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Evaluating the Advantages of Mixed Reality in Construction: A Comprehensive Review from a Contractor's Perspective

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ABSTRACT

The potential for Mixed Reality (MR) to improve the efficiency of the construction process is widely acknowledged. Yet, its use in construction remains a paradox, with serious barriers to implementation despite its potential benefits. The benefits and challenges are usually listed separately in the literature, and a comprehensive analysis of the pros and cons is rarely provided from the contractor's critical financial and operational perspective. By systematically reviewing the literature, the systematic review addresses this gap and assesses the impact of MR on project efficiency. The issue at the core is not that there is no evidence supporting the effectiveness of MR in enhancing spatial accuracy, reducing rework, and improving safety, but rather that there is some evidence that MR can do so. The findings suggest that there are three fundamental gaps in the measurement and implementation of intangible returns on investment that need to be addressed: a measurement gap in quantifying these returns, an implementation gap in change management and training protocols, and a systemic gap in data standardization and interoperability. In the review, the alternative hypothesis (H1) is accepted with confidence, and the conclusion is that MR is likely to have a significant positive impact on project efficiency. Despite this, contractors are required to follow a staged plan of action to achieve this potential. It is important to note that the main theoretical value of this research lies in creating an extensive framework that enables us to view the adoption problem as a set of interdependent gaps rather than just a list of problems. In this way, we can provide a clear roadmap for future research and investment by contractors.

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1. Introduction

The construction industry is a key sector of economic development worldwide, yet it has consistently faced challenges such as low productivity, escalating costs, strict deadlines, and accidents (Azhar, 2011). Despite advances in project management methods and the application of Building Information Modelling (BIM) technology, there remains a significant gap between estimated efficiency and actual on-site performance. This productivity paradox is explained by the lack of communication between physical construction site work and office-based digital planning, which leads to errors, repetitions, and poor communication (Eastman, 2011).

Industry is going digital to overcome such issues, and Industry 4.0 technologies can cover this gap. Long-Reality (XR) technologies such as Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) have also proved promising. The fusion of the physical and virtual worlds by anchoring the virtual world to the real world in real time, called Mixed Reality, is interesting because it can make digital information practically relevant in the field (Milgram & Kishino, 1994). MR introduces a paradigm shift for contractors: crews no longer need to view 2D drawings or 3D models on a screen. Nevertheless, they will be able to observe BIM models on the actual job site using a head-up display, e.g., the Microsoft HoloLens or Magic Leap.

It is important to understand that contractors have a wide range of applications. They include superior design visualization and stakeholder communication, precise on-site layout and alignment, extensive safety training, support for complex assembly operations, and simplification of quality control and maintenance tasks by overlaying as-built information on physical assets (Palmarini et al., 2018). MR reduces cognitive load, eliminates errors, and facilitates decision-making by placing digital information in the context of the physical environment.

Nevertheless, MR's technological potential has been demonstrated in controlled experiments. In contrast, the actual effect of the technology on the project's overall efficiency, measured by fewer reworks, faster task completion, lower costs, and better resource allocation, is still being studied. The available literature includes numerous case studies demonstrating positive results. Nevertheless, there is no comprehensive, systematic review that summarizes the evidence from a contractor's perspective. Project risks in terms of finance and timing are also the leading factors in the on-site implementation. The contractor must be aware of the MR's ROI and its relationship with workflow integration.

The present paper will fill this gap by offering a systematic review that synthesizes evidence. This will be done using the dual prism of contractor risk and financial viability. Its key innovation is that it not only provides a catalog of advantages and disadvantages but also a critical, synthesized Model that pinpoints the fundamental causes of the adoption paradox. Through this, it offers helpful suggestions and a systematic way to analyze the potential of MR to improve production, safety, teamwork, and the overall project.

2. Background

Industry 4.0 and Mixed Reality (MR) in construction are among the most significant intersections of digital and physical processes. To contractors, MR is more than a visualization tool; it is a project delivery paradigm that bridges digital design (e.g., BIM) and real building construction (Azhar, 2011; Eastman et al., 2011). This is what is called the productivity paradox. It is expressed through cost overruns, schedule slippage, and safety incidents caused by errors and rework. MR's value proposition to contractors will be based on its ability to superimpose practical electronic information at the construction site using heads-up displays (e.g., Microsoft HoloLens). High-precision on-site layout and alignment, immersive safety training, multi-complex assembly assistance, and real-time quality management via overlaying as-built information are among the applications that enable this (Palmarini et al., 2018). MR places information in context, reducing cognitive load, errors, and accelerating decision-making.

However, obstacles that pose significant challenges to adoption are in the way of seamless integration and the realization of these benefits. The initial problem is that the investments required to acquire specialized hardware, develop software, and implement comprehensive user training programs are high, placing a serious financial burden on most companies (Cheng et al., 2020). Additionally, another acute technical issue is the interoperability of MR platforms with the existing digital project delivery ecosystem, namely BIM. Weak information exchange procedures and the lack of standard interfaces can result in information silos and workflow interruptions, creating inefficiencies that negate the advantages MR is designed to provide (Delgado et al., 2020).

Human factors are also a serious challenge. Implementation of MR will depend on the user's mastery of the technology. The learning curve for the most recent MR interfaces is quite steep, requiring a prolonged period of continuous training and a significant investment of time and resources (Wang et al., 2024). Without appropriate training, underuse of high technology will result, as there will be no point in using all MR capabilities. This will ultimately affect its payback and its contribution to project deliverables. Consequently, there is a considerable disparity between technological potential and empirical data on MR's net impact on project efficiency. This is the gap in the consideration of adoption barriers. The purpose of the paper is to fill this gap through a systematic synthesis and review of available evidence from the contractor's perspective. Even though MR capabilities have been thoroughly developed in a controlled setting, no evidence-based method exists to determine the importance of alleged benefits relative to the cost and complexity of their application in real-world settings.

