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Drivers of, and Barriers to, the Adoption of Mixed Reality in the Construction Industry of Developing Countries

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Abstract: Mixed Reality (MR) that combines elements of both augmented reality (AR) and virtual reality (VR) has great potential for use in the construction industry. However, its usage in construction projects in developing countries has not been widely researched. This study aims to examine the major drivers of, and barriers to, the adoption of MR technologies (MRTs) in the construction sector of developing countries. A mixed methodology that included both qualitative and quantitative data analysis was used. The literature review revealed 37 barriers to, and 41 drivers of, MR adoption. A questionnaire was then distributed to 220 randomly selected respondents from the pertinent construction industry, representing all major stakeholders. The relative importance index (RII) was used to rank the barriers and drivers in terms of significance. The results showed that the primary barriers to MR adoption are the high cost of initial investment, public perception of the technology being immature, limited demand, and difficulty accessing relevant experts' knowledge. The key drivers of MR adoption include improved project knowledge, reduced overall project costs, low-cost and realistic training scenarios, reduced damage and development costs, and enhanced user experience. These findings provide insights into the major barriers and drivers of MR in the construction sector of developing countries and will help pertinent companies to focus their research and development (R&D) efforts on overcoming these barriers and promote their adoption to move towards the much sought-after construction automation and digitalization.

Keywords: augmented reality; construction automation; digitalization; mixed reality; virtual reality

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1. Introduction and Background

Mixed Reality (MR) technologies, including both augmented reality (AR) and virtual reality (VR), have a significant impact on the automation of the construction and architectural engineering industries in the modern era. MR refers to a blend of physical and digital worlds, unlocking natural and intuitive 3D human, computer, and environmental interactions. The development of MR technologies (MRTs) has rapidly progressed since 2010 [1,2]. These technologies connect the physical world to the digital world and provide a way to access construction project information digitally, leading to digital disruption and the digitalization of the otherwise technology-averse construction industry [3]. These technologies have numerous benefits in the construction industry, including virtual site visits and planning comparisons [4,5]. In addition, MR (AR and VR) help improve communication among stakeholders and offers clear visualization for engineers and designers, leading to a better understanding of ongoing or upcoming projects [1].

MRTs have been widely adopted across various domains, including education, entertainment, manufacturing, and information technology (IT), due to their accessibility and affordability [6]. The mining industry is one of the sectors that has embraced MRTs. Research has shown that VR solutions can enhance occupational health and safety for coal miners by providing VR training. In a relevant study, workers were trained by experienced professionals using motion capture systems, Head-Mounted Displays (HMDs), joysticks, and working methods. The results indicated that VR technology is a highly effective platform that can protect trainees from exposure to dangers and risks common in the mining environment [7]. Additionally, a VR-based training system has been developed to support the mining industry, and it has been found that the use of devices such as Magic Leap can improve the overall training experience [8].

MRTs have gained significant attention in the healthcare sector due to their remarkable capabilities and innovative approaches. These technologies have seen intensive growth in surgical practices. Recent research has indicated that both clinical and surgical training has been improved and that the usage of MRTs in the healthcare industry will continue to increase [9]. A study conducted between 2005 and 2015 reviewed the usage of MRTs in the healthcare industry and concluded that MR, especially VR, had shown more growth in three areas: eating disorders, cognitive and motor rehabilitation, and pain management [10].

VR can be useful for training and examining healthcare workers by subjecting them to immersive virtual surgery rooms, where they can perform certain procedures without needing expensive real-life facilities and subjects. MR can also enhance the experience of visitors at cultural heritage sites. AR-based mobile applications can be used as tour guides, and VR applications can simulate unapproachable places. These technologies can increase the interest of visitors, provide them with a more immersive experience, and encourage future visits [11].

The use of MR in the gaming sector is also dramatically increasing. Similarly, these advanced technologies play a crucial role in the education sector. A detailed analysis of the usage, benefits, and challenges of MRTs in education history has been presented in a relevant study [12]. Researchers have found that the increasing trend towards online studies and distant learning has led to the use of MRTs [13]. Researchers have developed a teaching system based on AR that shows increased student motivation levels and encourages innovation by enabling them to create design outputs during courses [14]. Additionally, a VR-based tool has been developed that provides an effective solution to the challenges faced by students in visualizing structures [15]. VR has been shown to create an effective education and learning environment and can enhance students' understanding of material [16]. Similarly, other recent studies have shown an increase in students' success rate when exposed to such immersive MRTs [15,16].

VR technology has been shown to assist people in solving difficult problems by allowing them to interact with digital devices [17]. While the primary use of MRTs has been in the entertainment and gaming industries, their adoption has rapidly expanded to sports, education, tourism, and training [18]. According to Goldman Sachs [19], the VR and AR markets are expected to reach a size of $80 billion by 2025.

