International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

A Study on the Driving Factors Influencing the Adoption of Augmented Reality during Construction Phase In Construction Projects

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ABSTRACT:

This study investigates the driving factors influencing the adoption of Augmented Reality (AR) during the construction phase of construction projects. Utilizing the Technology-Organization-Environment (TOE) framework, the research identifies key factors that affect the implementation of AR technology, including technological readiness, organizational culture, and environmental conditions. Through a comprehensive literature review and analysis of industry practices, the study highlights both the benefits of AR, such as enhanced efficiency and improved collaboration, and the challenges that hinder its adoption, including high costs and resistance to change. The findings emphasize the need for organizations to invest in technology, foster an innovation-friendly culture, and provide necessary training to maximize the potential of AR in construction. Future research directions are suggested to explore the long-term impacts of AR and emerging trends that may shape its use in the industry.

Keywords: Augmented Reality, Construction Phase, Technology Adoption, TOE Framework, Implementation Challenges

INTRODUCTION:

The construction industry has long been characterized by its complex and dynamic nature, often facing challenges related to inefficiencies, communication gaps, and safety concerns. In recent years, the emergence of digital technologies, particularly Augmented Reality (AR), has offered innovative solutions to address these persistent issues. AR enhances the construction process by overlaying digital information onto the physical environment, thereby facilitating real-time visualization and interaction with project data. This transformative technology has the potential to improve decision-making, enhance collaboration among stakeholders, and increase overall project efficiency. However, despite its promise, the adoption of AR in the construction phase remains inconsistent. Various factors influence the extent to which organizations embrace this technology, ranging from technological readiness and organizational culture to external environmental influences. Understanding these driving factors is crucial for fostering a conducive environment for AR implementation and maximizing its benefits. This study aims to explore the multifaceted driving factors that influence the adoption of Augmented Reality during the construction phase of projects. By examining technological, organizational, and environmental aspects through the lens of established frameworks such as the Technology-Organization-Environment (TOE) model, this research seeks to provide valuable insights into the current state of AR adoption in construction. Additionally, identifying the barriers and enablers of AR implementation will contribute to the development of strategies that facilitate smoother integration of this technology into construction practices. Ultimately, this study aspires to not only advance academic knowledge in this field but also offer practical recommendations for industry stakeholders aiming to leverage AR for improved construction outcomes.

LITERATURE RIEVEW:

Turner et al. (2020) explores the potential of Industry 4.0 technologies, such as digital twin applications, smart wearables, data analytics, and robotics, to address key challenges in construction in their paper *"Utilizing Industry 4.0 on the Construction Site: Challenges and Opportunities."* The study identifies problems like increasing project complexity, low productivity, labor shortages, lack of worker productivity data, and security risks from digital connections. Proposed solutions include adopting Industry 4.0 technologies to enhance productivity, using digital tools for worker training, implementing data analytics for cost estimation, and improving safety with digital twins. Future research is suggested in areas like smart fabrics, data repositories, autonomous vehicles, and digital twin adoption. Existing literature highlights gaps in real-time data integration and safety practices on construction sites.

Nishara et al. (2022) investigate the usability of a mobile augmented reality (AR) application for enhancing safety and productivity during the excavation process in construction in their paper *"The Usability of a Novel Mobile Augmented Reality Application for Excavation Process Considering Safety and Productivity in Construction."* Using a mixed-methods approach, both quantitative and qualitative data were analyzed to understand user satisfaction, usability challenges, and site-specific factors. Key problems included dissatisfaction with auditory aspects, lack of technical support, outdated machinery, and financial concerns hindering adoption. The study suggests improvements such as upgrading machinery, enhancing safety features, and adding self-levelling systems in the app. Future research should extend AR applications to multi-user experiments and validate findings across countries. The literature review highlights gaps in AR's application to excavation processes, emphasizing the need for further research on immersive experiences and technology adoption.

Mitterberger et al. (2023) developed a custom augmented reality (AR) system for bricklaying, integrating human-machine interaction to enhance craftsmanship and construction accuracy. The system uses visual-inertial tracking and edge-detection to guide brick placement with real-time precision and includes gamification elements for bricklayers. Despite improvements in precision and speed, challenges such as alignment issues between digital and physical models, novice user difficulties, and technical limitations due to substantial movement of bricklayers were observed. Future research aims to integrate AR with robotic fabrication, improve user interfaces, and explore collaborative human-machine systems in construction.

