Adnan, M.A. and Loganathan, S., 2025. Barriers to adoption of automation in Indian construction projects. In: Waidyasekara, K.G.A.S., Jayasena, H.S., Wimalaratne, P.L.I. and Tennakoon, G.A. (eds). *Proceedings of the 13th World Construction Symposium*, 15-16 August 2025, Sri Lanka. pp. 273-286. DOI: https://doi.org/10.31705/WCS.2025.21. Available from: https://ciobwcs.com/papers/

BARRIERS TO ADOPTION OF AUTOMATION IN INDIAN CONSTRUCTION PROJECTS

Mohammed Akberuddin Adnan[1] and Santhosh Loganathan[2]

ABSTRACT

The construction industry, while a critical economic sector, is characterized by inherent inefficiencies and a relatively low adoption rate of automation technologies. The present research investigates the barriers impeding the adoption of automation in Indian construction projects. A mixed-methods approach was employed, integrating a critical literature review, semi-structured interviews, and questionnaire surveys to investigate the barriers. Initially, a critical review of the existing literature was conducted to identify pertinent barriers. Subsequently, semi-structured interviews with construction professionals were carried out to contextualize these barriers within the Indian construction landscape. The findings from these qualitative phases informed the development of a questionnaire survey, which was pilot-tested and subsequently distributed to construction professionals across India. Statistical methods were utilized to rank the identified barriers. The principal barriers were identified as the need for enhanced training programs, high initial investment costs, and limited stakeholder awareness. Principal Component Analysis (PCA) facilitated the grouping of these barriers into five key components that include industry-related, economic, operational, technical, and human-related barriers. These results underscore the potential of automation to address critical barriers within the construction sector while simultaneously highlighting the necessity of developing targeted strategies to overcome the identified adoption barriers. The present research also offers actionable insights for stakeholders, aimed at promoting the effective adoption of automation and enhancing overall productivity within the Indian construction industry.

Keywords: *Automation Adoption; Automation Barriers; Construction Automation; Indian Construction.*

1. INTRODUCTION

The construction industry significantly contributes to global GDP, yet struggles with persistent issues of productivity, efficiency, and technology adoption. Unlike manufacturing, which has embraced automation, construction remains labour-intensive and fragmented (Bock, 2015). Productivity gains in construction have been negligible compared to manufacturing (McKinsey Global Institute, 2017). Large projects often suffer delays of up to 20% and cost overruns of 80% (McKinsey Global Institute, 2017). Defects account for 10%–25% of construction costs (Get It Right Initiative UK, 2024),

[1] Master's Student, Department of Civil Engineering, National Institute of Technology Tiruchirappalli, Tamil Nadu, India and Senior Engineer, Larsen & Toubro Limited, India, maadnan605@gmail.com
[2] Assistant Professor, Department of Civil Engineering, National Institute of Technology Tiruchirappalli, Tamil Nadu, India, lsanthosh@nitt.edu/santomaills@gmail.com

and the industry saw an 11% increase in workplace fatalities from 2021 to 2022 (US Bureau of Labor Statistics, 2024). These issues underscore the need for innovation through automation. In India, construction remains largely dependent on traditional practices, leading to inefficiencies and delays (Fellows et al., 2012). Fragmentation and a severe shortage of skilled labour exacerbate cost escalations. Though automation can potentially address some of these challenges, its adoption is hindered by multifaceted barriers (Bock, 2015). While countries such as the USA, Japan, China, and Malaysia have made progress, the Indian construction context is relatively slower with regard to adopting automation. Also, there is a paucity of literature on India-specific analysis of automation adoption barriers in construction. To address these gaps, the present study aims to identify and prioritise the barriers to the adoption of automation in Indian construction projects, particularly in the context of large water and effluent treatment projects. By analysing the barriers, the present study seeks to generate insights that can guide policymakers, industry leaders, and technology providers toward effective automation strategies, thereby enhancing safety, quality, productivity, and cost-efficiency in Indian construction projects.