In the United Kingdom (UK), data from a report on public goods revealed that MRTs are the primary advanced technologies used to enhance the efficiency of groundwork delivery and preservation, and aid in accountability and risk management. Similarly, in the United States (USA), the government's IT capability enhancement initiatives involve the usage of MR [1]. The emerging Citizen Technology Office (CTO) initiated the MR programs in 2017 to work on experimentation research and the clarification of related programs. Federal agencies in the USA are expecting these technologies to enhance their services in a wide range of applications, including the medical, education, and management areas [1].

In 2017, the Manufacturing Technology Center (MTC) conducted an experimental study to check the maturity and reliability of MR in construction-related companies. The results indicated that only 37% of construction company workers had some knowledge related to MR [20,21]. Davila [20] estimated that only 34.4% of construction companies in the UK had used these technologies. Additionally, a relevant study [22] found that the digitalization index range for the architecture, engineering, and construction (AEC) industry was the lowest among the 22 investigated industries.

Despite the rapid development of VR, AR, and other supporting MRTs, there have been limited studies offering a systematic inspection of their implementation and adaptation in construction engineering, education, and training [23]. Although VR has been implemented in architecture, engineering, and construction education [24], using an HMD can lead to serious problems, such as discomfort and poor depth perception [25]. While real-world depth cues are reliable, in AR, only a subset of these cues is provided. Additionally, the available depth information given by augmented objects often conflicts with the information given by the real-world environment, resulting in cue conflicts and perceptual unpredictability [26]. However, the obstacles that appear during implementation can be quickly overcome due to the continuous advancement of technology worldwide. The perception that MRTs are new technologies in the market and cannot be fully utilized in practice is incorrect [26].

MR (including both AR and VR) technologies are of great importance to the AEC industry because the built environment is intrinsically connected to 3-dimensional space, and professionals in this industry rely heavily on visual imagery to communicate. AR, in particular, is an essential technology for improving construction projects. While research has been conducted on both AR and VR for many years, interest in these technologies has recently resurged due to the development of more advanced and capable HMDs [27].

VR simulations provide an immersive and interactive environment that can assist architects in planning and designing buildings and cities [28]. They can also help reduce project costs, risks, and delivery time while allowing customers and users to experience the design of a structure before it is built [29]. AR has many useful applications in the construction industry that can significantly enhance construction productivity [30].

Research has helped create a comprehensive map of excavation, positioning, inspection, coordination, and other aspects of the construction process using MRTs. A clear scenario of AR in the AEC industry has been presented, with a review of important research efforts up to 2009 and an organization of various AR technologies with their pros and cons by a relevant study [31].

The adoption of AR in the AEC industry focuses on four main aspects: localization, natural user interface, cloud computing, and mobile devices [32]. However, the use of MR in the AEC area remains low in general [1]. A study conducted in 2017 found that only 37% of construction companies had experience using MR [33]. In another study, researchers compared the long-term effects of VR safety training with traditional methods. They trained one group with VR and the other with traditional safety methods. The results showed that VR-based training was more effective than traditional methods [34]. Additionally, scientists have developed a platform that uses 360-degree panoramic recorded videos from the real world and integrates them into VR for construction safety training. Results show that the platform improves workers' hazard-assessment skills [12]. Similarly, AR tools are also useful in developing a framework for maintaining gas and oil facilities, ultimately increasing the quality of work [35].

Similarly, research has shown that VR technologies and environments are beneficial for construction and safety training. They can help with project schedule control [36], promote better understanding among stakeholders [37], provide clear views of complex designs [38], and help trace faults and design errors [39]. These technologies can also help users create a sense of the project and target a suitable design area, even with complex structures [40], and facilitate mutual decision-making [41]. A cost estimation framework for construction using VR technology has been developed, which uses a real-time virtual reality model that allows clients and users to change the materials of floors, walls, and other parts of the structure and see the price impact in real-time [42]. This could be highly beneficial to estimators in the AEC industry [43]. Overall, adopting MRTs has played a crucial role in the construction industry, providing training programs that can help workers improve their regular activities. Traditional methods, such as simple computer-based learning, have not been effective in equipping decision-makers to interact with specific situations. In addition, on-site training for significant production value tasks, such as oil and gas plant maintenance, is often challenging because the site's conditions are not revealed until the project starts.

Therefore, the current research aims to study MR adoption in developing nations by analyzing its benefits and barriers and capitalizing on its potential to help developing nations catch up with developed ones. Historically, technological achievements in developing nations have lagged behind those in developed nations. However, MR technology (a nascent concept) can aid in closing the gap by expanding access to digital infrastructure and sectors, including construction and other connected industries. Furthermore, MR can assist developing nations in building a digital infrastructure that will be the cornerstone of their economic growth. The pertinent infrastructure could benefit from the introduction of MR technology by modernizing existing industries and fostering the development of new ones in developing countries. Therefore, investment in MR technology offers a special chance to support the expansion and development of the construction sector in developing nations. However, there is a limited number of published studies on MR adoption in the context of the construction industry for developing economies which presents a gap in research.