Abdalrahman Elshafey et al. (2023) developed a Technology Acceptance Model (TAM3) for integrating Augmented Reality (AR) and Building Information Modeling (BIM) in the construction industry, focusing on user acceptance among construction professionals in four developing countries. The study utilized a literature review and a questionnaire survey, incorporating demographic and TAM3 factors analyzed through reliability and regression analyses. Key findings revealed slow digital adoption and limited automation in the industry, with the EFA identifying critical influencing factors on user acceptance. Limitations included challenges in generalizing results due to sample size, and future research is recommended to involve larger samples and explore differences between developing and developed countries, as well as to enhance software usability and enjoyment.

Narges Ashtari et al. (2020) conducted a qualitative study to explore the current practices, challenges, and opportunities in creating Augmented and Virtual Reality (AR/VR) applications, focusing on creators new to the field. The research involved semi-structured interviews with 21 AR/VR creators who had recently worked on projects, excluding experienced developers to gain a broader perspective. Key challenges identified included difficulties in selecting appropriate authoring tools, debugging applications, and a lack of formal user testing and design guidelines. Recommendations included developing concrete design guidelines, updating tutorials, integrating debugging tools, and enhancing learning opportunities for end-user developers. The study highlights the need for community support and suggests future research should further investigate the challenges faced by AR/VR creators, particularly emphasizing the integration of testing tools and recognizing end-user developers as a significant contributor to AR/VR development.

Juan Manuel Davila Delgado et al. (2020) investigated the drivers and limitations of Augmented Reality (AR) and Virtual Reality (VR) adoption in the construction industry using a mixed research methodology that combined qualitative and quantitative approaches. The study involved four exploratory workshops with experts and focus group discussions to identify both driving and limiting factors, complemented by a questionnaire for quantitative analysis. Key limitations identified included high costs of hardware and training, specialized equipment requirements, skill shortages, and a fragmented industry structure. Recommendations for stakeholders included developing specific adoption strategies, short- and medium-term action plans, and addressing non-technical issues while focusing on workforce upskilling. The study emphasizes the need for further research on missing capabilities in AR and VR technologies and detailed cost-benefit studies to demonstrate their value, highlighting the complex dynamics surrounding the adoption of these technologies in the construction sector.

Ong, Mesman, and Yeam (2014) examined the challenges and prospects of utilizing Virtual Reality (VR) and Augmented Reality (AR) among primary school teachers in a developing country context, focusing on improving science education through technology. The study employed a qualitative approach, conducting semi-structured interviews with primary school science teachers using purposeful and snowball sampling techniques. Key challenges identified included a lack of teacher competency in using VR and AR, limited instructional design for VR, insufficient resources for effective utilization, and time constraints for students to master these technologies. Recommendations included providing teacher training, ensuring equipment availability, developing tailored instructional designs, implementing Bring Your Own Device (BYOD) policies, and creating engaging learning materials. The study suggests future research should involve larger and more diverse teacher samples, explore additional technologies, and consider environmental and technical support factors affecting VR and AR utilization in education

Ong, Mesman, and Yeam (2021) conducted a mixed-systematic review to explore the role of digital technologies in the Architecture, Engineering, and Construction (AEC) industry, focusing on tools like Building Information Modeling (BIM), augmented reality, and their implications for construction management and civil engineering. The study involved quantitative bibliometric analysis of 11,047 publications from Scopus, refining the literature to a final selection of 200 relevant articles from 1975 to 2020. Key challenges identified included inadequate expertise in digital technologies, cultural barriers, high costs, resistance to change, security risks, and insufficient demand for digital solutions from clients. The authors recommended developing strategies to address these challenges, enhancing research on blockchain, cybersecurity, and energy consumption techniques, and further investigating the impact of digital technologies on construction safety. The study highlights knowledge gaps and suggests future directions for research in the AEC sector.

