods, such as meetings and 2D drawings, often fail to effectively convey complex project details, leading to misunderstandings and costly mistakes. This paper examines four key technologies: 360-degree panoramic visualizations, Building Information Modeling (BIM), Virtual Reality (VR), and Augmented Reality (AR). These technologies offer advantages over traditional information conveyance methods by improving information comprehensibility and providing stakeholders with a clear and accessible visual representation of the project. They enhance engagement by creating more interactive and immersive experiences for stakeholders, regardless of their technical expertise. Real-time visualization technologies also facilitate decision-making, enabling stakeholders to make more informed and proactive decisions based on real-time project data. Additionally, they overcome geographic barriers by allowing remote stakeholders to participate in project discussions and decision-making processes. While implementation hurdles exist, such as cost and technical integration, embracing these technologies is crucial for promoting transparency, collaboration, and project success in the AEC industry.

Keywords

Real-time Visualization, Construction Communication, Stakeholder Engagement, BIM, VR/AR.

1. Introduction

Effective communication is vital in construction projects, as multiple stakeholders such as contractors, architects, clients, and regulatory bodies must collaborate to achieve a common goal (Prebanić & Vukomanović, 2021). These stakeholders can vary from subject matter experts in the architecture, engineering and construction (AEC) field to end user clients, potentially with very little previous exposure to AEC terminology, methodology and an understanding of the construction process in the field. Traditional communication methods, including meetings, emails, and drawings, often lack the immediacy and clarity needed to convey complex project details at a level that is understandable to the project decision makers (Noghabaei et al., 2020). This can lead to misunderstandings, delays, and costly mistakes. In recent years, multiple methods of conveying real-time construction progress have emerged as powerful tools to enhance stakeholder engagement (Houng et al., 2024). These technologies range from improved construction management platforms used by large enterprises such as the U.S. Army Corps of Engineers with the goal of "improving collaboration among the entire project team including external stakeholders" (Paul, 2023), many of which may be geographically dispersed, to construction companyies such as McCarthy Building Companies implementation of virtual reality (VR) technology and Building Information Modeling (BIM) cave to allow stakeholders to walk through jobsites remotely (Gaudiosi, 2015). These collaborative and immersive experiences allow stakeholders to increase collaboration, exploring construction projects virtually, providing a more intuitive understanding of the design and construction progress and providing consistent quality information for decision-making. By improving transparency and decision-making, these tools can facilitate better collaboration and more informed choices.

This paper explores the benefits of these rapidly advancing technologies, specifically that support 360-degree VR tours, immersive experiences and augmented reality for construction stakeholder communication, focusing on

their ability to enhance transparency, improve engagement, and facilitate decision-making. Drawing upon existing research and industry best practices, the paper concludes by offering practical recommendations for implementing these technologies to maximize their potential in improving construction project communication and collaboration.

2. Traditional Stakeholder Communication Challenges

Imagine a large construction project – a bustling network of architects, engineers, contractors, subcontractors, and various stakeholders, all striving to bring a complex vision to life. Now, picture their communication channels primarily consisting of face-to-face meetings, paper documentation, and intricate 2D drawings. This scenario, unfortunately, represents the traditional state of construction stakeholder communication, fraught with challenges that can significantly hinder project success.

2. 1 Geographic Barriers and the Dispersion of Stakeholders

One significant challenge stems from the very nature of construction projects – they often involve geographically dispersed stakeholders. Coordinating meetings and ensuring timely information flow across different locations can be a logistical nightmare. This collaboration challenge is amplified when stakeholders cannot meet easily or understand information quickly, resulting in the delay of decisions that may be critical to the project (Zaker & Coloma, 2018). Remote stakeholders may also feel disconnected from the project due to a lack of ease in participating in critical conversations or inability to visit the project site (Zaker & Coloma, 2018). The use of advancing technologies that allow for real-time construction progress visualization during the construction phase of the project is paramount to maintain the communication and understanding of these remote stakeholders throughout the project lifecycle.

2. 2 The Knowledge Gap and Stakeholder Understanding

Compounding the issue of location is the varying level of construction knowledge among stakeholders. Some, like architects and engineers, possess deep technical expertise. However, others, including clients, investors, or even community members, may lack the background to fully grasp technical drawings or complex construction terminology. This knowledge gap can lead to misinterpretations and miscommunication, especially when the primary mode of communication is dialogue or 2D drawings. This knowledge and communication gap can ultimately lead to increased project cost and delays. The AEC industry recognizes the need for a better medium to convey information to these vital stakeholders in a manner that they can better understand. Bouchlaghem et al. (2005) explores the ability of real-time construction technologies as a means to effectively bridge this knowledge gap, allowing non-technical stakeholders to visualize and comprehend the project's intricacies.