To bridge this research gap, the current study highlights the key barriers and drivers for MR adoption in developing countries. It is important to identify the barriers and drivers of MR adoption in developing economies' construction industry to move towards a more globally smart construction industry. It must be noted that MRTs in this study are limited to AR and VR only, and other supportive MRTs are not considered in this study. In this context, the use of the relative importance index (RII) technique is a good way to quantify and rank the relevant factors. It is encouraging to see that reduced project expense and knowledge are key drivers for MR adoption, which can help the construction industry of developing countries achieve better outcomes with less cost and time. The findings of this study can provide valuable insights for decision-makers in the relevant construction industry to adopt the latest tools and technologies and improve their overall efficiency and productivity.

2. Tools and Methods

Exploratory and mixed research methods are commonly used to investigate complex systems and associated phenomena. They allow for the collection and analysis of both qualitative and quantitative data [1]. In the case of MR adoption in the construction industry, these methods are useful for exploring the perceptions and opinions of key stakeholders and identifying the influential factors. By combining qualitative and quantitative data analysis, researchers can gain a deeper understanding of the factors that contribute to the barriers to, and drivers of, MR adoption and provide valuable insights for decision-makers in the construction industry of developing countries. Accordingly, qualitative and quantitative data analysis techniques have been used in this study.

The initial stage of qualitative data analysis in this study involved identifying the barriers to the adoption of MR in construction projects by reviewing previous research papers. After gathering all relevant data, the barriers and drivers were analyzed to filter out those that pertained specifically to the construction industry and its projects. A total of thirty-seven barriers associated with the adoption of MR in construction projects were extracted from articles published worldwide. Table 1 shows the list of extracted barriers to MR adoption.

Similarly, published research articles were consulted to collect data on the drivers related to the adoption of MR in the construction industry. Forty-one drivers were extracted, which were specifically linked to construction projects. The list of drivers in the adoption of MR is presented in Table 2.

Table 1. Barriers to MR adoption in construction projects.

Sr. No.	Barriers	References
1	MRTs are considered immature technologies	[1,33,44,45]
2	The limited size of 3D models to be displayed	[1,46,47]
3	Uncomfortable and heavy HMDs available for MR	[1,46]
4	Narrow field of view	[1,46]
5	Low-resolution displays are available for MRTs	[1,46]
6	Power and battery limitations for using MRTs	[1,46]
7	There are skill shortages and difficulty to access skilled graduates	[1,44,46,47]
8	There is a lack of market knowledge regarding MR	[1]
9	Issues are there with data security and ownership using MR	[1,45]
10	MR has branding problems and inaccurate public perceptions	[1]
11	There is a lack of time to explore immersive technologies	[1]
12	There is difficulty to assess and access experts' knowledge	[1,46]
13	MRTs are seen as a cause of job insecurity	[1,47]
14	There is limited access to finance	[1,33]
15	There is an aversion to adopting new technologies	[1,33,47]
16	Special requirements are to be provided for implementation	[1]
17	There is a lack of standards for data exchange	[1,46]
18	There are expensive hardware and training requirements	[1,33]
19	MRTs require specialized high-processing equipment	[1,46,47]
20	Large space is required for MR gadgets	[1]
21	There is a lack of multi-user capabilities for using MR	[1]
22	MRTs remains a fragmented industry	[1,44,45]
23	There is a lack of client interest in using MR	[1,47]
24	MRTs sample may not be representative of the wider population	[1]
25	User experience motion sickness, nausea, sweating, and headaches leading to vomiting	[46,48]
26	High initial capital investment is required for the MR	[44]
27	There is a problem in correctly setting up the system	[33]
28	The demand for MR is insufficient	[44]
29	A significant modeling effort may be required and should be taken into consideration when building an MR application	[47]
30	There are difficulties in translating changes to BIM models	[46]
31	MRTs have low accuracy in tracking and mapping	[46,47]
32	There are social concerns of people regarding the adoption of MR	[47]
33	There is insufficient demand for MR adoption	[44]
34	These technologies lack systemized evaluation processes	[46]
35	MRTs require high initial capital investment	[44]
36	MRTs have time-consuming algorithms	[45,46]
37	There is limited opportunity to experience real working conditions	[46,47]

Table 2. Drivers of MR adoption.