2. LITERATURE REVIEW

Automation in construction refers to technologies that reduce human intervention in executing construction tasks (Groover, 2016). These technologies fundamentally transform conventional methods, including machine-centred approaches, real-time sensing and robotic execution. With Industry 4.0, the scope of automation now includes digitalization and information modelling (Oesterreich & Teuteberg, 2016), supported by CAD-robotics integration and digital fabrication. This study adopts Davis's (2022) definition, encompassing tools and processes that automate construction workflows.

Technologies such as building component manufacturing (BCM) automate off-site fabrication of structural components like floors, walls, and full modules using materials such as steel, concrete, and wood (Bock, 2015). Additive manufacturing (3D printing) is increasingly used for producing customized parts and on-site repairs, although it faces challenges related to material reliability and performance (Delgado et al., 2019). Despite ongoing material development, large-scale component printing is becoming viable. On-site automation includes Single-Task Construction Robots (STCRs) like scaffold-mounted arms, wall-painting robots, and concrete sprayers to perform repetitive tasks (Groover, 2016). However, safety and integration challenges remain, prompting the development of networked robotic factories. Additionally, wearable exoskeletons enhance worker capacity but face barriers of cost, safety, and usability (Chen et al., 2018).

The literature review was conducted using Google Scholar, Scopus, Web of Science, and Science Direct. A total of 114 sources, including 80 journal articles, 20 conference papers, 5 book chapters, and 9 industry reports, were reviewed. This comprehensive review ensured a balanced academic and industry perspective on automation barriers. A systematic approach such as PRISMA was not adopted due to the scoping and exploratory nature of the research, which aimed to broadly map themes and insights across heterogeneous sources rather than evaluate a specific intervention or clinical outcome. The flexibility of the scoping approach allowed for inclusion of diverse publication types and contextual understanding relevant to Indian construction. The literature review revealed that most studies focus on specific automation technologies rather than general barriers, and there is a notable absence of credible research addressing barriers to automation adoption in Indian construction projects. Table 1 represents the barriers identified from the literature review.

Table 1: Identified barriers

Code	Barriers	Indicative Sources
B1	High initial cost	Tafazzoli et al., (2024), Waqar et al., (2024), Aghimien et al. (2024), Oke et al., (2023), Espinoza et al., (2023), Huang et al. (2022), Jäkel et al., (2022), Boya et al., (2022), Pradhananga et al., (2021), Delgado et al., (2019), Kamaruddin et al., (2016), Bock (2015), Mahbub (2008)
B2	High operation and maintenance cost	Waqar et al., (2024), Aghimien et al., (2024), Oke et al., (2023), Espinoza et al., (2023), Huang et al., (2022), Boya et al., (2022), Kamaruddin et al., (2016), Mahbub (2008)
B3	Easy access to low wage labour	Pradhananga et al., (2021), Delgado et al., (2019)
B4	Lack of government initiatives and support	Aghimien et al., (2024), Oke et al., (2023), Jäkel et al., (2022), Huang et al., (2022), Delgado et al., (2019)
B5	Lack of skilled operator and expertise	Tafazzoli et al., (2024), Liu et al., (2024), Waqar et al., (2024), Aghimien et al., (2024), Oke et al., (2023), Espinoza et al., (2023), Jäkel et al., (2022), Huang et al., (2022), Boya et al., (2022), Bademosi and Issa (2021), Pradhananga et al., (2021), Delgado et al., (2019), Kamaruddin et al., (2016)
B6	Need for training and retraining	Liu et al., (2024), Aghimien et al., (2024), Jäkel et al., (2022), Huang et al., (2022), Bademosi and Issa (2021), Delgado et al., (2019), Mahbub (2008)
B7	Job loss concerns	Tafazzoli et al., (2024), Liu et al., (2024), Oke et al., (2023), Boya et al., (2022), Pradhananga et al., (2021), Bademosi and Issa (2021), Delgado et al., (2019)
B8	Conservative work culture	Liu et al.. (2024), Aghimien et al.. (2024), Huang et al., (2022), Pradhananga et al., (2021), Delgado et al., (2019)
B9	Low level of awareness	Mahbub (2008), Jäkel et al., (2022), Aghimien et al., (2024)
B10	Product complexity	Liu et al., (2024), Aghimien et al., (2024), Oke et al., (2023), Boya et al., (2022), Huang et al., (2022), Pradhananga et al., (2021), Bock (2015), Mahbub (2008)
B11	Immature technology and unproved effectiveness	Aghimien et al., (2024), Liu et al., (2024), Espinoza et al., (2023), Jäkel et al., (2022), Huang et al., (2022), Pradhananga et al., (2021)
B12	Easily and locally not available	Aghimien et al., (2024), Huang et al., (2022), Boya et al., (2022), Kamaruddin et al., (2016), Mahbub (2008)
B13	Fragmented nature of supply chain	Liu et al., (2024), Aghimien et al., (2024), Oke et al., (2023), Huang et al., (2022), Bademosi and Issa (2021), Pradhananga et al., (2021), Delgado et al., (2019), Mahbub (2008)

