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PERCEIVED IMPORTANCE OF AUGMENTED/VIRTUAL/MIXED REALITY ON CONSTRUCTION TIME, COST, AND QUALITY

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Augmented, virtual, and mixed reality (AR/VR/MR) technologies enhance construction efficiency and save time and cost by enabling several functions such as collaborative and interactive simulations, visualizing data, and comparison of different designs. This study aims to evaluate the impact of AR/VR/MR implementations on project time, cost, and quality criteria and their integration with other technologies, and rank these impacts according to professionals' perceptions. To achieve the study objective, a comprehensive literature review was first conducted, followed by a questionnaire survey administered by industry representatives (i.e., civil engineers and architects). The findings indicate that AR/VR/MR technologies play a key role in eliminating reworks, time and cost overruns, and quality errors, enhancing time/cost savings, and improving quality-related processes. In addition, the construction literature revealed a high concentration of studies focusing on the integration of these technologies with Building Information Modelling (BIM). On the other hand, considering the overall results and the architects' responses, the findings show that the importance of these technologies on project performance criteria is quality, time, and cost, respectively. The findings are expected to help industry professionals understand the contributions of AR/VR/MR applications to improving project performance.

Keywords: Project scheduling, Digitalization, Construction industry, Defect management, Real-time data.

1 INTRODUCTION

Advanced technologies play a major role in quality assurance/control, performance evaluation practices, and ensuring the project adhere to the defined schedule, scope, and cost metrics (Bórquez *et al.* 2025). In this respect, this requirement provides momentum towards more collaborative and interactive experience merging physical and digital assets to delivering construction projects, such as augmented, virtual, and mixed reality (AR/VR/MR) technologies (Seyman-Guray and Kismet 2024). While VR enables the user to experience a simulated virtual environment, AR provides an interactive experience of a physical world, and MR combines elements of both AR and VR by allowing virtual and real-world objects (Maqsoom *et al.* 2023, Seyman-Guray and Kismet 2024). Although these technological implementations in construction projects entail a variety of benefits such as progress monitoring and tracking, hazard recognition and safety training in terms of safety, detection of design errors and collisions, cost estimation, and time savings (Umair *et al.* 2022, Senanayake *et al.* 2024), the adoption of these technologies

in the industry is still slightly poor. According to the study of Seyman-Guray and Kisme (2024), approximately 36% of the professionals in the Turkish construction sector utilize AR and VR technologies. Besides, a survey administered to the UK construction industry professionals showed that 50% of the respondents had adopted VR, while 30% had adopted AR (Davila Delgado *et al.* 2020).

The current literature focused on the impact of AR, VR, and MR technologies on time, cost, and quality in different project types, either as standalone tools or a tool interoperable with other technologies. For instance, Esendal and Kazaz (2025) adopted AR for visualization during the design stage of a villa project and found that AR applications drive project success by optimizing time, minimizing costs, and producing high-quality product. Bórquez *et al.* (2025) addressed the application of AR through the integration of Building Information Modelling (BIM) and ultrasonic sensors for realizing the fast and accurate rebar counting and collects real-time visual data. As such, they emphasized that low construction quality resulting from human errors can be prevented. Liang *et al.* (2025) performed a case study applying VR and BIM technologies in renovation projects and revealed that these technologies eliminated communication barriers and design errors through trial and error, resulting in time and cost savings. In addition, Maqsoom *et al.* (2023) investigated the barriers and drivers to MR adoption and found that a second significant driver was the lower project cost resulting from the potential of MR.

Although various studies have been conducted in the construction literature regarding AR/VR/MR-oriented practices, this study offers a holistic guideline for construction practitioners by addressing the constructive impacts of all, both, or one of the technological tools on time, cost, and quality performance, which constitute the research gap of this study. Moreover, this study aims to evaluate the effectiveness of AR/VR/MR technologies in terms of time, cost, and quality by using mean rank analysis. Therefore, construction professionals can benefit from the findings by focusing on the most important criteria based on the opinions of civil engineers and architects, and the specific outcomes in different performance context determined through a literature review. Overall, this study is expected to enhance the awareness of the role of modern technologies in preventing the occurrence of risks that could negatively impact construction projects.

2 METHODOLOGY

Firstly, a comprehensive literature survey was conducted to examine the effects of AR, VR, and MR technologies on construction time, cost, and quality. In this vein, related publications were retrieved from the Scopus database using the search string (TITLE-ABS-KEY ("virtual reality" OR "augmented reality" OR "mixed reality") AND TITLE-ABS-KEY ("time" OR "cost" OR "quality") AND TITLE-ABS-KEY ("construction project" OR "construction industry" OR "project management")), which resulted in 1,106 publications. The exclusion criteria used for the search strategy were: (i) including only journal articles, (ii) published in English only, and (iii) considering the studies published between 2022 up to and including January 2026. A total of 179 articles were retrieved after applying the exclusion criteria. Title/abstract investigation for each study yielded 48 studies and then full text review resulted in 41 relevant studies to be considered in this study.