Sr. No.	Drivers in the Adoption of MR in Construction Projects	References
1	MRTs reduce overall spending on the projects	[1,45,47,49]
2	It will help to increase labor productivity in projects	[1,33,47,49]
3	MRTs contribute to better project delivery	[1,33]
4	Having difficulties accessing labor will drive MR adoption	[1]
5	MRTs improve collaboration between parties	[1,49]
6	MRTs improve project understanding	[1]
7	Government incentives will drive its adoption	[1]
8	A decrease in the construction Budget will drive its adoption	[1]
9	MRTs help to improve the company's image and will drive its adoption	[1]
10	MRTs should be part of the trend for better adoption	[1]
11	MRTs help in obtaining a differentiating advantage in the market	[1]
12	MRTs help in making strategic decisions from top management	[1]
13	MRTs help in improving the reputation of the organization	[1]
14	Client requirements for the use of MR in projects	[1]
15	MRTs show a way to provide new and better services	[1]
16	MRTs help in improving the organizations' work culture	[1]
17	MRTs help in enabling market expansion	[1]
18	MRTs are an organizational need to be more efficient and productive	[1]
19	MRTs reduce overall risk	[1,33,47]
20	MRTs help in fostering the research curiosity of the employees	[1,45,49]
21	MRTs help in increasing research and development investment in the construction sector	[1]
22	MRTs are reliable technologies	[33,49]
23	MRTs provide timely feedback	[46,49]
24	MRTs help in better requirement understanding	[46,49]
25	MRTs help in better contextual understanding	[46]
26	MRTs help in better impact assessments	[46]
27	MRTs help in increasing inclusivity	[46]
28	MRTs help in improving user experience	[46]
29	MRTs help in real-scale visualization of design	[45,46,48]
30	MRTs help in better understanding of design impacts	[46]
31	An easier understanding of simulation results is provided using MR	[45,46,48]
32	MRTs help in efficient decision making	[46]
33	Easier multidisciplinary assessments are provided	[46]
34	MRTs help in the visual understanding of construction progress	[46]
35	MRTs provide a visual analysis of the ongoing project	[46,48]
36	MRTs minimize travel	[46]
37	MRTs help in reducing the risk to the technicians	[46–48]
38	MRTs help in the better understanding of facility needs	[46]
39	MRTs provide visual asset information in real-time	[46]
40	MRTs provide inexpensive and more effective training scenarios	[46]
41	MRTs help in reducing damage, repair, and development cost	[45]

2.1. Data Collection

A comprehensive questionnaire was developed for quantitative data collection that included three sections. The first section of the questionnaire asked respondents to provide information about their age, experience, company, company's business, designation, education, and employment status. The second section of the questionnaire comprised the barriers to adopting MR in the construction industry, while the third section focused on the drivers for adopting MR in the construction industry.

Based on the extensive review of the published literature and data analysis, 37 barriers and 41 driving factors for the adoption of MR in construction projects were identified, as previously listed in Tables 1 and 2. The purpose of the questionnaire was to validate and quantify both sets of factors. The questionnaire used a ranking scale from 1 to 5 to code the responses of the participants, with rank 1 indicating the lowest importance (strongly disagree) and rank 5 indicating the highest importance (strongly agree). Respondents were asked to assign an importance value to each of the barriers and drivers.

The study utilized a representative sample of the construction industry population. Experts from engineering consultancies, design firms, construction companies, and technology development companies with a focus on MR were invited to participate in the survey. The respondents were selected from contractors, clients and authorized construction consultants involved in contract awarding activity. A total of 220 questionnaires were randomly distributed among the participants, including consultants, contractors, and clients. However, only 124 fully completed questionnaires were included in the final analysis, and incomplete questionnaires were discarded.

2.2. Assessment of Participant Profile

To ensure the data's validity, the questionnaires included information about the participants' profiles, such as their age group, experience level, company type, education level, and employment status. The age range of the participants in the data collection ranged from less than 20 to 41 years. The experience levels of the participants ranged from less than a year to 20 years. The educational levels of the participants ranged from Matriculation to Ph.D. The employment status field in the questionnaire included permanent, contractual, and temporary terms of employment.

3. Results

3.1. Respondents' Demographics

After the data collection process, 124 questionnaires were accepted for further analysis. To exclude incomplete responses, a pattern of similar responses in answering most of the questions was checked. Additionally, the data of five randomly chosen sub-criteria were analyzed for their accuracy. If a respondent's answer for all five sub-criteria was significantly different from most other respondents' answers, their response was removed.

The response data were recorded and processed using Microsoft Excel. The age group data showed that 4 percent of the respondents were between the ages of 20 and 25, while 44 percent were between the ages of 26 and 30. Among the respondents, 28 percent and 22 percent were between the ages of 31–35 and 36–40, respectively.

Regarding the respondents' company profiles, 61 percent of those who responded were contractors, and the client category was the second most populous, accounting for 32 percent of all individuals, whereas 7 percent of respondents selected the consultant category as shown in Figure 1.