Code	Barriers	Indicative Sources
B14	Project-based and task-based industry	Liu et al., (2024), Tafazzoli et al., (2024), Espinoza et al., (2023), Jäkel et al., (2022), Huang et al., (2022), Bademosi and Issa (2021), Delgado et al., (2019)
B15	Low level of digitalization	Liu et al., (2024)
B16	Lack of R&D	Liu et al., (2024), Espinoza et al., (2023), Huang et al., (2022), Pradhananga et al., (2021), Delgado et al., (2019), Bock (2015)
B17	Lack of relevant codes and standards	Liu et al., (2024), Waqar et al., (2024), Espinoza et al., (2023), Jäkel et al., (2022), Huang et al., (2022), Bademosi and Issa (2021), Pradhananga et al., (2021)
B18	Safety concerns	Waqar et al., (2024), Tafazzoli et al., (2024), Liu et al., (2024), Aghimien et al., (2024), Espinoza et al., (2023)
B19	Inadequate technical infrastructure	Tafazzoli et al., (2024), Oke et al., (2023), Espinoza et al., (2023), Bademosi and Issa (2021)
B20	Regulations limiting the use	Tafazzoli et al., (2024)
B21	Limited flexibility of automation technologies	Liu et al., (2024), Tafazzoli et al., (2024)

**B1- Barrier Number 1*

3. METHODOLOGY

The present study adopted a mixed-methods approach to examine barriers to automation adoption in Indian construction projects. The methodology integrated qualitative and quantitative techniques to ensure a comprehensive analysis. A critical literature review and semi-structured interviews with industry professionals informed the development of a structured questionnaire, which was pilot tested by 4 experts (3 from industry and 1 from academia). The finalised survey was circulated among construction professionals across India. This triangulated approach combining literature, expert opinion, and field data enabled robust identification of key automation barriers. Such integrative frameworks are recognized as effective for addressing complex AEC challenges, especially where socio-technical resistance exists. Statistical tools were applied to rank and prioritise the barriers, ensuring conclusions were evidence-based and practically relevant. Principal Component Analysis (PCA) was used to group barriers into thematic categories, providing structured and scalable insights.

3.1 DATA COLLECTION

Barriers identified from the literature review guided the design of the initial questionnaire. Semi-structured interviews were conducted with 12 professionals from various sectors of the Indian construction industry (Table 2). These online and offline interviews validated literature findings in the Indian context and identified any additional country-specific barriers. Open-ended questions encouraged respondents to share insights based on their experience. These responses helped refine and expand the questionnaire. A pilot survey was conducted to check the instrument's clarity and completeness, and feedback led to minor adjustments to improve reliability. The final survey was distributed via Google Forms to 75 professionals with direct or related experience in construction automation, resulting in 66 completed responses. The respondent profile is shown in Table 3. Each barrier was rated on a five-point Likert scale. The survey reached professionals across India, enabling diverse, representative results to support nationally relevant conclusions.