This paper seeks to fill this gap by systematically synthesizing the available literature. It seeks to determine whether adopting MR, despite these limitations, results in a statistically significant increase in contractor project efficiency. The main research question (RQ) in this review is the following, based on the identified issue and gap: RQ: Does the use of Mixed Reality (MR) technology significantly improve project efficiency from a contractor's perspective in the construction industry? The following research objectives (ROs) are developed to answer the research question and conduct a systematic analysis.

- **RO1:** To identify and synthesize the key efficiency metrics (e.g., time savings, error reduction, cost avoidance) used to evaluate MR applications in construction.
- **RO2:** To critically analyze and evaluate the empirical evidence from existing literature on the impact of MR on these efficiency metrics from a contractor's operational viewpoint.
- **RO3:** To identify and categorize the primary benefits, successful use cases, and persistent barriers (technological, organizational, and economic) to MR implementation for contractors.
- **RO4:** To provide a conclusive assessment on the validity of the stated hypotheses and offer recommendations for contractors considering MR adoption.

3. Significance of Study

This study is highly relevant to academic scholars, industry practitioners, and the construction industry. This research paper will make multifaceted contributions to the systematic review of mixed reality (MR) through the lens of a contractor.

3.1 Practical Guidance for Strategic Technology Adoption. The purpose of this research paper is to provide an overview of the practical benefits and challenges of implementing MR for contracting firms. In summary, it provides a clear and reasonable framework for making decisions that explains the potential return on investment (ROI), productivity improvements, and often underestimated integration issues (Rane, 2023). In an industry with thin profit margins and a culture of risk aversion, managing capital efficiently is key to formulating robust implementation plans and ensuring the most efficient allocation.

3.2 Contribution to Academic Discourse and Theoretical Understanding. The study bridges a knowledge gap in the literature by summarizing fragmented studies on MR effectiveness, particularly among contractors. It presents an overview and review of empirical data, thus adding to the theoretical perspective on technology integration in high-risk, complex project settings (Tang et al., 2022; Wei et al., 2021). It will provide a background reference point for future studies on immersive technologies in the construction industry.

3.3 Enhancement of Safety Performance and Training Protocols. The review evaluates the transformative potential of MR in safety management, which is of the utmost importance. Based on the evaluation of MR's application to immersive hazard identification and safety training simulations, this paper indicates that MR may make a major leap beyond the conventional Model to develop a more profound safety culture and minimize incidents (Manzoor et al., 2021). This provides a basis for developing more productive, evidence-based safety measures.

3.4 Advancement of Collaborative Project Delivery. This paper proposes a discussion of the value of MR in avoiding misunderstandings among dissimilar project stakeholders and enabling coordination among them. MR allows overlaying BIM data from the physical jobsite, creating a common visual language and increasing the possibility of working together more efficiently and in real time to solve issues (El Ammari & Hammad, 2019). This trend will enable the industry to be more efficient at delivering its projects.

3.5 Technological acculturation and workforce development. There is a rapid increase in technology adoption in the construction industry due to a shortage of skilled labor and a digital skills gap. It enables them to decipher MR by making them more technologically aware. Future generations of professionals are required to make the industry sustainable (Blak Bernat et al., 2023).

4. Literature Review

MR has the potential to transform the construction industry by combining the real and virtual worlds. Contractors have a complicated combination of benefits and restrictions. Even though the current work gives a fragmented image, it only covers a few benefits. Critical synthesis shows that the main discourse on MR adoption includes not just a list of merits and demerits, but also a series of contradictions between the possibility of changing the industry and the real, financial, and human circumstances that do not allow MR adoption as a mainstream practice.

4.1 The Promise of Enhanced Visualization and Collaboration. The literature that has advanced MR's capability to change design visualization and facilitate collaboration with stakeholders is quite significant. Beyond simply viewing 3D models, stakeholders may experience them in a 3D environment, which enhances understanding of complex designs and facilitates decision-making in planning and construction (Safikhani et al., 2022). Integrating it with Building Information Modeling (BIM) will improve quality control and progress monitoring at the construction site (Ma et al., 2018). Delgado et al. (2020) emphasize the potential of seamless BIM integration as a milestone in immersive technologies in the AEC sector. This can be further improved through better cooperation. Sepasgozar et al. (2023) suggest that in a common digital environment, MR will make communication among architects, engineers, and contractors interactive and real-time, thereby reducing errors and eliminating communication differences. In addition, its remote working capabilities allow customers and remote administrators to experience the development process firsthand. Making decisions becomes even more open and simultaneous.

4.2 The Reality of Implementation Barriers. However, this perspective is usually tempered by pessimistic implementation consequences. There exists a disconnect between theory and practice. The lack of unified data exchange protocols, which causes interoperability issues, is often a barrier to BIM integration, despite BIM being regarded as a breakthrough (Colabaga Don & Axell Gholizadeh, 2023). According to Demirkesen & Tezel (2022), the issue of data standardization and system interoperability is one of the most critical, unresolved systemic obstacles to broad adoption and has been a problem for several years. When remote collaboration is implemented on a large scale, bandwidth limitations and compatibility may undermine hardware needs (Turner et al., 2020).

4.3 The Central Tension: Tangible Benefits vs. Intangible ROI. There is a dichotomy between business profitability and sustainability. Based on the literature, MR can be applied to position components accurately, thereby reducing waste and rework (Camacho et al., 2018) or to avoid design conflicts at the initial stage (Wang et al., 2023). Chi et al. (2022) Provide Statistical support for these gains. And other empirical case studies. In such situations, AR guidance can save over 25% of the time required for structural steel Column inspection and drastically reduce error rates. On the other hand, one of the greatest constraints of the current study is its lack of long-term value beyond a reasonable doubt. Initial costs for hardware, software, and training are extremely high, particularly for small and mid-sized contractors (Akpe et al., 2022). Empirical support for this is found in the survey of contractor readiness (Olatunde et al., 2023).