Tariq Masood and Johannes Egger (2019) investigated the success factors and challenges of Industrial Augmented Reality (IAR) using the Technology, Organization, Environment (TOE) framework. The study included 22 field experiments with assembly operators and field technicians, following ethical approval from the University of Cambridge. Key findings emphasized the importance of focusing on organizational issues over purely technological aspects, highlighting the need for user acceptance through customizable instructions and the adaptation of shop floor processes for AR integration. Recommendations included addressing scalability challenges in software applications, providing training to alleviate resistance to change, and integrating AR with existing enterprise systems. The study outlines implications for both academia and industry, discusses its limitations, and suggests further research on organizational fit and compatibility in the implementation of IAR, grounding its findings in established academic theory.

Patrick Dallasega et al. (2020) explored the integration of Lean Construction Management with Building Information Modeling (BIM), Augmented Reality (AR), and Virtual Reality (VR) technologies to enhance project performance. The methodology applied Lean Construction principles alongside the Last Planner System (LPS) for scheduling, utilizing the Villego® simulation game to facilitate practical learning for students through collaborative planning and execution tasks. Data collection focused on metrics like construction time, safety breaches, and material waste, leading to continuous improvement processes based on task analysis. Challenges included lower-than-expected tablet usage, complications with VR for users lacking training, and mixed feedback on AR's utility. The study advocates for implementing Lean methodologies, improving information sharing with BIM, and using AR and VR for enhanced project visualization. Future research directions suggest exploring broader applications of these technologies, assessing their long-term impacts, and evaluating collaboration dynamics within real-world construction settings. The research is part of the EU-funded COCkPiT project and highlights improvements in Key Performance Indicators through the integration of advanced technologies.

Oscar Danielsson, Magnus Holm, and Anna Syberfeldt (2023) examined the current status and future challenges of Augmented Reality Smart Glasses (ARSG) in industrial assembly applications. Their methodology involved designing lean production processes for new products, with a cross-functional team evaluating alternatives based on lean criteria and testing configurations with simple materials. The study identified several limitations of ARSG, including current battery technology restricting full-day use, insufficient overlay accuracy, and the technology's immaturity in industrial contexts. It also highlighted challenges related to user interface design, reliability, and work safety. The authors emphasized that AR can simplify information for assembly operators and provide effective decision support in complex environments but called for improved user interfaces, enhanced battery life, and the development of standards for human-machine interaction. Future research directions include validating ARSG integration processes, exploring ergonomic and economic aspects, surveying operators' perspectives, and systematic testing of ARSG to ensure efficient implementation in production systems. The study underlines the need for improved authoring tools and the validation of ARSG content to enhance their application in manufacturing engineering.

L. Barazzetti et al. (2015) explored the generation process of Hybrid Building Information Modeling (HBIM) and its integration with augmented reality applications, focusing on cultural heritage documentation and user community engagement. The methodology involved creating detailed HBIM from various data sources, primarily through laser scanning and photogrammetry, supported by a geodetic network for accurate registration. Challenges identified included the high operational demands of detailed HBIM on mobile devices, memory limitations, the lack of commercial software for managing geometric complexity, and potential information loss during model format conversions. The authors emphasized the need for advanced software to handle geometric intricacies and suggested using augmented reality to enhance user interaction with cultural heritage. Recommendations included developing interoperable file formats to minimize data loss and creating specialized families for complex model openings. Future research aims to expand the use of BIM technology among broader user communities and to address mobile device memory issues, fostering interaction between users and cultural heritage while promoting interactive learning and preservation efforts.

Jeevan Devagiri et al. (2021) conducted a systematic review of the advancements and challenges associated with the integration of Artificial Intelligence (AI) and Augmented Reality (AR) in industrial applications. The methodology assessed various tools, techniques, and platforms that leverage AI within AR, focusing on hybrid prototyping techniques for assembly assessment and the role of AR interfaces in early product design and planning. Key challenges identified included inaccuracies and instability in algorithms for mesh reconstruction and the complexity of location-aware communication in spatial applications. The review highlights how AI-empowered AR can enhance operational efficiency and remote collaboration, particularly for individuals with vision impairments through tools like Bright software and CoVAR. The authors suggest promising areas for future research, emphasizing the development of advanced digital artifacts, improved object detection techniques, and complex algorithms to enhance industry experiences. The paper contributes to filling existing gaps in the literature on AR and AI applications in manufacturing, providing guidelines for future investigations in this evolving field.