Table 2: Profile in interviewees

Code	Role	Experience	Location (India city)	Duration (min)
P1	P&M Engineer	13	Trichy	26
P2	Site Engineer	10	Trichy	10
P3	Quality Engineer	25	Hyderabad	15
P4	Site Engineer	5	Trichy	10
P5	Contractor	30	Hyderabad	10
P6	Planning Engineer	5	Delhi	20
P7	Project Manager	13	Hyderabad	24
P8	Site Engineer	14	Guwahati	10
P9	Planning Engineer	5	Guwahati	20
P10	Project Manager	28	Hyderabad	15
P11	Automation team	20	Chennai	40
P12	Automation team	8	Chennai	14

**P1-Professional Number 1*

Table 3: Profile of survey respondents

Category	Parameter	Percentage	Category	Parameter	Percentage
Education	Diploma	28.78	Experience	1-5 Years	22.72
	Graduate	43.93		5-10 Years	39.39
	Postgraduate	27.27		10-15 Years	31.81
State	Madhya Pradesh	12.12		15-20 Years	6.06
	Rajasthan	13.63	Department	Execution	27.27
	Karnataka	6.06		Planning	34.84
	Tamil Nadu	25.75		Safety	4.54
	Odisha	42.42		Design	22.72
				Quality	10.6

3.2 DATA ANALYSIS

Statistical techniques were employed to derive meaningful insights. Cronbach's Alpha (α) assessed internal consistency, with values above 0.7 indicating strong reliability (Nunnally & Bernstein, 1994). Shapiro-Wilk and Kolmogorov-Smirnov tests tested data normality (Shapiro & Wilk, 1965), using a p-value > 0.05 as the threshold. Since most data were non-normal, non-parametric methods were adopted. The Kruskal-Wallis H test evaluated variations across demographic groups (Kruskal & Wallis, 1952). Barriers were ranked using mean and standard deviation, with ties resolved based on lower standard deviations. The dataset's suitability for factor analysis was verified using the KMO test and Bartlett's sphericity test. Principal Component Analysis (PCA) was then applied to reduce dimensionality, extracting factors with eigenvalues above one and using Varimax rotation to enhance interpretability. These components informed the development of strategies to address automation barriers in the Indian construction context.

4. RESULTS AND DISCUSSIONS

The subsequent sections present the findings derived from analysis of the data collected. The identified barriers are ranked and categorized, providing a structured understanding of their relative importance and interrelationships.

4.1 SEMI- STRUCTURED INTERVIEWS

Semi-structured interviews of 12 construction professionals were conducted in offline and online modes to identify the barriers to the adoption of construction automation in the Indian context. The semi-structured interviews gave insights into the barriers based on practical ongoing Indian conditions. The interviews helped in selecting the most critical barriers in the Indian context. Newly identified barriers that were unidentified in the literature and are included in the questionnaire are "need for manual rework (finishes) even after automation" and the "lowest bidder system in awarding contracts". Changes in wordings were made in the survey according to interviews, for instance, identifying barriers from "easy access to labour" to "easy access to low-wage labour", considering the Indian context. The summary of the perceived barriers (as extracts from the interviews), as derived from the semi-structured interviews, is presented in Table 4. A total of 35 barriers to automation adoption were initially identified through literature review, from which 21 barriers were synthesized based on their repetitiveness and their applicability in the Indian context. Two additional barriers derived from interviews were selected for the survey, bringing the total count to 23 barriers. Pilot testing with three industry professionals ensured clarity and design adequacy, leading to finalization of the questionnaire based on their feedback. The main survey was administered using Google Forms, where participants rated each barrier on a five-point Likert scale, and responses were collected widely across Indian construction professionals to ensure robust representation.

Table 4: Summary of semi-structured interviews

Code	Summary (perceived barriers)
P1	Physically active skilled operator required, need for training and retraining, complex to use, high initial, maintenance, operation cost, job security concern, manual work required even after automation, easy availability of low-wage labour, aversion to change, project-based industry, lack of client awareness, complexity of the product.
P2	Need for training, need for skilled operators, high initial, maintenance, and operational costs, lack of government initiatives, lowest bidder system.
P3	Easy availability of low wage labour, low level of awareness, inadequate technical infrastructure supporting implementation, and job security concerns.