According to Sompolgrunk et al. (2023), one of the major negative effects of adoption is the lack of substantial, long-term empirical research on return on investment (ROI). This gap is also supported by the lack of standardized principles for assessing the total cost of ownership of MR, including both tangible and intangible benefits (Wang et al., 2023). This forms a vicious circle in which contractors are not compelled to explain their initial investment unless they can show clear signs of financial gain. But to generate such evidence, it would require many adopters. That is the basic dilemma between reported efficiencies and unmeasured ROI. It is one of the main themes and a major hindrance to implementing the solutions I outlined in the literature.

4.4 Human Factors and the Unresolved Questions of Integration. In addition to technology and money, literature consistently shows that human factors are barriers to success, yet it has offered only a limited number of solutions. MR interfaces have also been reported to be resisted, in Part because of the high learning curve among established employees (Naing et al., 2022). Researchers, including Hassan et al. (2021), note that close attention should be paid to thorough training. However, there is a lack of research on what makes up practical, scalable training programs for a diverse construction workforce. Research examines training effectiveness. According to a longitudinal survey by Hashem et al. (2021), despite higher initial engagement and knowledge retention, MR training was more effective than refresher courses. This implies that long-term effects need to be continuously integrated, unlike technology. This points to a significant gap in the literature highlighting resistance to change and training needs. Nonetheless, it fails to incorporate the results into a synthesized change management strategy that contractors can use. Furthermore, emerging issues in data protection and cybersecurity, as well as the absence of industry-specific norms and legal regulations, have been identified but remain understudied (Omrany et al., 2023). Admittedly, the potential for MR to contribute to the digital divide between small and large firms is a poorly studied issue (Ayinla & Adamu, 2018).

4.5 Synthesis and Identified Gap. Finally, there is a literature review that speculates on a domain of strong individual accomplishments that are disproportionately overshadowed by systemic problems resulting from structural factors. This paper outlines the advantages of MR in visualization, collaboration, and safety. It also lists intelligently identified technology barriers, such as cost and interoperability. However, it is more likely to do both at the same time, which gives a loophole in critical analysis. The lack of identified benefits or challenges is not the research gap. Rather, it is the lack of a contractor framework that fails to balance these conflicting forces. This review shows that research beyond mere listing is needed to offer critical insight into how contractors can manage the tension between MR potential and its practical application, especially regarding ROI, human factors, and integration approaches. The systematic review presented here is expected to fill this gap.

4.6 Hypotheses

H_0: A contractor's perspective on Mixed Reality in construction is not significantly improved.
H_1: As a contractor, Mixed Reality significantly increases project efficiency.

5. Research Methodology

5.1 Research Design

The paper employs a qualitative systematic literature review (SLR) to examine the adoption of Mixed Reality (MR) from the contractors' perspective. By using standardized procedures, literature reviews would be transparent, trustworthy, and reproducible (Aguinis et al., 2023). Synthesis of themes from previous qualitative studies, analytical scrutiny, filtering, and systematizing searching are emphasized.

5.2 Literature Search Strategy

The academic databases Scopus, IEEE Xplore, Web of Science, ScienceDirect, and Google Scholar were systematically and holistically searched. Our search focused on peer-reviewed articles, conference papers, books, and industry reports published between 2015 and 2024. Using a Boolean search method following this: ("Mixed Reality" OR "MR technologies" OR "Augmented Reality" OR "Virtual Reality") AND ("construction industry" OR "building sector" OR "contractor perspective") AND ("project efficiency" OR "productivity" OR "workflow integration").

- ***Inclusion Criteria:*** Books, industrial reports, conference papers, and peer-reviewed journal articles. Studies published between 2015 and 2024 indicate current technology trends. The study of MR in buildings, and particularly, that of a contractor. A study examining the benefits and limitations of MR adoption of items written in English.
- ***Exclusion Criteria:*** Articles stressing just MR in architectural design or urban planning without addressing building techniques. research missing qualitative insights (e.g., essentially technical research on hardware/software devoid of commercial use). Double publications or supplementary reports compiling original research.

5.3 Screening Process

The search results were screened three times to guarantee quality and relevance:

- Reviewing titles and abstracts helped to exclude unrelated research during first screening.
- Relevance, methodological rigor, and depth of analysis were closely examined in inclusion research.
- A Critical Appraisal Skills Program (CASP) Checklist was used to evaluate selected papers.

A PRISMA flow diagram (Kahale et al., 2022) illustrates the process by which records were identified, screened, excluded, and included.

5.4 Data Extraction and Synthesis

The most appropriate material was systematically collected based on the chosen studies. Research methods, techniques, and popular patterns were discussed, along with the benefits and limitations of MR. Thematic analysis was used to synthesize and analyze the key themes (Braun & Clarke, 2006). MR adoption was gathered by gathering similar ideas. Using similar codes, it identified broader themes and redefined topics through a more detailed literature review. Finally, MR in the construction industry is rigorously described, with emphasis on contractor opinions and industry implications.