Bon-Gang Hwang et al. (2021) investigated the challenges and strategies for adopting smart technologies in the construction industry, specifically focusing on Singapore. The methodology included a comprehensive literature review to identify key challenges, followed by pilot interviews with industry experts to validate findings and a survey distributed to gather data from construction practitioners. Post-survey interviews provided deeper insights into the survey results, with statistical analysis performed using SPSS for data interpretation. The study identified numerous challenges, including data sharing issues, regulatory compliance, data ownership concerns, high implementation costs, lack of standards, legal uncertainties, and a shortage of skilled specialists. To address these challenges, the authors recommended training a skilled workforce, offering government incentives, enhancing communication and change management, establishing a data exchange framework, and clarifying data ownership responsibilities. Future research directions suggest exploring the impact of nonpersonalization on technology adoption, studying specific applications of smart technologies across different geographical locations, and developing a roadmap for their adoption. The study highlights the importance of aligning stakeholder interests to reduce resistance and proactively addressing regulatory compliance challenges.

Luís Fernando De Souza Cardoso et al. (2023) conducted a systematic literature review on the industrial applications of Augmented Reality (AR), focusing on its challenges, user confidence, tracking methods, and the quality and accuracy of virtual elements. Following Budgen and Brereton's guidelines, the research comprised three phases: planning, conducting, and outcomes. The planning phase established research questions and review procedures, while the conducting phase identified and evaluated previous studies, leading to insights about various industry segments, tools, and implementation challenges. Key challenges identified included hardware limitations affecting mobility and production layout, environmental noise impacting vocal command performance, user discomfort from head-mounted displays (HMDs), and issues with marker-based tracking methods. The study highlighted that AR applications can reduce the need for on-site experts and enhance remote assistance for production support. Recommendations for improving AR adoption included utilizing natural markers for tracking, investing in more affordable hardware, and optimizing real-time rendering algorithms to enhance visualization quality. Future research directions suggest investigating the environmental impacts of AR, focusing on ergonomic designs for visualization devices, and developing Internet-based mobile AR systems to overcome current technological limitations.

Ayaz Khan et al. (2021) conducted a literature review on the integration of Building Information Modeling (BIM) and immersive technologies (ImTs) in the Architecture, Engineering, and Construction (AEC) industry, employing the PRISMA method for systematic analysis. The study involved the identification, screening, eligibility, and inclusion of 444 articles, ultimately categorizing them into eight AEC-related domains using content analysis and bibliographic analysis with the Vos-Viewer tool. The review identified several challenges, including low quality and collaboration issues, difficult content creation processes, high skillset requirements, interoperability obstacles, limited battery life, and high setup costs. Additionally, issues such as motion sickness, inaccurate registration, and limited model storage capacity in extended reality (XR) devices were noted. The authors emphasized that integrating ImTs can enhance stakeholder engagement through real-time data exchange between BIM and XR, while recommending the development of robust XR systems for data storage. Future research directions include exploring ImTs in modular construction, addressing technological limitations, and investigating risk identification using mixed reality with BIM. The study encourages further exploration of immersive technologies across various AEC sectors and highlights the importance of incorporating sustainable development goals into future research.

Hyojoo Son et al. (2015) explored advancements in as-built data acquisition and its applications in production monitoring within civil infrastructure projects. The study employed a methodology involving 3D data collection, utilizing 4D Building Information Modeling (BIM) and 3D point clouds to measure progress. It emphasized the importance of aligning as-built data with as-planned models and featured hybrid approaches that combined photogrammetry and laser scanning for enhanced accuracy. The authors identified challenges, including incomplete design documents that hinder accurate recordings of as-built conditions, difficulties in tracking decision-based changes during construction, and subtle deviations due to poor workmanship that are hard to document. The study advocates for the development of fully automated 3D reconstruction methods and algorithms capable of effectively handling incomplete point clouds. It also highlights the need for improved integration of photogrammetry and laser scanning to enhance accuracy and the potential for automated modeling to accurately track construction progress. Future research directions include enhancing automation in construction tasks, fostering collaboration between academia and industry, and exploring automation in additional tasks like dismantling and renovation, while emphasizing the need for further developments in analyzing 3D as-built data.