Code	Summary (perceived barriers)
P4	Lack of skilled operators and expertise, safety concerns, inadequate technical infrastructure supporting implementation, low level of digitalization, high initial cost, and maintenance costs.
P5	changing site conditions, uniqueness of projects, need for training and retraining, lack of skilled operators, lack of awareness, low project budgets, lack of client support, high initial, maintenance and operation costs, and easily not available.
P6	Lack of R&D, project-based industry, low level of digitalization, poor database management, some projects lack internet connectivity, initial cost, unproven effectiveness, need for training, lack of awareness.
P7	Changing needs for every task, need for training, lack of operators and expertise, low level of awareness/exposure, high initial, maintenance, and operation cost.
P8	High initial cost, easy availability of low wage labour, need for training, lack of skilled operators and expertise, job security concerns.
P9	High initial, maintenance, and operation costs, manual work required even after automation, easy availability of low wage labour, lack of support from top management, need for training, training will not give ROI when workmen are rotated due to sub-contractor, lack of skilled operators and expertise, job security concerns.
P10	High initial cost, inadequate technical infrastructure, job loss for labourers, need for training, lack of skilled operators and expertise, and complex nature of automation technology.
P11	Easy availability of low wage labour, aversion to change, unproven effectiveness, high initial cost, maintenance, low flexibility, need for training, challenging to update, need for training, lack of skilled operators and expertise, lack of codes and standards.
P12	Initial cost, sometimes manual work (finishes) required even after automation, special materials needed (e.g. 3d printing), safety concerns, unproven effectiveness, limited flexibility of automation technologies.

**P1- Professional Number 1*

4.2 RANKING OF BARRIERS

The barriers were ranked according to their Mean Item Score (MIS) and Standard Deviation (SD). Descriptive statistics were done using SPSS software, and Mean Item Score (MIS) and Standard Deviation were calculated. Table 5 represents the final ranking of barriers.

Table 5: Ranking of barriers

Code	Barrier	MIS	SD	Rank
B6	Need for training and re-training	4.015	0.953	1
B1	High initial cost	3.833	1.075	2
B9	Low level of awareness (exposure) among stakeholders	3.712	1.12	3
B5	Lack of skilled operators and expertise	3.697	1.176	4
B12	Easily and locally not available	3.652	1.116	5
B8	Conservative work culture and resistance to change	3.53	1.07	6
B19	Inadequate technical infrastructure supporting implementation	3.485	0.996	7

Code	Barrier	MIS	SD	Rank
B2	High operation and maintenance cost	3.47	1.14	8
B4	Lack of government initiatives and support	3.455	1.01	9
B10	Product complexity	3.455	1.112	10
B23	Lowest bidder system in awarding contracts	3.455	1.139	11
B20	Regulations limiting the use	3.424	0.993	12
B18	Safety concerns	3.364	1.172	13
B11	Immature technology and unproved effectiveness	3.348	1.015	14
B16	Lack of R&D	3.318	1.098	15
B17	Lack of relevant codes and standards	3.318	1.152	16
B7	Job loss concerns	3.303	1.007	17
B14	Project-based and task-based industry	3.303	1.189	18
B21	Need for manual rework (finishes) even after automation	3.303	1.24	19
B3	Easy access to low wage labour	3.288	1.31	20
B22	Limited flexibility of automation technologies	3.273	1.001	21
B15	Low level of digitalization	3.182	1.136	22
B13	Fragmented nature of supply chain	3.121	1.089	23

B1-Barriers Number 1

The barriers with the same MIS value were ranked according to their standard deviation; the factor with the lower standard deviation will be given a higher rank (Delgado et al., 2019), as the lower standard deviation represents a more consistent rating by the respondents to a particular factor.