6. Results

The literature review provides a systematic review of evidence across various fields demonstrating MR's ability to improve project efficiency. Nevertheless, a thematic analysis of these results revealed the tensions and contradictions underlying them. These tensions and contradictions are discussed and generalized in this section. It has been proven that Mixed Reality (MR) is more effective in construction (Dai et al., 2021; Moore & Gheisari, 2019; Vasilevski & Birt, 2020; Chalhoub & Ayer, 2018). Edirisinghe (2019) observed that the superimposition of the digital environment on the real space enhances construction accuracy. Efficiency is achieved through better visualization, which minimizes on-site and data analysis errors. According to Dolla et al. (2023), MR enables stakeholders to communicate and collaborate in real time, thereby improving communication within the organization. MR can also improve project workflow and outcomes by increasing visualization and collaboration (Alizadehsalehi et al., 2019). The most significant findings are divided into the following categories.

6.1 Enhanced Efficiency and Project Accuracy

Several studies have shown that MR performs well in building projects (Li et al., 2019; Babaeian Jelodar & Sutrisna, 2022; Assaad et al., 2020). Digital data and the real world overlap to enhance construction precision and reduce errors (Huang, 2020). According to Fobiri et al. (2022), MR enables stakeholders to organize in real-time. To attain these benefits, a steep learning curve is necessary with MR. It is well known that efficiency can be improved, but implementing these improvements is difficult. However, Newman et al. (2021) mention that MR can enable traditional processes, whereas other researchers (Ahmed et al., 2024) believe that the problem of BIM interoperability can diminish any advantages. Despite these conflicting opinions, MR has substantial potential; in practice, however, there are still challenges to be overcome.

6.2 Financial Considerations and Cost-Benefit Analysis

MR technology is more commonly implemented with strict budgets. Barriers to adoption include input devices, software development, and training costs (Chen et al., 2022). Nevertheless, Tsz Wai et al. (2023) claim that MR has the potential to reduce costs by reducing errors and redundancy. Economists disagree with the MR analysis. Cost savings may be difficult to estimate, and calculating the return on investment (ROI) may be difficult. This change will have economic advantages for larger corporations and disadvantages for smaller ones (West et al., 2024). This difference implies that financial viability is determined by industry adoption rates and business size.

6.3 Integration Challenges and Technological Compatibility

MR integration into traditional construction approaches poses challenges for data synchronization and interoperability. According to Oraee et al. (2022), the exchange of data protocols and integration with BIM systems should be smooth. The building industry may be slow to adopt updated technologies, a trend reinforced by the steep learning curve of MR technology, which poses a barrier to its use (Hwang et al., 2022). Some studies claim that integration issues can be alleviated through gradual adoption and industry-wide standardization of MR technology (Soltani et al., 2023). It is imperative to note, however, that opinions differ regarding the level of customization required. Although some workers argue that uniform MR solutions should be adopted across the industry, it is believed that specific building procedures require a tailored approach that would entail additional fees and complexity (Abbasnejad et al., 2024).

6.4 User Training and Workforce Adaptation

Construction professionals' technological knowledge significantly determines the success of MR adoption. Maqsoom et al. (2023) noted that in-depth user training programs are required, as without appropriate knowledge, the MR potential may be diminished. Nevertheless, as observed by Dallasega et al. (2023), resistance to change has been a major challenge, especially among experienced construction workers who are accustomed to traditional processes even after training. Studies have shown that successful MR implementation needs technical skills and practice. The question about the most appropriate education course is controversial. Even though some experts support formal training systems, on-the-job training within a larger program is suggested (Nwaogu et al., 2024).

6.5 Safety and Risk Mitigation

MR has been shown to improve safety on building sites by enhancing safety training and the recognition of dangers. Wu et al. (2022) note the potential of Virtual Reality (VR) as a component of MR to simulate hazardous conditions, thereby enabling employees to train safety measures in a controlled, safe setting. This observation is consistent with Xu et al. (2020), who found that immersive MR training can enhance awareness of workplace safety measures, thereby minimizing workplace accidents. However, some believe that MR is too dependent on online education. Although VR-based simulation provides high-quality training, experience cannot be substituted (Abotaleb et al., 2023). Ramos-Hurtado et al. (2022) caution that overemphasizing MR safety precautions may give employees the perception that they are safe, thereby concealing them from safety risks.

6.6 Client Satisfaction and Communication Improvements

MR enables real-time visualization of the project, which is feasible and convenient for customers and contractors. According to Omrany et al. (2023), MR is useful for aligning expectations and project outcomes by enabling interaction with online simulations of building projects. It has been linked to improved communication with clients via MR, as MR reduces misunderstandings and encourages real-time feedback (Wen & Gheizari, 2020). Meanwhile, MR's effectiveness in communicating with clients is not consistently accepted across studies. Despite arguments that MR makes people more open, some believe that non-technical clients cannot grasp MR models, leading to misconceptions rather than clarity (Harikrishnan et al., 2021). It means that, even though MR can enhance communication with clients, its use will be limited to digital visualization knowledge.

6.7 Regulatory Compliance and Legal Considerations

The legal environment in the construction industry is continuously changing. Ruzakova & Grin (2020) state that MR data should comply with regulations, such as licensing requirements and intellectual property rights. In addition, the potential legal consequences of MR in the digital context should be considered, as they may create a weakness (Girgin et al., 2023). Imbalanced MR rules in construction may create confusion among contractors. There are also experts in the more restrictive industry who argue that excessive statutory limitations can harm creativity and delay MR applications.

6.8 Data Security and Privacy Challenges

The emergence of MR raises concerns about privacy and data security. The authors of the study, Tanga et al. (2022), note the importance of effective cybersecurity policies and the possibility of unauthorized access to confidential project information. One of the major determinants of stakeholder confidence is MR-generated data integrity and anonymity. How security issues should be dealt with is not agreed upon. Even though the other authors propose company-specific security controls tailored to the business's particular needs, others argue that industry-wide cybersecurity controls should be implemented (de Soto et al., 2022).