2. 3 Ensuring Continuity in Communication Quality

Maintaining consistent communication quality throughout a project's lifecycle is crucial but challenging in the traditional setup. As projects progress, the sheer volume of information, changes, and updates can overwhelm stakeholders. There is a need for robust systems to manage this dynamic flow of information, ensuring that all stakeholders have access to accurate and up-to-date details (Whyte et al., 2016). This continuous access to reliable information is essential for effective decision-making, collaboration, and overall project success.

2. 4 From Reactive to Proactive: The Need for Effective Decision-Making

The traditional reliance on physical documents and delayed communication often results in a reactive approach to decision-making. Issues are addressed as they arise, rather than proactively anticipated and mitigated. This reactive approach can lead to costly rework, schedule overruns, and strained stakeholder relationships. Houng et al. (2024) emphasizes the need for systems that enable real-time data sharing and collaboration, fostering a more proactive and efficient decision-making process.

3. Construction Visualization: Technologies for Enhanced Communication

The AEC industry has responded to the traditional communication challenges presented above using technological advancements focused on providing transparent and current data to all stakeholders. These technologies bridge the knowledge and geographical gap that hinders understanding of current construction progress and can provide real-time details to proactively resolve issues prior to construction impacts occurring. The following technologies provide the AEC industry the ability to provide real-time construction progress visualization with stakeholders of all knowledge levels and locations to address these challenges:

3. 1 360° Panoramic Visualizations

This technology uses omnidirectional photography to capture a full 360-degree view of a location, creating an immersive visual experience (Shinde et al., 2023). By stitching together multiple images, a seamless panorama is created that can be explored interactively by the stakeholders. Stakeholders can explore these real-world views on readily accessible technologies such as computers or tablets. 360-degree panoramas provide a cost-effective and accessible way to capture and share a realistic representation of the current construction progress, in an accessible manner.

3. 2 Building Information Modeling (BIM)

BIM software creates a comprehensive digital representation of a building, encompassing not only its physical geometry but also data about its components, materials, and construction processes (Whyte et al., 2016). This information-rich model can be used to simulate the construction process, identify potential clashes, and analyze building performance. BIM models can also be exported to other visualization technologies, such as VR and Augmented Reality (AR) systems (Prebanic et al., 2021).

3. 3 Virtual Reality (VR)

VR technology creates immersive, interactive 3D environments that allow users to experience a space as if they were physically present. By using specialized hardware, such as a head-mounted display, VR provides a sense of presence and engagement that surpasses other visualization methods (Heydarian et al., 2015). VR can be used in construction for not only design reviews as has been the traditional implementation, but also collaborative virtual walkthroughs of project sites (Shinde et al., 2023) by those stakeholders that may not be physically present at the project site.

3. 4 Augmented Reality (AR)

AR technology superimposes digital information, such as BIM models or sensor data, onto a user's view of the real world. Typically accessed through a mobile device or headset, AR allows users to see the design intent directly on the construction site (Wang et al., 2013). This technology can be used to improve communication, enhance worker understanding, and facilitate training (Noghabaei et al., 2020).

4. Advantages of Visualization Technology Compared to Traditional Stakeholder Communication

4. 1 360-Degree Panoramic Visualizations: Full Photo Immersion

360-degree panoramic visualizations offer several benefits over traditional 2D drawings, which can be difficult for stakeholders unfamiliar with construction to comprehend (Pereira et al., 2017). While 2D drawings provide limited perspectives, 360-degree panoramas create an immersive experience, giving stakeholders a comprehensive view of the project site (Pereira et al., 2017). This technology also offers a more convenient and engaging way to share information compared to paper documentation, as panoramas can be easily shared electronically and accessed from various devices (Pereira et al., 2017) including VR headsets, large format screens or even tablets and mobile phones. This increased visibility into the actual state and details of construction allows stakeholders, regardless of their location, to stay informed about project progress.

The relatable visual aspect of utilizing the detail provided by 360-degree photographs also allows stakeholders with less AEC industry experience to view the site or construction issue in a more understandable manner than sketches, details or even 3D models alone. Ouederni (2020) writes about how 360-degree photography and videos were used by professors at the American University in Cario to provide students with virtual site visits during the height of the COVID-19 pandemic. In this case the stakeholders are students learning about construction. One student was quoted stating that the 360-degree videos “gives us a feeling that we are present at the construction site so we can look around us and explore it” (Ouederni, 2020). This experience allows for increased comprehension by the stakeholders that in this case may be learning about construction, but in other situations may be the responsible decision maker needing to provide a solution to a critical design or construction issue.