Reliability analysis yielded a Cronbach's Alpha of 0.925, confirming excellent internal consistency (Nunnally & Bernstein, 1994). Normality tests using Shapiro-Wilk and Kolmogorov-Smirnov methods revealed p-values < 0.05 for all barriers, indicating non-normal distribution (Shapiro & Wilk, 1965), and necessitating the use of the Kruskal-Wallis H-test for further non-parametric analysis (Kruskal & Wallis, 1952). The Kruskal-Wallis H-test showed no statistically significant difference in opinions across different groups of construction professionals, with p-values above 0.05 for all 23 barriers. This indicated a general consensus regarding the barriers affecting automation adoption. For critical ranking, barriers were prioritized based on Mean Item Score (MIS) and Standard Deviation (SD) calculated through SPSS, following methodologies suggested by Olanrewaju et al., (2020). The systematic ranking provided clear insights into the industry's key concerns regarding automation, forming the foundation for subsequent recommendations and strategy development. Need for training and re-training, high initial cost of technologies related to construction automation, low level of awareness (exposure) among construction stakeholders, lack of skilled operators and expertise, and unavailability of automation-related technologies locally and in an accessible manner are top-ranked barriers.

4.3 CATEGORIZATION OF BARRIERS

The categorization of barriers was conducted to condense the number of factors into identifiable subscales using Principal Component Analysis (PCA) (Field, 2013). A minimum of 15 variables is recommended for PCA, which this study satisfied. The Kaiser-Meyer-Olkin (KMO) value achieved was 0.814, which exceeds 0.6 threshold (Kaiser, 1974), while Bartlett's Test of Sphericity produced a significant result ($p < 0.05$) with a chi-square value of 779.616 and 253 degrees of freedom, confirming the dataset's suitability for PCA (Bartlett, 1954). Exploratory Factor Analysis (EFA) using PCA with varimax rotation extracted five principal components explaining a cumulative variance of 62.96%, surpassing the recommended 50% threshold. Two barriers, B8 and B10, were removed for having factor loadings below 0.3 (Field, 2013). The naming of the components was guided by theoretical reasoning and researcher judgment as suggested by Williams et al. (2010), providing a structured categorization of the barriers affecting automation adoption in the Indian construction sector. The categorization derived from this study is presented in Table 6 and discussed below.

Table 6: Categorization of barriers

	Categories	C1	C2	C3	C4	C5
Industry-related barriers						
B12	Easily and locally not available	0.617				
B13	Fragmented nature of supply chain	0.549				
B14	Project-based and task-based industry	0.692				
B16	Lack of R&D	0.524				
B22	Limited flexibility of automation technologies	0.803				
B23	Lowest bidder system in awarding contracts	0.810				
B9	Low level of awareness (exposure) among stakeholders	0.512				
Economic barriers						
B1	High initial cost		0.783			
B2	High operation and maintenance cost		0.684			
B4	Lack of government initiatives and support		0.469			
B6	Need for training and retraining		0.592			
Technical barriers						
B5	Lack of skilled operator and expertise			0.399		
B11	Immature technology and unproved effectiveness			0.338		
B15	Low level of digitalization			0.713		
B19	Inadequate technical infrastructure supporting implementation			0.520		
Operational barriers						
B17	Lack of relevant codes and standards				0.822	
B18	Safety concerns				0.394	
B20	Regulations limiting the use				0.455	

	Categories	C1	C2	C3	C4	C5
B21	Need for manual rework (finishes) even after automation				0.571	
Human-related barriers						
B3	Easy access to low wage labour					0.611
B7	Job loss concerns					0.779
Extraction Method: Principal Component Analysis.						
Rotation Method: Varimax with Kaiser Normalization.						