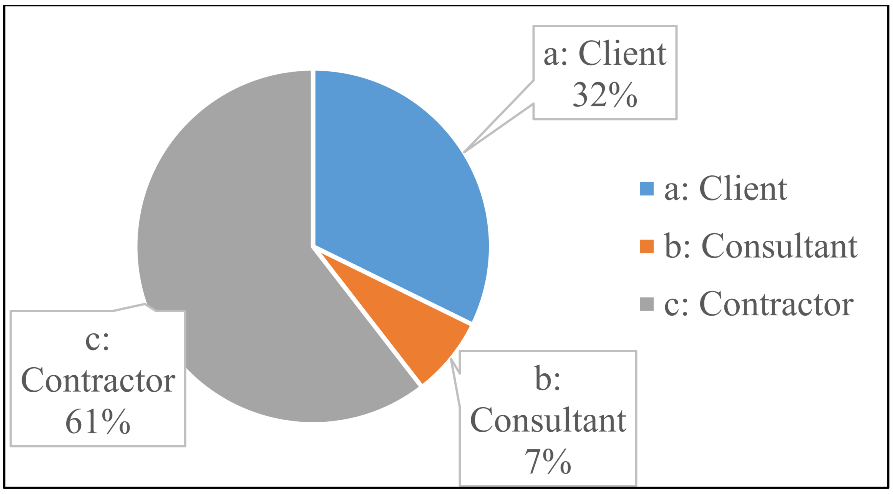

Figure 1. Respondent's affiliation.

The study also analyzed the educational level of the respondents. The findings indicated that 82 percent of the participants had completed a bachelor's degree, while master's degrees were the second most common level of education. Only 3% and 2% of the respondents reported having completed an M. Phil. and Intermediate education, respectively. In terms of employment status, 48 percent of the participants held permanent positions, while 37% and 15% were employed on a contractual or temporary basis, respectively.

3.2. Relative Importance Index (RII)

As discussed previously, RII scores were calculated for the drivers and barriers. The first category for which RII was calculated was financial stability. According to Johnson and LeBreton [50], RII is a useful tool for determining the contributions of specific variables to an overall system or phenomenon. To experimentally determine the characteristics that contribute to the implementation and preference of selecting a particular contractor and bid evaluation, RII was used, and was derived using Equation (1). In Equation (1), W represents the weight given to each element by respondents (ranging from 1 to 5), A represents the highest weight (i.e., 5 in the current study), and N represents the total number of respondents. The RII was calculated using Microsoft Excel. Equation (2) shows the calculations for L26 as a sample input. All subsequent calculations were conducted in a similar way.

$$\text{RII} = \frac{\Sigma \text{W}}{\text{A} \times \text{N}} \tag{1}$$

$$\text{RII for L26} = \frac{545}{124 \times 5} = 0.879 \tag{2}$$

The corresponding values are presented in Table 3, where L represents the serial number of the MR barrier previously listed in Table 1.

In addition to calculating the RII for MR barriers, the study also calculated the relative importance values for MR drivers in the construction industry, which are shown in Table 4. These values were obtained by inserting the given values into the RII formula, as shown in Equation (1).

According to the RII data presented in Table 5, barrier L26 obtained the highest ranking with an RII of 0.879. In the top 5, barriers L1, L33, L12, and L28 were also present with RIIs of 0.866, 0.853, 0.847, and 0.845, respectively.

The top five drivers related to the adoption of MR in the construction industry, as shown in Table 6, are D6, D1, D40, D41, and D28, with RII values of 0.911, 0.892, 0.881, 0.879, and 0.873, respectively.

Table 3. Relative importance index for barriers.

Rank	L	ΣW	AxN	RII
1	L26	545	620	0.879
2	L1	537	620	0.866
3	L33	529	620	0.853
4	L12	525	620	0.847
5	L25	524	620	0.845
6	L18	517	620	0.834
7	L35	512	620	0.826
8	L22	509	620	0.821
9	L23	506	620	0.816
10	L15	504	620	0.813
11	L20	498	620	0.803
12	L21	497	620	0.802
13	L29	495	620	0.798
14	L28	490	620	0.790
15	L30	486	620	0.784
16	L10	479	620	0.773
17	L16	475	620	0.766
18	L14	468	620	0.755
19	L8	466	620	0.752
20	L7	462	620	0.745
21	L36	458	620	0.739
22	L24	448	620	0.723
23	L32	447	620	0.721
24	L19	443	620	0.715
25	L6	425	620	0.685
26	L5	420	620	0.677
27	L27	411	620	0.663
28	L3	408	620	0.658
29	L11	406	620	0.655
30	L2	398	620	0.642
31	L13	393	620	0.634
32	L9	390	620	0.629
33	L4	383	620	0.618
34	L17	371	620	0.598
35	L37	364	620	0.587
36	L34	359	620	0.579
37	L31	343	620	0.553

Table 4. Relative importance index of drivers.