4. 2 Building Information Modeling (BIM): Detailed Understandable Design

As outlined by Whyte et al. (2016), BIM provides a significant advantage over 2D drawings by presenting a data-rich, dynamic model encompassing all building aspects. This model facilitates better decision-making by enabling stakeholders to analyze design options, simulate construction sequences and identify clashes before the start of construction. BIM can allow for more accurate quantity takeoffs and provide detailed cost estimates, key information to allow stakeholders to make more educated project decisions (Balali et al., 2018). Past the design phase, BIM also fosters real-time collaboration, allowing stakeholders to access the latest project information, design changes, and schedules, which is a significant improvement over static paper documentation. A model that allows the contractor to update the design with the current installation on site, can convey a more accurate representation of constructability challenges to the design and client teams. One study (Halder et al., 2021) describes the use of BIM linked to 360-degree photographs captured on-site by robots, creating a virtual environment from which stakeholders could monitor construction progress remotely. This collaborative environment enhances communication and ensures all stakeholders are working with the most current data to make data driven decisions. It also allows for the proactive realization of issues, allowing for the stakeholders to investigate and resolve the problems identified in the model by contractors virtually, before impacting the project cost and schedule when the issue is realized during construction.

4. 3 Virtual Reality (VR): Immersive Visualization of the Space

Heydraian et al. (2015) discusses how the immersive and realistic experience created by VR surpasses 2D drawings and static visualizations. They show that the ability for stakeholders to virtually "walk through" the building, gaining a sense of scale and spatial relationships are significantly improved when compared to the difficult interpretation perceived from 2D drawings alone. This immersive quality of VR enhances communication by enabling stakeholders to experience the space firsthand, leading to a better understanding of design intent and reducing potential for misinterpretations (Heydarian et al., 2015). VR also allows for interactive engagement with building components and exploration of various design options, which is more engaging than reviewing paper-based documentation. This hands-on approach within the virtual environment promotes better comprehension and retention of information by the stakeholders, regardless of prior construction knowledge. It can also facilitate the review of many potential solutions in real time, increasing the speed of decisions that could otherwise delay the project and potentially result in cost and schedule impacts.

4. 4 Augmented Reality (AR): Design and Real Time Progress Combined

Wang et al. (2013) discusses the advantages that AR provides by overlaying digital information, such as BIM models, onto the physical construction site, giving stakeholders a contextualized understanding that goes beyond traditional 2D drawings. AR surpasses traditional paper documentation by providing real-time information and on-site updates to stakeholders. By combining technologies such as 360-degree photography with modeling such as BIM, the stakeholder can experience design and actual construction progress in a spatially relatable medium. This real-time integration of information enhances communication by allowing stakeholders to visualize the design in its actual environment and identify potential conflicts (Wang et al., 2013). Access to the latest BIM models, schedules, and other crucial data streamlines communication and facilitates better decision-making.

5. Implementation Hurdles for Advanced Visualization Technologies

The implementation of these real-time visualization technologies in the AEC industry is not without several challenges. A key hurdle is the smooth transfer of data and compatibility between conventional CAD systems and VR platforms (Bouchlaghem et al., 2005). Despite years or development, the absence of robust methods for transferring complete BIM data, including cost information, into VR environments, restricts the practical widespread application of these technologies (Noghabaei et al., 2020). Balali et al. (2018) emphasizes that while BIM has revolutionized the AEC industry, transitioning to newer technologies, such as 5D BIM (3D plus cost and time) can be time consuming, highlighting the challenge of integrating real-time cost estimation within VR environments. While the information provided in more advanced BIM technologies can increase efficiency in data driven decision making, accounting for the time to integrate the information must be considered.

Additionally, the financial burden of implementing AR/VR technologies and the demand for specific hardware and software can pose an obstacle, particularly for smaller companies (Zaker & Coloma, 2018). Ensuring the precision and realism of virtual environments is paramount, as discrepancies between virtual and physical conditions can affect the efficacy of these tools (Heydarian et al., 2015). If the on-site progress is not accurately translated into the virtual or augmented reality environments, the value of the information is diminished, reducing the advantages gained by the stakeholders depending on these technologies to provide crucial information.