Patrick Dallasega et al. (2018) conducted a systematic literature review to investigate the role of Industry 4.0 as an enabler of proximity in construction supply chains. The methodology involved a three-step approach—planning, conducting, and documenting the review—resulting in the identification of 178 relevant publications through comprehensive keyword searches across multiple databases. The findings revealed that poor integration of new technological competencies often leads to inefficiencies, while incompatible technologies hinder data transfer and harmonization of processes. Communication issues were noted as sources of costly production waste, and a reluctance among subcontractors to adopt new technologies was highlighted. The authors emphasized that Industry 4.0 concepts could enhance inter-organizational collaboration, with digital transformation keys such as data, automation, connectivity, and access being crucial for improving performance. They suggested that Building Information Modeling (BIM) could further enhance collaboration and efficiency within construction supply chains by addressing communication barriers. Future research directions include evaluating the proposed framework through case studies, exploring characteristics of proximity not yet discussed in the literature, investigating the relationship between proximity aspects and Industry 4.0 concepts, and assessing the efficiency trade-offs between distance and closeness in construction supply chains.

Xianbo Zhao and Jun Wang (2017) conducted a scientometric review of research on Building Information Modeling (BIM) to analyze trends and visualize key findings. The study employed co-author, co-word, and co-citation analysis methods, analyzing a total of 614 bibliographic records using CiteSpace software for literature visualization. While the research did not identify specific problems within the BIM context, it highlighted key findings regarding BIM implementation and identified hot topics relevant to practitioners. The analysis suggested that BIM technologies effectively address management issues in construction, and it noted that collaboration among researchers is essential for enhancing BIM research outcomes.The authors recommended several avenues for future research, including exploring BIM research trends after 2016, investigating emerging technologies in BIM applications, and analyzing the impact of BIM on project outcomes. They also suggested examining collaboration patterns among BIM researchers globally, assessing the effectiveness of BIM training programs, and exploring BIM's role in sustainable construction practices. Additionally, they proposed studying the integration of BIM with other technologies, identifying gaps in current BIM literature, evaluating user experiences with BIM tools, and conducting longitudinal studies on the success of BIM implementation. Overall, the study primarily focused on engineering and construction technology, emphasizing the importance of continued exploration in the rapidly evolving field of BIM.

Akekathed Sanglub, Prachyanun Nilsook, and Panita Wannapiroon (2018) explored the integration of Imagineering, Augmented Reality (AR), and Digital Twin technologies to enhance digital competence and learning efficiency. The methodology involved a literature review on Imagineering processes and synthesized documents related to AR and Digital Twin environments. This synthesis led to the development of a conceptual framework for Imagineering in AR and Digital Twin contexts, which consists of six steps: imagination, design, development, presentation, improvement, and evaluation. This new process is referred to as ARDT (Augmented Reality and Digital Twin).The study identified several challenges associated with deploying Digital Twin technologies, such as managing complex equipment configurations, effective data management and security, and ensuring real-time synchronization between physical and virtual products. It also highlighted the need to balance the depth and breadth of Digital Twin applications.To address these challenges, the authors recommended utilizing Digital Twin for real-time problem analysis and predictions, implementing simulations to enhance product planning and development, and applying Imagineering principles to foster creative design and innovation.For future research, the authors suggested focusing on collaborative learning efficacy, exploring broader applications of Digital Twin technology, assessing the long-term impacts of Imagineering on digital competence, and analyzing the challenges of implementing Digital Twin across various industries. Overall, the study emphasizes the integration of Imagineering, AR, and Digital Twin to advance digital competence and innovation in education and industry.

Georges Younes, Rany Kahil, Mayssa Jallad, et al. (2017) examined the application of digital technologies in archaeology and cultural heritage, focusing on the Roman Theater of Byblos. The study employed a methodology that involved constructing a computerized model of the theater, which was based on historical studies that hypothesized its original shape. The researchers provided detailed procedures for creating virtual and augmented reality applications tailored to enhance the understanding and appreciation of the theater.The study acknowledged several challenges, including the theater's largely missing original structure, the scarcity of remains complicating reconstruction efforts, and the displacement of the theater affecting alignment accuracy. Additionally, visitors often struggled to appreciate the site's significance due to the poor condition of the ruins.To address these issues, the researchers developed a virtual and augmented reality application that included a low polygon count model for a navigation mesh and an obstacle avoidance system to ensure user safety. They utilized Visual Simultaneous Localization and Mapping (VSLAM) for accurate tracking and tackled lighting challenges in outdoor environments to improve performance.Looking forward, the researchers plan to apply similar digital technologies to other archaeological sites in Lebanon. The paper emphasizes the potential of digital applications to enhance cultural heritage conservation and visitor engagement through innovative modeling and historical studies.