Rank	Drivers	ΣW	AxN	RII
1	D6	565	620	0.911
2	D1	553	620	0.892
3	D40	546	620	0.881
4	D41	545	620	0.879
5	D28	541	620	0.873
6	D15	539	620	0.869
7	D3	538	620	0.868
8	D26	533	620	0.860
9	D18	523	620	0.844
10	D16	520	620	0.839

Table 4. *Cont.*

Rank	Drivers	ΣW	AxN	RII
11	D36	515	620	0.831
12	D11	513	620	0.827
13	D9	510	620	0.823
14	D19	508	620	0.819
15	D2	507	620	0.818
16	D5	497	620	0.802
17	D34	492	620	0.794
18	D13	491	620	0.792
19	D30	488	620	0.787
20	D8	485	620	0.782
21	D32	481	620	0.776
22	D33	477	620	0.769
23	D24	475	620	0.766
24	D20	470	620	0.758
25	D38	467	620	0.753
26	D4	460	620	0.742
27	D37	459	620	0.740
28	D10	458	620	0.739
29	D25	457	620	0.737
30	D39	450	620	0.726
31	D12	445	620	0.718
32	D27	443	620	0.715
33	D35	438	620	0.706
34	D17	433	620	0.698
35	D21	424	620	0.684
36	D29	409	620	0.660
37	D14	380	620	0.613
38	D22	371	620	0.598
39	D31	352	620	0.568
40	D23	347	620	0.560
41	D7	325	620	0.524

Table 5. Top 5 barriers as per RII.

Barriers	SA	A	N	D	SD	ΣW	AxN	RII	Rank
L26	69	39	12	4	0	545	620	0.879	1
L1	72	27	20	4	1	537	620	0.866	2
L33	58	48	13	3	2	529	620	0.853	3
L12	64	37	15	4	4	525	620	0.847	4
L28	57	47	14	37	15	524	620	0.845	5

Table 6. Top 5 drivers as per RII.

Drivers	SA	A	N	D	SD	ΣW	AxN	RII	Rank
D6	63	56	4	0	1	565	620	0.911	1
D1	79	29	12	2	2	553	620	0.892	2
D40	65	45	13	1	0	546	620	0.881	3
D41	69	41	10	2	2	545	620	0.879	4
D28	66	43	10	4	1	541	620	0.873	5

4. Discussion

This section discusses the top 5 barriers to and drivers of the adoption of MR in the construction industry of developing countries.

4.1. Significant Barriers to MR Adoption

The top 5 barriers to MR adoption, as presented in Table 5, are discussed below.

4.1.1. High Initial Capital Investment Is Required for the Use of MR

Since construction projects are typically large in scale, there is a perception that implementation of MR technology would necessitate a substantial number of high-cost devices such as HMDs and other related equipment. As a result, a considerable amount of initial investment would be necessary to integrate MR technology into a construction project, which would increase the overall project cost. To address this challenge, it is essential to direct research and development (R&D) efforts toward developing low-cost devices and technologies that meet the unique needs of the AEC industries, in keeping with the limited finances available in developing countries. Given the significant investments required to implement MR in terms of equipment, space, time, and upskilling, the investments can only be justified by designing MR hardware and software specifically tailored to developing countries' AEC sectors.

Another issue generally associated with MR devices is that of battery limitations and lower efficiency in darker places. It is crucial to increase the efficiency and battery life of these devices to make them more practical and convenient for construction site use. These are essential factors that were also highlighted in a study by Delgado et al. [1], where the high cost and perceived immaturity of MRTs were identified as major barriers to their adoption in the AEC industry. The current study complements these findings. Accordingly, further research is necessary to address these challenges and develop tailored solutions that cater to the unique requirements of the AEC industry in developing countries.

4.1.2. MRTs Are Considered Immature Technologies

MRTs are in nascency in the construction industry of developing countries, and they are sometimes considered immature technology. Construction projects demand a higher degree of precision, consistency, and efficacy. However, current MR (including both VR and AR) devices are unable to manage the extremely sophisticated 3D information models routinely used in construction projects. Most MR devices were originally designed for the entertainment industry, and as a result, they lack the capabilities necessary for the AEC industries. Additionally, due to a lack of technical skills, awareness, and the complexity of the technology, MR adoption in these industries is not straightforward and requires further adoption efforts, awareness, and modifications to devices.

The existing MR devices need to be customized to suit the specific needs of the construction industry in developing countries. They should be improved to handle large-scale data processing while also providing sustainable battery backup and system memory. By doing so, it will be possible to address the perception regarding MR's immaturity in the construction sector. Customized MR devices will offer the high precision, consistency, and efficiency that is required in construction projects, making them more attractive to the industry. This can be achieved through continuous R&D to identify the specific capabilities lacking in existing MR devices and address them to make them more suitable for the AEC industry of developing countries. These results align with the studies by Delgado et al. [1,44], which concluded that AR technology is not yet fully matured and not considered mainstream (at least not as mature as VR), but that the efforts made by developers are headed in the right direction. Similarly, the authors also found that the primary obstacle to adopting MR in construction is the belief that they are immature technologies that cannot be fully utilized in practice yet.