6.9 Accessibility and Digital Inclusion

The problem of digital inclusion and access comes with the introduction of MR technology and especially affects smaller construction companies with limited resources. MR will widen digital inequalities, as it will be used effectively only by large companies, as Liu et al. (2024) warn. Even though other research indicates that the intervention and financing of the government can further increase the availability of MR, others also think that the natural course of technological development will finally lead to lowering the price of it, which will allow smaller companies to afford it in the long term (Elliott & Olbina, 2023).

6.10 Sustainable Construction Practices and Long-Term Viability

MR makes things easier, reduces material waste, and enhances resource utilization to promote sustainable structures. Ogunseiju et al. (2021) remark that the more precise the use of materials, which is facilitated by visualization tools through MR, the less harmful it can be to the environment due to a decrease in demand. How well MR adjusts to changing times will determine its long-term viability. This is compared with changing industry norms. Cheng et al. (2020) are also concerned about technology obsolescence, as they believe that the rapid pace of change in MR can make existing spending habits obsolete within several years. This raises the question of whether MR acceptance should be undertaken cautiously to prevent premature obsolescence.

6.11 Hypothesis Result

This synthesis and literature review, as a systematic literature review, rejects the null hypothesis (H0). The findings validate the alternative hypothesis (H1) that the application of Mixed Reality in construction is an effective tool for enhancing project efficiency, as perceived by contractors. It is not a conjecture based on inconclusive facts, but on voluminous empirical evidence. This shows that the implementation benefits are concrete and outweigh the problems. The rationale for (H1) is that the results of different studies are similar.

1. **Reduce Errors and Rework.** MR enables space conflicts and errors during installation and instantly eliminates costly corrective actions by providing a more precise representation of BIM models in the field (Dai et al., 2021; Chalhoub & Ayer, 2018).
2. **Accelerates Task Completion.** According to the literature, time savings can be measured in large processes, such as layout (Huang, 2020) and inspections (Chi et al., 2022). This results in a 25% reduction in inspection time, with a direct positive impact on workflow.
3. **Improves Coordination and Communication.** MR helps establish mutual understanding among stakeholders and minimize communication gaps (El Ammari & Hammad, 2019; Sepasgozar et al., 2023).

Although high initial costs, interoperability problems, and a steep learning curve are well-documented serious problems (Hwang et al., 2022), the literature presents them as barriers to implementation rather than as nullifiers of MR effectiveness. The most significant result is that, when such obstacles are actively addressed (through strategic investment, training, and gradual integration), the overall impact of these barriers on efficiency is quite favorable. Thus, the weight of the evidence is conclusive in favor of H1.

7. Discussion

The results of this systematic review summarize a fundamental contradiction in the uptake of MR: a demonstrated high level of potential is repeatedly counterbalanced by a web of persistent obstacles to adoption, leaving the industry in a frozen developmental phase. This discussion extends beyond enumerating such contradictions to propose a conceptual framework for their causes. We hypothesize that the seeming contradictions in the literature are caused by three inherent, mutually reinforcing gaps that, together, make it difficult to advocate for and implement MR adoption by a contractor.

7.1 The Measurement Gap: The Intangible ROI Dilemma

In this review, a fundamental dissonance is identified: there is consensus that MR can achieve efficiency gains, yet inconsistent reporting of the value achieved. The essence of this dissonance lies not in the deprivation of benefits but in a drastic failure of the methods used to measure value. The literature also includes studies showing increases in task-level efficiency (e.g., a 25% reduction in inspection time). Still, they lack strong, standardized frameworks to quantify intangible benefits such as improved client satisfaction, enhanced collaboration, and avoided costs from rework or safety incidents (Sompolgrunk et al., 2023). The value of MR is usually preventive and intangible, making it difficult to capture in traditional project accounting models (Wang et al., 2023). This is a vicious circle where high initial expenditures cannot be justified without strong ROI data, but they cannot produce that data without being widely adopted. This measurement divergence can be seen as the reason for the efficiency gains being recorded alongside widespread financial reluctance among contractors.

7.2 The Implementation Gap: Beyond Technical Training to Change Management

The misunderstanding of the most effective training and integration practices indicates a lack of consideration of human and organizational factors in available studies. Although research can be effective in identifying problems such as user resistance and training requirements, it is not always successful in developing an action plan that can be scaled to others. It is not whether training is required, but rather what an effective training program is to implement in a diverse workforce, and how it can become Part of a continuous learning culture (Naing et al., 2022). Moreover, the literature reports resistance to change, but provides little synthesis of established change management protocols. This is based on the specifics of the socio-technical context of the construction industry. This implementation gap indicates that the difficulty lies not in the technology's usability. Instead, it lies in the lack of a clear roadmap for the human and organizational transition required by the technology.

7.3 The Systemic Gap: Interoperability as an Industry-Wide Failure

The constant confusion about interoperability and data standards stems from their misrepresentation as technical obstacles. As a matter of fact, they are a major systemic failure that requires unprecedented cooperation from the industry. The existing system of competing proprietary ecosystems and the absence of standardized data exchange protocols (Delgado et al., 2020; Demirkesen & Tezel, 2022) create information silos that undermine the very essence of MR's value proposition. To a contractor, this systemic gap would turn the issue of adoption into not merely knowing about the capabilities of MR, but instead needing to traverse a disjointed technological environment, which may necessitate expensive custom solutions and workarounds.

This discussion unifies these conflicting issues into a logical gap Model. This Model more comprehensively explains the paradox of MR adoption compared to previous literature. It shows that the barriers are not independent but mutually reinforced; the measurement gap increases perceived risk, which is compounded by implementation and systemic gaps. As such, the way to go is a multi-pronged approach that focuses on all three areas simultaneously, not individually.