Pauline Chauvet, Nicolas Bourdel, Lilian Calvet, et al. (2019) explored the integration of augmented reality (AR) with diffusion tensor imaging (DTI) during laparoscopic myomectomies, utilizing AR overlays with preoperative imaging to enhance endoscopic video. This approach involved fiber tracking through specialized software, enabling the assessment of water diffusion directionality in tissues and facilitating real-time visualization for surgical incision decisions. While the study identified challenges such as the high cost of the AR system and technical difficulties in achieving real-time AR in mobile organs, it emphasized the benefits of enhanced visualization of uterine muscle fibers, with DTI providing additional insights over standard MRI. The risk of uterine rupture post-myomectomy was reported at 0.7-1%, with no reliable predictive factors identified. The AR system, which operates on a standard desktop PC, has the potential to improve surgical accuracy and outcomes. Future research will focus on evaluating surgical complications and conducting a cost-effectiveness analysis of the AR system, as well as its effectiveness in various surgical procedures. The study noted the good histological correlation in tractography studies of the fibroid uterus, highlighting the importance of fiber direction evaluation in three-dimensional imaging.

Jorge Bacca, Silvia Baldiris, Ramon Fabregat, Sabine Graf (2013) conducted a systematic review of literature on augmented reality (AR) in education, adhering to PRISMA guidelines and analyzing 32 studies published between 2003 and 2013. The review highlighted the use of mixed evaluation methods for data collection, including questionnaires, interviews, and surveys, with research samples typically ranging from 30 to 200 participants. Key challenges identified included difficulties in maintaining superimposed information, usability frustrations among students, excessive focus on virtual content, and technology that interrupts natural interactions. Additionally, AR applications tended to be designed for specific knowledge fields, making it challenging for teachers to create new learning content. Recommendations included improving algorithms for tracking and image processing, conducting usability studies, and developing authoring tools for educators. The review emphasized the need for longitudinal research to assess the long-term effects of AR technology exposure and to analyze student behavior in diverse learning scenarios, advocating for personalization to foster inclusive learning. Overall, it identified significant gaps in existing systematic reviews concerning AR's educational applications and highlighted trends and opportunities for future research.

Susan Yoon, Karen Elinich, Joyce Wang, Christopher Steinmeier, Sean Tucker (2012) explored the use of augmented reality (AR) and knowledge-building scaffolds to enhance learning among middle school students during a field trip. Employing a quasi-experimental design, the study involved participants grouped into four conditions: no digital augmentations or scaffolds (Condition 1), digital augmentation only (Condition 2), light scaffolding with directed questions (Condition 3), and a combination of digital augmentation and knowledge-building scaffolds (Condition 4). Data collection included surveys, response forms, and observations, revealing that students in Condition 1 exhibited no significant knowledge increase. Notably, Conditions 3 and 4 resulted in more serious and less playful student behavior, and the rushed responses raised concerns about accurately reflecting learned concepts. The study concluded that while AR and scaffolds enhanced collaboration and improved conceptual knowledge of electrical circuits, the effectiveness of some scaffolds remained inconclusive. Recommendations for future research included deeper investigations into scaffold effectiveness, clearer directions for group work, consultations of previous answers, explanations of knowledge-building prompts, post-intervention surveys, and adjustments to mitigate over-formalization. Overall, the findings suggested that AR and scaffolding positively impact cognitive theorizing abilities in informal science learning environments, underscoring the potential of digital technologies to enhance engagement and learning outcomes.

Tariq Masood, Johannes Egger (2019) conducted a study on the implementation success factors of industrial augmented reality (AR) using a mixed methodology design that combined quantitative and qualitative survey components. They collected 84 valid questionnaires from participants contacted via emails and professional networks, utilizing the Technology, Organization, Environment (TOE) framework for the quantitative analysis, while the qualitative part aimed to uncover additional challenges not previously addressed in the literature. The study identified several significant challenges to AR implementation, including low user acceptance due to system weight and ergonomics, insufficient decoding time for QR codes, increased cognitive workload with certain scanning equipment, visual fatigue, data transfer and integration difficulties, content authoring challenges, and high implementation costs. The authors emphasized the importance of identifying critical success factors, addressing organizational issues over purely technological ones, ensuring scalability of AR solutions, involving users in the implementation process, and conducting thorough testing prior to full deployment. For future research, they suggested utilizing acceptance models at the user level, investigating process adaptations for AR, exploring operator health and safety during AR usage, and examining industry-specific challenges related to AR implementation. Overall, the study highlighted the need for a balanced focus on both technical and organizational aspects in the successful adoption of AR technologies in industry.