4.1.3. There Is Insufficient Demand for MR Adoption

The construction industry typically follows established standard operating procedures (SOPs). The adoption of new technologies such as MR may face significant barriers in developing countries due to a lack of awareness, technical skills, knowledge, and other obstacles. As a result, the demand for MR in the construction sector is currently low. However, as the technology continues to develop and tailored solutions are created for the specific needs of the construction industry, it is expected that the adoption will increase.

To facilitate adoption, awareness campaigns should be initiated to promote the advantages of MR technology in construction, such as improving project understanding, cost efficiency, and effective training. Additionally, educational institutions can play a vital role in attracting new talent to the field by offering programs that provide specialized training in MR. Further, companies providing MR services and solutions should provide professional training to construction industry employees on the best use of this technology. By increasing the awareness and knowledge of MR, the construction industry can be encouraged to adopt these technologies, which can lead to improved efficiency and cost-effectiveness in construction projects.

There is currently a low demand for MR in the construction industry due to a lack of understanding of its benefits. As a result, construction companies may find it challenging to switch from established practices to new technology, as it would require a significant capital investment. Additionally, due to a shortage of professionals trained in this technology, there may be a lack of experts' availability that discourages construction organizations from adopting these technologies.

The findings of Martínez et al. [45] support the need to improve the integration of new technology into social practices. The researchers found that many people are not yet familiar with MR technology, contributing to its low demand. By promoting the advantages of MR and providing education and training opportunities, the construction industry can work towards increasing the adoption of this technology and realizing its full potential.

4.1.4. Difficulty in Assessing and Accessing Experts' Knowledge

Limited numbers of people are pursuing careers in MR because the technology is still young, difficult to adopt, and lacks implementation standards. The lack of standards makes it hard to measure the knowledge and abilities of those working in MRTs. Furthermore, due to the lower number of experts in this field, it is challenging to assess their knowledge about the technology and engage them meaningfully in construction projects involving huge finances.

To address this issue, major universities in developing countries should launch higher education programs targeted at MRTs. This would give a boost to R&D efforts and improve the technology itself. MR companies should also sponsor R&D efforts in universities to facilitate this. This conclusion aligns with Delgado et al.'s [1,46] findings, which indicated that the construction industry is still in its early stages compared to the entertainment sector. MR expertise is difficult to attract for construction organizations, as professionals tend to prefer the entertainment and gaming industries. There is a lack of graduates with the necessary skills, and only large corporations have dedicated MR development teams to date [1].

4.1.5. User Experience Motion Sickness, Nausea, Sweating, and Headaches Leading to Vomiting

The prolonged use of MR devices such as HMDs can cause motion sickness, nausea, sweating, headaches, and vomiting in users, which is a major limitation in the adoption of MR technology. Due to the complexity and time required for construction projects, prolonged usage of these devices can be uncomfortable for most users.

To mitigate these issues, efforts should be made to improve the design and development of MR devices to minimize discomfort and curb their negative side effects for users. Additionally, providing frequent breaks during prolonged usage and limiting the amount of time spent in the virtual environment can help reduce the incidence of symptoms associated with motion sickness and other discomforts. As noted by Liagkou et al. [48,51], the side effects of VR navigation can be attributed to a mismatch between the user's visual and physical experience, leading to a disconnect in the brain's biochemistry. Addressing these issues will require continued R&D to improve the technology and reduce negative side effects for users.

4.2. Top 5 Drivers for MR Adoption

Table 6 presented the top 5 drivers in the adoption of MR in the construction sector of developing countries. These drivers are discussed below.

4.2.1. MRTs Improve Project Understanding

The adoption of MR technology in the construction industry is driven primarily by the benefits it offers in enhancing project knowledge. With the use of MR, construction projects can be virtually simulated, or real-world settings can be overlaid with digital information, resulting in a deeper understanding and visualization of the project. This provides a zero-risk environment for the project and any issues associated with it can be resolved in a virtual space. As a result, using MRTs allows for the observation of various stages of a project, leading to an improved overall understanding and minimization of project risks.

The current study's findings support the study by Ashtari et al. [52], which indicated that using AR can lead to faster learning, mistake reduction, and significant time savings, in addition to promoting safer operations and reducing operational expenses.