8. Conclusion

This systematic literature review assesses the effects of Mixed Reality (MR) on a project's efficiency, as perceived by contractors. The study supports the second hypothesis (H1), which proves that MR results in quantifiable changes in spatial accuracy, collaboration, and safety performance. Minimized rework, faster task completion, and better resource allocation represent the disruptive power of MR in the construction sector.

This potential, however, is not necessarily fulfilled. The journey to successful adoption is full of challenges, which the review has encapsulated into three main gaps: Measurement, Implementation, and Systemic. Academia and industry need to be strategic and collaborative to embrace MR fully. This framework has the following implications, resulting in the following recommendations and findings. The large start-up cost requires a long-term emphasis on ROI. Contractors must consider implementing in stages, starting with high-value use cases such as complex MEP assemblies or client presentations. This will demonstrate clear value and develop a solid business case for further rollout.

There should be equal investment in technological capital and human capital. In addition to training in technical skills, it is necessary to design comprehensive change management programs to eliminate workforce resistance and to use technology to the maximum extent possible. This involves developing standardized industry-wide training protocols. Moreover, data synchronization cannot be addressed by individual companies. Cooperation among software developers, contractors, and standard bodies in developing open standards and common data protocols is vital to ensuring seamless integration of MR with existing digital tools such as BIM.

Academia is key to filling in the mentioned gaps. The future work should not be technical feasibility research but rather the creation of sound frameworks for quantifying the intangible benefits of MR and the total cost of ownership. Moreover, the consequences of applying change management strategies and the legal aspects of the data generated by MR must be explored as soon as possible. To become a transformative technology rather than a divisive one, MR needs to develop scalable solutions and financial models that make it accessible to small and medium-sized enterprises (SMEs). Moreover, it would be advisable to develop MR further to minimize waste and improve resource management, thereby facilitating sustainable building activities.

Mixed Reality is a paradigm shift, but the construction industry is moving toward integrating it into project delivery. Even though MR is effective, it isn't easy to apply it on a large scale. The barriers to MR can be overcome through a strategic, human-centered, and collaborative approach that yields significant gains in efficiency, safety, and overall project success.

9. References

Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. Leadership and management in engineering, 11(3), 241-252.

Ayinla, K. O., & Adamu, Z. (2018). Bridging the digital divide gap in BIM technology adoption. Engineering, construction and architectural management, 25(10), 1398-1416.

Aguinis, H., Ramani, R. S., & Alabduljader, N. (2023). Best-practice recommendations for producers, evaluators, and users of methodological literature reviews. Organizational research methods, 26(1), 46-76.

Alizadehsalehi, S., Hadavi, A., & Huang, J. C. (2019, June). BIM/MR-Lean construction project delivery management system. In 2019 IEEE technology & engineering management conference (TEMSCON) (pp. 1-6). IEEE.

Assaad, R., El-Adaway, I. H., & Abotaleb, I. S. (2020). Predicting project performance in the construction industry. Journal of construction engineering and management, 146(5), 04020030.

Ahmed, Y. A., Shehzad, H. M. F., Khurshid, M. M., Abbas Hassan, O. H., Abdalla, S. A., & Alrefai, N. (2024). Examining the effect of interoperability factors on building information modelling (BIM) adoption in Malaysia. Construction Innovation, 24(2), 606-642.

Abbasnejad, B., Soltani, S., Karamoozian, A., & Gu, N. (2024). A systematic literature review on the integration of Industry 4.0 technologies in sustainability improvement of transportation construction projects: state-of-the-art and future directions. Smart and Sustainable Built Environment.

Abotaleb, I., Hosny, O., Nassar, K., Bader, S., Elrifaee, M., Ibrahim, S., ... & Sherif, M. (2023). An interactive virtual reality model for enhancing safety training in construction education. Computer Applications in Engineering Education, 31(2), 324-345.

Akpe, O. E. E., Mgbame, A. C., Ogbuefi, E., Abayomi, A. A., & Adeyelu, O. O. (2022). The role of adaptive BI in enhancing SME agility during economic disruptions. *International Journal of Management and Organizational Research*, *1*(1), 183-198.

Blak Bernat, G., Qualharini, E. L., Castro, M. S., Barcaui, A. B., & Soares, R. R. (2023). Sustainability in project management and project success with virtual teams: A quantitative analysis considering stakeholder engagement and knowledge management. Sustainability, 15(12), 9834.

Babaeian Jelodar, M., & Sutrisna, M. (2022). Guest editorial: Working smarter by applying advanced technologies in construction: enhancing capacity and capability in construction sector for infrastructure project delivery. Journal of Engineering, Design and Technology, 20(4), 861-865.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Cheng, J. C., Chen, K., & Chen, W. (2020). State-of-the-art review on mixed reality applications in the AECO industry. Journal of Construction Engineering and Management, 146(2), 03119009.

Colabaga Don, M., & Axéll Gholizadeh, E. (2023). Standardization Beyond Compliance: A Study on BIM Standardization in the Swedish AEC Industry from a Contractor's Perspective.

Camacho, D. D., Clayton, P., O'Brien, W. J., Seepersad, C., Juenger, M., Ferron, R., & Salamone, S. (2018). Applications of additive manufacturing in the construction industry–A forward-looking review. Automation in construction, 89, 110-119.

Chi, H. L., Kim, M. K., Liu, K. Z., Thedja, J. P. P., Seo, J., & Lee, D. E. (2022). Rebar inspection integrating augmented reality and laser scanning. Automation in Construction, 136, 104183.

Chalhoub, J., & Ayer, S. K. (2018). Using Mixed Reality for electrical construction design communication. Automation in construction, 86, 1-10.

Chen, X., Chang-Richards, A. Y., Pelosi, A., Jia, Y., Shen, X., Siddiqui, M. K., & Yang, N. (2022). Implementation of technologies in the construction industry: a systematic review. Engineering, Construction and Architectural Management, 29(8), 3181-3209.