Shalini Chandra, Nanda Karippur, Kumar (2018) explored the factors influencing organizational adoption of augmented reality (AR) in e-commerce using the technology-organization-environment (TOE) framework. The study analyzed data collected from potential adopters in Singapore, India, and the USA, employing statistical analyses to assess common method bias and conduct validity tests, including content, convergent, and discriminant validity.

The findings indicated no serious multicollinearity issues or significant common method bias. The authors highlighted that organizations should focus on enhancing technological competence for successful AR adoption, with top management support being crucial for the implementation of AR technologies. Understanding consumer readiness was also identified as a key factor in enhancing AR adoption intentions. To attract consumers, organizations are encouraged to address the competitive advantages that AR offers and to develop strong research and development teams for effective AR integration. Future research suggestions included exploring AR adoption across different geographies, developing dynamic models to predict behavioral intentions over time, incorporating additional factors in firm-level adoption studies, and further investigating organizational acceptance of new technologies. The validated model proposed in the study could also be applied to other technologies like virtual reality. Overall, the research underscored the significance of technological, organizational, and environmental factors in the adoption of AR in the retail sector.

Tariq Masood, Johannes Egger (2019) investigated the success factors and challenges of Industrial Augmented Reality (IAR) using the technology-organization-environment (TOE) framework. The study conducted 22 field experiments, focusing on assembly tasks with assembly operators and field technicians, utilizing Microsoft HoloLens to display 3D holograms. Ethical approval was obtained from the University of Cambridge, and informed consent was collected from participants prior to the experiments. Findings revealed that low visibility of virtual content negatively affects IAR performance, integration conflicts can disrupt shop-floor processes, and expert workers may experience a higher cognitive workload when using IAR. Additionally, user experience was found to significantly influence the effectiveness of IAR solutions, and there remains a lack of widespread adoption of IAR technology. The authors emphasized the importance of addressing organizational issues over technological aspects, ensuring user acceptance through customizable instructions, adapting shop floor processes for AR integration, and developing cost-effective content authoring methods. They suggested that future research could focus on scalability challenges in software applications, provide training to mitigate resistance to change, and align AR solutions with existing enterprise systems. The study also discussed its limitations and outlined implications for both academia and industry, linking theoretical insights with practical applications in the context of IAR.

Héctor Martínez, Danai Skournetou, Jenni Hyppölä, Seppo Laukkanen, Antti Heikkilä (2014) explored the drivers and bottlenecks in the adoption of Augmented Reality (AR) applications, analyzing five major application domains including education, industry, military, travel, and tourism. The study provided an overview of common challenges in AR implementation across these fields, discussing the evolution of AR software algorithms and hardware devices while emphasizing the need for standardization in AR applications. Key challenges identified included lack of accuracy in virtual object alignment, time-consuming algorithms that hinder real-time tracking, absence of common standards for AR technology, limited flexibility in existing applications, and privacy concerns associated with new AR devices. The authors argued that standardization of AR patterns is essential for enhancing flexibility and usability, and called for the development of authoring tools to enable user-created AR applications. They suggested that future research should focus on critical design issues in AR applications, explore user acceptance and changes in technology perception, investigate collaborative AR environments for improved educational outcomes, examine AR's impact on tourism customization trends, and develop standardized methods for markerless AR systems in large facilities. Overall, the research aimed to provide insights for future AR developments by considering both developers' and users' perspectives.