4.2.2. MRTs Reduce Overall Spending on the Projects

MRTs have the potential to reproduce construction projects digitally using the recently introduced digital twin approach. By identifying and rectifying problems in the virtual environment, project designs can be optimized to save costs and reduce the chances of human error. Integrating the real environment with the digital environment makes monitoring project work much easier, allowing for improvements to be made virtually and noticed in real time. As a result, the project can be completed in the best possible manner, leading to better outcomes at a lower cost. These findings are consistent with the research of Liagkou et al. [48,51], who found that VR applications in the industry can decrease design and production costs, maintain product quality, and reduce the time needed to go from product concept to production concept.

4.2.3. MRTs Provide Inexpensive and More Effective Training Scenarios

The use of MRTs in employee training can simulate real-world scenarios, enabling employees to practice their skills in a safe and controlled digital environment. This approach can significantly enhance the quality of training by providing hands-on experience in a real-world setting, leading to a more productive work environment. Additionally, by reducing the time required to learn new skills, training costs can be significantly reduced while simultaneously improving the quality of training.

This finding is consistent with the research conducted by Yin et al. [33], who surveyed the current research trends, findings, and limitations of MRTs. They concluded that these technologies hold great promise in enabling more effective training procedures.

4.2.4. MR Helps in Reducing Damage, Repair, and Development Cost

Efficient project progress tracking and comparison can be achieved by creating a virtual environment using MR. This minimizes the risk of damage and associated repairs since the project has already been simulated digitally. Moreover, utilizing MR can lead to the discovery of the most efficient approach to execute the project, which results in reduced development costs. Therefore, the integration of MR in the construction industry can lead to decreased project risks and development costs. These findings align with the conclusions of Martínez et al. [45], who found that AR can contribute to cost reduction in various ways, including reducing costs in industrial processes, decreasing errors, and improving safety measures.

4.2.5. MRTs Help in Improving User Experiences

MRTs offer a unique and immersive experience to users, unlike any other technology. These technologies have the potential to significantly transform how we interact with our surroundings. In MRTs, the user does not need to issue commands since the device responds to the user's environment and interprets their gestures and actions in real-time. MRTs provide us with a new world of possibilities, allowing us to interact with inanimate objects, feel more connected to people and our environment, and envision things exactly as we want them to be. These technologies also have immense potential in the healthcare, manufacturing, and media industries. This conclusion is supported by the findings of Yin et al. [53], who found that MR's immersive experience allows workers to simulate careless or erroneous actions and their resulting consequences, thereby enhancing their training and safety procedures.

5. Conclusions

The research aimed to identify the drivers of, and barriers to, adopting MR in the construction industry. The study reviewed relevant literature to determine key limitations and drivers. A survey questionnaire was then distributed to construction professionals in a developing country, and responses were recorded. Based on the RII values, the drivers and barriers were ranked.

The findings indicated that high capital costs, perceptions of MR being an immature technology, insufficient demand, lack of experts, and users' health concerns are the primary limitations to adopting MR in developing countries' construction industry. To overcome these limitations, R&D efforts should be focused on reducing the cost of devices. Additionally, advertising campaigns can promote the advantages of MR projects, and professional training programs can create employment opportunities related to these technologies.

The primary drivers in the adoption of MR were the improvement in understanding of projects, reduction in overall project spending, effective training, reduction in damage and development costs related to the project, and improved user experience. These results can be used to facilitate the adoption of MRTs in the construction industry of developing countries by promoting the drivers and curbing the barriers to moving towards a more digital and automated global construction industry.

5.1. Implications

This study has the following implications:

1. Stakeholders should prioritize efforts to reduce the cost of MR devices. This can be achieved through funding R&D in various universities and similar institutions.
2. MR devices should be tailored to meet the demands of the construction industry, which requires devices that can handle complex data for an extended period. Existing

MR devices developed with a focus on developed countries may not be suitable for the construction industry of developing countries.
3. Advertisements should be launched to increase awareness of the advantages of MR in the construction industry.
4. Acquiring expertise and knowledge of MRTs should be facilitated in developing countries by establishing higher education programs in this technology in major universities. Additionally, R&D efforts in this subject should be increased to attract young talent in this field.

5.2. Limitations and Future Studies

This study has limitations as it involved professionals from a developing country with limited exposure to modern technologies. As a result, the findings may not be generalizable to developed countries where technology adoption may be different. However, researchers from other countries can use this study to gain insight into primary barriers and drivers and validate their findings. In addition, the current study only discusses the top 5 drivers and barriers. However, future studies can focus on each of the reported barriers and drivers and develop holistic adoption frameworks. Moreover, this study can also be used to identify regional differences in MR technology adoption. In addition, this study only focused on VR and AR as MRTs; future works may consider other supporting technologies and expand the scope to extended reality (XR).

Further research is necessary to address the limitations identified in this study and to facilitate the drivers for the adoption of MR in the construction industry. Additionally, future research can be conducted in other countries to compare the results with this study and to identify any cross-country differences in adopting this technology.

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