Following that, nearly 500 online questionnaires were randomly sent out to participants in the Türkiye construction industry and 347 replies were received. After rechecked the background information of the respondents and removed missing data, data from an online questionnaire of 307 was used to evaluate and rank the technologies by importance. The questionnaire consisted three parts. Part 1 included several questions covering the information about participants' gender,

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proficiency as well as experience in the construction industry. Part 2 explained the definitions of three critical technological tools to the respondents, which is a crucial premise for assessing their importance level on project performance criteria. In Part 3, participants were asked to rate the importance/role of AR/VR/MR using 1 (least important) − 7 (extremely important) Likert scale. Civil engineers and architects were selected as participants in the questionnaire survey due to their practical experience and familiarity with the concepts examined in this study. The profile of the participants is presented in Table 1. More than a half of the participants had 0-10 years of construction experience (n = 185), were male (n = 203), and were civil engineers (n = 242).

Table 1. Profile of participants.

Gender		Proficiency		Working experience in the industry	
	n		n	Years	n
Male	203	Civil Engineer	242	0-10	185
Female	104	Architect	65	11-20	90
				21-40	32

3 RESULTS AND DISCUSSIONS

The results of the literature review showed that AR/VR/MR practices play important roles in achieving project objectives. As such, the practicality of these technologies demonstrates their ability to improve the effectiveness and efficiency of construction projects and provide real-time information. For instance, Alhady *et al.* (2024) and Liang *et al.* (2025) integrated these technologies into BIM and GIS to follow the trial-and-error approaches in the digital process, achieved interaction and interoperation in the virtual environment with digital model and collect the topological and geological information. These technologies also improve project time performance through time savings, reduced rework, minimized wasted time, and shorter task completion times (Ghosh and Karmakar 2023, Liu *et al.* 2025, Osorto Carrasco and Chen 2025, Sia *et al.* 2026). Such improvements can also generate substantial economic benefits. Accordingly, the literature revealed that these technologies mainly maximize cost savings, minimize reworks and cost overruns, and improve cost management (Ghosh and Karmakar 2023, Senanayake *et al.* 2024). Alhady *et al.* (2024) pointed out the concept of Extended Reality (XR) that integration of VR, AR, and MR technologies and found that simulations to the user by combining VR and AR tools with other tools contribute to cost savings in infrastructure projects such as bridges. Through a questionnaire survey, Maqsoom *et al.* (2023) addressed the critical factors in the adoption of MR and found that MRs provide satisfactory construction performance at a lower cost. Yogeeswaran *et al.* (2023) developed an AR-based solution for prefabricated construction to provide working methods with minimal cost by focusing on assembly and disassembly processes using QR codes. Although this study focuses on the various contributions of them, the financial challenges associated with their implementation such as hardware and licensing costs, model preparation effort, training burden can be faced (Marinho *et al.* 2026).

Beyond their contributions to project cost and time performance, these technologies also play a significant role in improving project quality. The literature highlights their potential to prevent quality failures, identify the root causes of defects, and enhance planning and scheduling quality (Badamasi *et al.* 2022, Nassereddine *et al.* 2022). For example, Bórquez *et al.* (2025) demonstrated that an AR-based tool integrated with ultrasonic sensor technology can support quality control and rebar inspection on construction sites. Similarly, Liao and Luo (2025) integrated AR with BIM in green construction projects and reported more accurate and real-time defect detection compared with conventional manual inspection methods, enabling immediate

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feedback. In the context of construction training, Patka *et al.* (2025) centered VR-based training model by defining different defect types, quality issues, defect causes, affected elements/materials. They concluded that participants' conceptual knowledge of construction quality and defects significantly increased through VR training. Fig. 1 provides an overview of the effects of technological tools on time, cost, and quality performance reported in the literature. It also summarizes studies on the integration of these tools with other technologies across various project types, including building, infrastructure, and renovation projects.