Delgado, J. M. D., Oyedele, L., Demian, P., & Beach, T. (2020). A research agenda for augmented and virtual reality in architecture, engineering and construction. Advanced Engineering Informatics, 45, 101122.

Demirkesen, S., & Tezel, A. (2022). Investigating major challenges for industry 4.0 adoption among construction companies. Engineering, Construction and Architectural Management, 29(3), 1470-1503.

Dai, F., Olorunfemi, A., Peng, W., Cao, D., & Luo, X. (2021). Can mixed reality enhance safety communication on construction sites? An industry perspective. Safety Science, 133, 105009.

Dolla, T., Jain, K., & Delhi, V. S. K. (2023). STRATEGIES FOR DIGITAL TRANSFORMATION IN CONSTRUCTION PROJECTS: STAKEHOLDERS'PERCEPTIONS AND ACTOR DYNAMICS FOR INDUSTRY 4.0. Journal of Information Technology in Construction, 28.

de Soto, B. G., Georgescu, A., Mantha, B., Turk, Z., Maciel, A., & Sonkor, M. S. (2022). Construction cybersecurity and critical infrastructure protection: new horizons for Construction 4.0. J. Inf. Technol. Constr., 27, 571-594.

Dallasega, P., Schulze, F., & Revolti, A. (2023). Augmented Reality to overcome Visual Management implementation barriers in construction: a MEP case study. Construction management and economics, 41(3), 232-255.

El Ammari, K., & Hammad, A. (2019). Remote interactive collaboration in facilities management using BIM-based mixed reality. Automation in Construction, 107, 102940.

Edirisinghe, R. (2019). Digital skin of the construction site: Smart sensor technologies towards the future smart construction site. Engineering, Construction and Architectural Management, 26(2), 184-223.

Elliott, J. W., & Olbina, S. (2023). Benefits and obstacles to the adoption of reality capture technologies in the US Commercial and infrastructure construction sectors. Buildings, 13(3), 576.

Eastman, C. M. (2011). BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. John Wiley & Sons.

Fobiri, G., Musonda, I., & Muleya, F. (2022). Reality capture in construction project management: A review of opportunities and challenges. Buildings, 12(9), 1381.

Girgin, S., Fruchter, R., & Fischer, M. (2023). A case study towards assessing the impact of mixed reality-based inspection and resolution of MEP issues during construction. Journal of Information Technology in Construction, 28.

Hwang, B. G., Ngo, J., & Teo, J. Z. K. (2022). Challenges and strategies for the adoption of smart technologies in the construction industry: The case of Singapore. Journal of Management in Engineering, 38(1), 05021014.

Hassan, P. F., Noor, M. S. M., & Mohammad, H. (2021). Challenges in education and training to develop malaysian construction workforce. International Journal of Sustainable Construction Engineering and Technology, 12(2), 53-69.

Hashem M. Mehany, M. S., Killingsworth, J., & Shah, S. (2021). An evaluation of training delivery methods' effects on construction safety training and knowledge retention-a foundational study. International Journal of Construction Education and Research, 17(1), 18-36.

Huang, Y. (2020). Evaluating mixed reality technology for architectural design and construction layout. Journal of civil engineering and construction technology, 11(1), 1-12.

Harikrishnan, A., Abdallah, A. S., Ayer, S. K., El Asmar, M., & Tang, P. (2021). Feasibility of augmented reality technology for communication in the construction industry. Advanced Engineering Informatics, 50, 101363.

Kahale, L. A., Elkhoury, R., El Mikati, I., Pardo-Hernandez, H., Khamis, A. M., Schünemann, H. J., ... & Akl, E. A. (2022). Tailored PRISMA 2020 flow diagrams for living systematic reviews: a methodological survey and a proposal. F1000Research, 10, 192.

Li, Y., Song, Y., Wang, J., & Li, C. (2019). Intellectual capital, knowledge sharing, and innovation performance: Evidence from the Chinese construction industry. Sustainability, 11(9), 2713.

Liu, Z., He, Y., Demian, P., & Osmani, M. (2024). Immersive technology and building information modeling (BIM) for sustainable smart cities. Buildings, 14(6), 1765.

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. IEICE TRANSACTIONS on Information and Systems, 77(12), 1321-1329.

Manzoor, B., Othman, I., Pomares, J. C., & Chong, H. Y. (2021). A research framework of mitigating construction accidents in high-rise building projects via integrating building information modeling with emerging digital technologies. Applied Sciences, 11(18), 8359.

Ma, Z., Cai, S., Mao, N., Yang, Q., Feng, J., & Wang, P. (2018). Construction quality management based on a collaborative system using BIM and indoor positioning. Automation in Construction, 92, 35-45.

Moore, H. F., & Gheisari, M. (2019). A review of virtual and mixed reality applications in construction safety literature. Safety, 5(3), 51.

Maqsoom, A., Zulqarnain, M., Irfan, M., Ullah, F., Alqahtani, F. K., & Khan, K. I. A. (2023). Drivers of, and barriers to, the adoption of mixed reality in the construction industry of developing countries. Buildings, 13(4), 872.

Naing, T. M., Sadeghifam, A. N., & Joo, M. S. (2022). Identifying the critical barriers factors to the implementation of building information modelling (BIM) in the Sarawak's construction industry. Civil and Sustainable Urban Engineering, 2(1), 21-32.

Newman, C., Edwards, D., Martek, I., Lai, J., Thwala, W. D., & Rillie, I. (2021). Industry 4.0 deployment in the construction industry: a bibliometric literature review and UK-based case study. Smart and Sustainable Built Environment, 10(4), 557-580.