Cybersickness (CS), a common problem in immersive settings, also presents a tangible challenge for user experience and adoption (Shinde et al., 2023) of some VR and AR applications. Shinde et al. (2023) explains how CS can impact the ability of stakeholders to utilize 360-degree environments. While the detail of the project can be better conveyed using immersion technologies, the stakeholder can hardly find benefit if experiencing nausea, headaches or dizziness. CS mitigation such as gaze-contingent peripheral blurring or gaze-contingent peripheral occlusion may need to be considered when implementing these technologies to improve the stakeholders experience and gain full benefit of the real time data provided (Shinde et al., 2023).

Finally, technical constraints, such as suboptimal image quality, stitching errors in 360-degree panoramas, and the fixed vantage point, can also diminish the overall visualization quality (Shinde et al., 2023). Limitations of flat-screens ability convey the full 3D experience of BIM and VR/AR can reduce value of these technologies (Zaker & Coloma, 2018), as opposed to the use of more advanced and expensive immersion technologies such as VR headsets or BIM caves. Zaker and Coloma (2018) explain that overcoming these challenges is vital for realizing the full potential of real-time visualization technologies in the AEC industry, and thus capitalizing on the benefits gained for stakeholder communication and decision making.

6. Effective Implementation of Real-Time Visualization Technology

Implementing real-time visualization technologies requires a strategic approach that addresses both technological and organizational factors. While the initial cost of adopting these technologies can be a barrier, particularly for smaller firms, exploring phased implementation strategies when adopting these communication techniques can ease the transition (Prebanić & Vukomanović, 2021). A phased approach could begin with integrating readily available and lower-cost options like 360-degree panoramas, before progressing to more advanced VR or AR systems (Pereira et al., 2017). Prebanić & Vukomanović (2021) indicate that collaboration among firms to share resources and expertise can also help mitigate the costs associated with procuring and establishing new technologies. They go on to suggest that leveraging cloud-based solutions can reduce upfront investment and offer more flexible access for multiple users regardless of geographic location.

Whyte et al. (2016) suggests that successful implementation goes beyond simply acquiring technology - it necessitates a comprehensive re-engineering of existing processes to fully capitalize on the collaborative potential of BIM and VR/AR. This includes defining clear roles and responsibilities for different stakeholders within the digital environment. Standardized workflows for data exchange, model updates, and communication protocols are crucial to ensure consistency and minimize confusion among project stakeholders (Whyte, et al., 2016). Whyte et al. also indicates that maintaining data integrity is paramount to avoid costly errors and rework. Implementing robust quality control measures for validating data inputs and model updates can help ensure accuracy and consistency. They propose that linking visualization tools with real-time progress monitoring systems ensures that the virtual representations accurately reflect actual site conditions.

Additionally, prioritizing user-centered design principles is key to successful adoption of new technologies. Conducting regular feedback sessions with stakeholders can identify areas for improvement and ensure that the technologies meet their practical needs (Heydarian et al., 2015). Reviewing analytics and benchmarking user performance in virtual environments provides valuable insights into the effectiveness of these tools as representations of real-world scenarios (Heydarian et al., 2015).

Finally, acknowledging the continuous evolution of these technologies, ongoing research is crucial. While there are a myriad focus areas for the research, a major topic includes developing more intuitive and user-friendly interfaces for VR/AR applications and exploring additional affordances within virtual environments to better support specific stakeholder communication needs (Shinde et al., 2023).

7. Conclusion

The challenges of traditional construction stakeholder communication, which relies on face-to-face meetings, paper documentation, and 2D drawings, are evident. Adopting digital technologies like 360-degree panoramic visualizations, BIM integrations, VR, and AR have been increasingly used to address these challenges, providing benefits to project communication and decision making. These technologies can provide clear visualizations, accessible information, and consistent communication, ultimately enabling more proactive and efficient decision-making for successful construction projects. As discussed, the benefits of these digital technology include enhanced information detail/transparency, improved understanding for stakeholders with limited construction knowledge, and the ability to overcome geographical barriers through the virtual environments. These advantages foster a more collaborative and

transparent project conditions where stakeholders can effectively contribute to achieving a shared vision. Despite these benefits, implementation challenges exist, including financial burden, technical integration, data accuracy, and potential user discomfort, and must be acknowledged and addressed to realize the full potential of real-time visualization technologies in the AEC industry. Embracing these technologies is not solely about improving efficiency but also about fostering a collaborative, transparent project environment where stakeholders can effectively contribute to a shared vision.

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