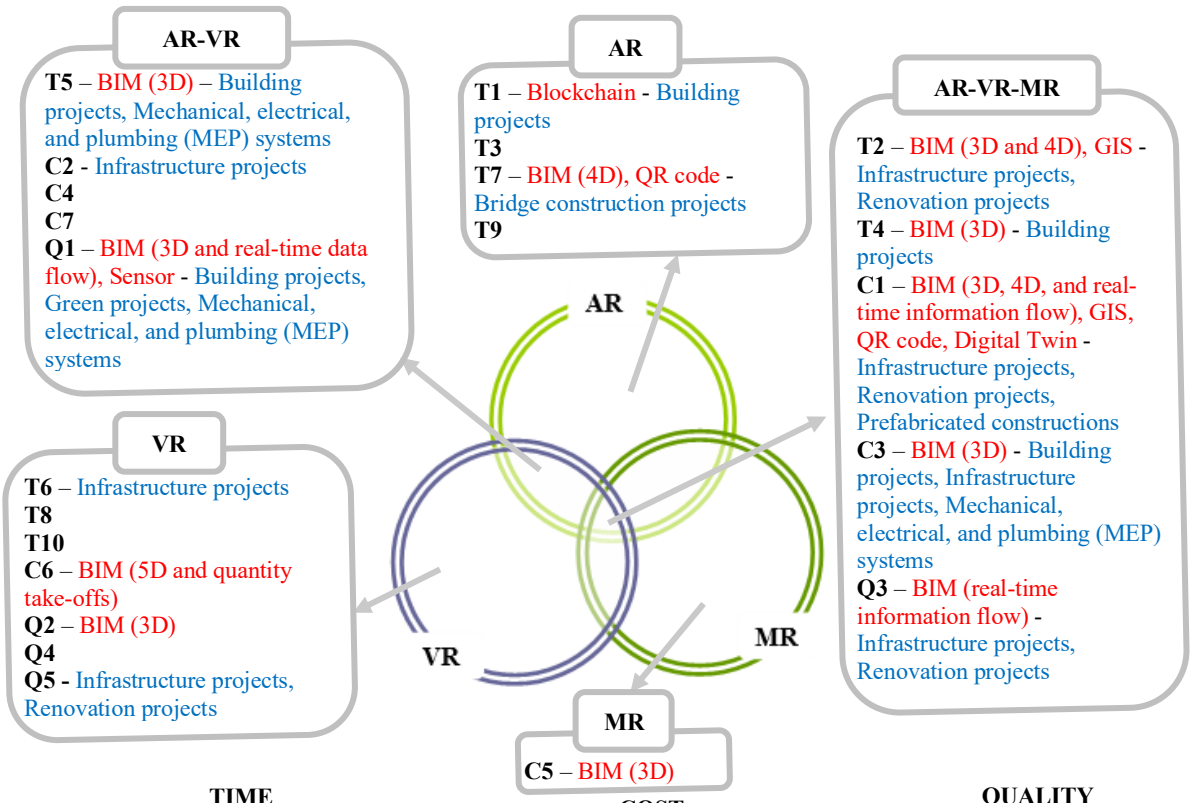


Fig. 1. The effects of AR/VR/MR practices on time, cost, and quality.

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Moreover, following a literature review, these findings were supported by data obtained from participants in different roles. To identify the most important aspects of AR/VR/MR with respect to the three performance criteria—time, cost, and quality—the mean score was used to rank and assess their impact. Table 2 shows the mean and standard deviation (SD) values. According to Huang *et al.* (2022), a higher mean score indicates greater significance of the criterion. The mean score ranking of performance criteria given by all participants is quality, time, and cost, respectively, which is the same as that of the architect participants. In terms of the civil engineer participants, quality is the top ranked performance criteria for AR/VR/MR practices, and cost was rated as more important than time (Table 2). This could be because, considering simulation-based technologies allow civil engineers to manage potential conflicts and clashes between other engineering fields, cost impacts may be more critical than time performance for them (Qasem and Almohassen 2025). The findings highlight that AR/VR/MR adoption was the most significant contributor in terms of identification of quality failures and effective quality management.

Table 2. Ranking of the project performance indicators for AR/VR/MR practices.

Project Performance	All Participants			Civil Engineer			Architect		
Criteria	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank
Time	4.51	1.67	2	4.46	1.66	3	4.71	1.67	2
Cost	4.50	1.70	3	4.50	1.69	2	4.49	1.73	3
Quality	4.64	1.68	1	4.60	1.71	1	4.75	1.60	1

4 CONCLUSIONS

This study assessed the contributions of AR/VR/MR implementations on project time, cost, and quality. To achieve the study objective, a comprehensive literature review was conducted to explore their benefits, followed by a questionnaire survey for the assessment of their importance level. It was observed that existing literature promotes the use of simulation-based technologies for effective project management in terms of schedule planning, budget management, and quality outcomes. According to the opinions of civil engineers and architects, these technological practices were the top-ranked in enhancing construction quality, while their contributions to cost-effective solutions were considered more significant by the civil engineers. In future studies, other performance criteria, such as safety, sustainability, and client satisfaction, could also be included to examine the effects of these practices, thereby contributing to a broader body of knowledge. A limitation of the questionnaire survey is that only provided detailed information about the technological tools when responding. Hence, researchers can consider whether respondents have any practical experience with AR/VR/MR technologies in future attempts. As the findings of the current study were based solely on the opinions of civil engineers and architects, future research could include a broader range of construction professionals to enhance the generalizability of the findings. The findings of this study reflect the perceptions of the majority of civil engineers and focus more on practitioners with less than 10 years of experience, an imbalanced data distribution. Overall, this study offers insights that can aid construction practitioners better understand the effective practical performance of AR/VR/MR practices.

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