Förnamn Efternamn, Tytti Viljakainen, Niklas Eriksson (2020) investigated the drivers and barriers for organizations in adopting Augmented Reality (AR), specifically in the context of repair and maintenance applications. Utilizing a qualitative and exploratory research method, the study collected data through expert interviews to identify the factors influencing AR adoption. Key findings highlighted several barriers, including low resolution and increased latency causing discomfort, distorted views due to focus distance differences, safety risks associated with AR glasses, limited computational power for complex algorithms, inaccuracies in AR techniques affecting virtual content localization, lack of organizational readiness and common goals, absence of standardization, and social acceptance issues related to AR glasses. On the positive side, the research noted that AR solutions can improve situational awareness for field workers, reduce travel costs and work hours through remote assistance, and enhance efficiency and precision in repairs by leveraging mobile and VR technologies. The authors suggested that future studies should explore AR business prospects in Finland, investigate competition with international companies utilizing AR technology, examine the impact of travel restrictions on AR digitalization, discuss user acceptance factors for further AR adoption, and analyze the merging boundaries of work, play, and learning. The literature review also encompassed technology adoption and acceptance theories, alongside the TOE framework for thematic analysis, ultimately reflecting the technical constraints as significant barriers to AR adoption.

Hala Nassereddine, Awad Hanna, Dharmaraj (2022) explored the application of Augmented Reality (AR) in the construction industry, focusing on its use cases, benefits, challenges, and future trends. The research methodology comprised three main phases: a literature review, a survey of industry practitioners, and subsequent analysis. Key findings highlighted 22 obstacles to AR implementation, categorized into Financial, Human, Organizational, Technological, and Others, with respondents assessing the impact of each obstacle. Notable challenges included a lack of skilled personnel, high implementation costs, resistance to change among stakeholders, integration issues with existing technologies, absence of industry standards for software and hardware, cultural resistance within organizations, insufficient management support for AR initiatives, and data privacy and security concerns. The study emphasized the need for a mathematical model to adjust the perceived impact of these obstacles based on familiarity and conducted cluster analysis to identify key barriers affecting AR adoption. Future research directions suggested the development of AR implementation plans for construction, the inclusion of broader datasets involving Facility Managers and Owners, the creation of a framework to assess AR benefits, the identification of metrics to measure AR impact throughout projects, and the formulation of strategies for technology integration and user buy-in. The comprehensive literature review identified 43 AR use cases and 16 potential benefits, providing a foundational understanding of AR's capabilities and challenges within the construction sector.

Bahar Dashti, Roberto Viljevac-Vasquez (2020) conducted a degree project in Architectural Design and Construction Project Management, focusing on the integration of digitalization, including Augmented Reality (AR), Virtual Reality (VR), and Building Information Modeling (BIM) within the construction industry. The study employed thematic analysis for qualitative data analysis, conducting semi-structured interviews with 13 managers, and utilized the UTAUT and TOE frameworks to guide the research, with the interview guide revised based on initial findings. Key challenges identified included a lack of client demand for BIM and AR/VR technologies, high effort expectancy hindering technology adoption, outdated work routines obstructing digitalization progress, limited knowledge of these technologies among industry professionals, and perceptions of the technologies as expensive and immature. To overcome these barriers, the study suggested increasing client demand for BIM and AR technologies, enhancing staff knowledge and training, fostering organizational structures that support innovation adoption, improving internal communication processes, and investing in AR and BIM technologies to boost efficiency. Future research directions proposed exploring the cost-effectiveness and user-friendliness of technology, investigating the long-term value of digital technologies in construction, and assessing the maturity of AR and VR technologies. The literature review highlighted that while AR improves access to construction information, there remains limited research on AR and BIM integration, with applications noted in training, safety, and architectural visualization, though managers viewed AR/VR as costly yet potentially valuable in the future.

CONCLUSION

In conclusion, the adoption of Augmented Reality (AR) in the construction phase offers significant potential to enhance efficiency and collaboration while addressing common industry challenges. This study identified key driving factors influencing AR adoption, including technological readiness, organizational culture, and environmental conditions, through the Technology-Organization-Environment (TOE) framework. While advancements in technology and increased awareness of AR's benefits are encouraging, barriers such as high implementation costs, resistance to change, and a lack of skilled personnel remain prevalent. To overcome these obstacles, organizations must invest in technology and foster a culture that embraces innovation. Additionally, developing industry standards and providing adequate training can enhance usability and effectiveness. Overall, the insights from this research can inform strategies to promote successful AR integration in construction. Future research should focus on long-term impacts of AR adoption and emerging trends that could further influence its application in the industry.

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