Nwaogu, J. M., Yang, Y., Chan, A. P., & Wang, X. (2024). Enhancing drone operator competency within the construction industry: Assessing training needs and roadmap for skill development. Buildings, 14(4), 1153.

Oraee, M., Hosseini, M. R., Edwards, D., & Papadonikolaki, E. (2022). Collaboration in BIM-based construction networks: a qualitative model of influential factors. Engineering, Construction and Architectural Management, 29(3), 1194-1217.

Omrany, H., Al-Obaidi, K. M., Husain, A., & Ghaffarianhoseini, A. (2023). Digital twins in the construction industry: a comprehensive review of current implementations, enabling technologies, and future directions. Sustainability, 15(14), 10908.

Ogunseiju, O. O., Akanmu, A. A., & Bairaktarova, D. (2021). Mixed reality based environment for learning sensing technology applications in construction. Journal of information technology in construction.

Olatunde, N. A., Gento, A. M., Okorie, V. N., Oyewo, O. W., Mewomo, M. C., & Awodele, I. A. (2023). Construction 4.0 technologies in a developing economy: awareness, adoption readiness and challenges. *Frontiers in engineering and built environment*, *3*(2), 108-121.\\\s

Palmarini, R., Erkoyuncu, J. A., Roy, R., & Torabmostaedi, H. (2018). A systematic review of augmented reality applications in maintenance. Robotics and Computer-Integrated Manufacturing, 49, 215-228.

Ramos-Hurtado, J., Muñoz-La Rivera, F., Mora-Serrano, J., Deraemaeker, A., & Valero, I. (2022). Proposal for the deployment of an augmented reality tool for construction safety inspection. Buildings, 12(4), 500.

Rane, N. (2023). Integrating building information modelling (BIM) and artificial intelligence (AI) for smart construction schedule, cost, quality, and safety management: challenges and opportunities. Cost, Quality, and Safety Management: Challenges and Opportunities (September 16, 2023).

Ruzakova, O. A., & Grin, E. S. (2020). Intellectual Property Protection in the Field of Virtual and Augmented Reality Technologies (VR, AR). *Perm U. Herald Jurid. Sci.*, *49*, 502.

Sepasgozar, S. M., Khan, A. A., Smith, K., Romero, J. G., Shen, X., Shirowzhan, S., ... & Tahmasebinia, F. (2023). BIM and digital twin for developing convergence technologies as future of digital construction. Buildings, 13(2), 441.

Soltani, S., Maxwell, D., & Rashidi, A. (2023). The state of industry 4.0 in the Australian construction industry: an examination of industry and academic point of view. Buildings, 13(9), 2324.

Safikhani, S., Keller, S., Schweiger, G., & Pirker, J. (2022). Immersive virtual reality for extending the potential of building information modeling in architecture, engineering, and construction sector: systematic review. *International Journal of Digital Earth*, *15*(1), 503-526.

Sompolgrunk, A., Banihashemi, S., & Mohandes, S. R. (2023). Building information modelling (BIM) and the return on investment: a systematic analysis. *Construction Innovation*, *23*(1), 129-154.

Tang, X., Wang, M., Wang, Q., Zhang, J., Li, H., & Tang, J. (2022). Exploring Technical Decision-Making Risks in Construction Megaprojects Using Grounded Theory and System Dynamics. Computational Intelligence and Neuroscience, 2022(1), 9598781.

Tsz Wai, C., Wai Yi, P., Ibrahim Olanrewaju, O., Abdelmageed, S., Hussein, M., Tariq, S., & Zayed, T. (2023). A critical analysis of benefits and challenges of implementing modular integrated construction. International journal of construction management, 23(4), 656-668.

Tanga, O., Akinradewo, O., Aigbavboa, C., & Thwala, D. (2022). Cyber attack risks to construction data management in the fourth industrial revolution era: a case of Gauteng province, South Africa. Journal of Information Technology in Construction, 27.

Turner, C. J., Oyekan, J., Stergioulas, L., & Griffin, D. (2020). Utilizing industry 4.0 on the construction site: Challenges and opportunities. *IEEE Transactions on Industrial Informatics*, *17*(2), 746-756.

Vasilevski, N., & Birt, J. (2020). Analysing construction student experiences of mobile mixed reality enhanced learning in virtual and augmented reality environments. Research in Learning Technology, 28.

Wang, J., Zhang, S., Fenn, P., Luo, X., Liu, Y., & Zhao, L. (2023). Adopting BIM to facilitate dispute management in the construction industry: A conceptual framework development. Journal of Construction Engineering and Management, 149(1), 03122010.

Wang, K., Guo, F., Zhou, R., & Qian, L. (2024). Implementation of augmented reality in BIM-enabled construction projects: a bibliometric literature review and a case study from China. Construction Innovation, 24(4), 1085-1116.

West, J., Evangelista, A., Siddhpura, M., & Haddad, A. (2024). Asset maintenance in Australian commercial buildings. Frontiers in Built Environment, 10, 1404934.

Wu, S., Hou, L., Zhang, G. K., & Chen, H. (2022). Real-time mixed reality-based visual warning for construction workforce safety. Automation in Construction, 139, 104252.

Wen, J., & Gheisari, M. (2020). Using virtual reality to facilitate communication in the AEC domain: A systematic review. Construction Innovation, 20(3), 509-542.

Wei, C., Huang, K., Zhang, N., Qin, X., & Siddique, A. (2021). Discussion on ecological protection technology of high and steep slope of expressway. In IOP Conference Series: Earth and Environmental Science (Vol. 632, No. 2, p. 022022). IOP Publishing.

Xu, Z., & Zheng, N. (2020). Incorporating virtual reality technology in safety training solution for construction site of urban cities. Sustainability, 13(1), 243.