**C1- Category Number 1*

4.3.1 Industry-Related Barriers

The Indian construction industry encounters several distinct barriers that hinder automation adoption. A major challenge, ranked third, is the "Low level of awareness (exposure) among stakeholders" (B9). Many remain unaware of automation's potential benefits, limiting informed decisions and investment (Jäkel et al., 2022; Mahbub, 2008). Ranked fifth, "Easily and locally not available" (B12) reflects the lack of a domestic supply chain for automation tools, resulting in dependence on costly imports (Boya et al., 2022; Huang et al., 2022). The "Fragmented nature of the supply chain" (B13) adds further complexity, as subcontracting and disjointed workflows make integration difficult (Delgado et al., 2019; Mahbub 2008; Oke et al., 2023). The "Project-based and task-based industry" (B14) also limits ROI on automation, since each project and task is unique—unlike the automotive sector—restricting the reuse of specialized tools (Espinoza et al., 2023; Huang et al., 2022). The "Lack of R&D" (B16) constrains local innovation and adaptation of automation technologies. Similarly, "Limited flexibility of automation technologies" (B21) highlights the inability of current systems to meet diverse construction needs (Liu et al., 2024; Tafazzoli et al., 2024). Finally, the "Lowest bidder system in awarding contracts" (B23) prioritizes short-term cost savings over innovation, discouraging investments in long-term automation solutions.

4.3.2 Economic Barriers

Economic constraints are a major hindrance to automation adoption in India. The top-ranked barrier is the "Need for training and retraining" (B6). This highlights the financial burden of continuously upskilling the workforce to operate and manage advanced systems (Jäkel et al., 2022; Liu et al., 2024). With a predominantly unskilled and semi-skilled labour pool, Indian companies must allocate substantial resources to training, which can discourage automation initiatives. Ranked second, "High initial cost" (B1) of automation technologies remains a primary concern for most stakeholders (Oke et al., 2023; Tafazzoli et al., 2024). Additionally, the eighth-ranked "High operation and maintenance cost" (B2) deters adoption, as many companies lack the financial resilience to bear recurring expenses related to automated equipment (Mahbub, 2008; Oke et al., 2023). "Lack of government initiatives and support" (B4) further exacerbates the problem (Delgado et al., 2019; Oke et al., 2023). Despite India's focus on infrastructure development, policies and subsidies promoting automation adoption remain limited, leaving stakeholders to bear the financial burden entirely. This gap underscores the urgent need for government intervention to incentivize automation adoption through tax benefits, grants, or low-interest loans.

4.3.3 Technical Barriers

The Indian construction sector also grapples with significant technical hurdles. Ranked fourth, "Lack of skilled operators and expertise" (B5) is a major obstacle (Boya et al., 2022). Operating automated machinery and implementing digital systems requires specialized knowledge, which is scarce in India. The seventh-ranked barrier, "Inadequate technical infrastructure supporting implementation" (B19) (Bademosi & Issa, 2021; Oke et al., 2023), further compounds the problem. In many parts of India, such infrastructure is either underdeveloped or entirely absent, making the deployment of automation systems impractical. Another key barrier is the "Immature technology and unproved effectiveness" (B11). Given that automation in construction is still emerging in India, many stakeholders are hesitant to adopt unproven technologies (Aghimien et al., 2024; Espinoza et al., 2023). Moreover, the "Low level of digitalization" (B15) in the construction sector reflects the lack of foundational digital infrastructure required for implementing automation solutions effectively (Liu et al., 2024).

4.3.4 Operational Barriers

Operational barriers also play a significant role in limiting automation adoption. The “Lack of relevant codes and standards” (B17) reflects the regulatory vacuum in India concerning automation in construction. Without clear guidelines and standards, stakeholders are uncertain about the legal and procedural requirements for deploying automated systems (Huang et al., 2022; Pradhananga et al., 2021). "Safety concerns" (B18) remain another critical issue. Despite the potential of automation to improve safety, stakeholders often perceive advanced machinery as risky due to the lack of proven safety protocols and training (Waqar et al., 2024). Similarly, "Regulations limiting the use" (B20) underscore the restrictive policies that hinder the application of automated technologies, particularly in sensitive sectors such as water infrastructure and urban development (Tafazzoli et al., 2024). The "Need for manual rework (finishes) even after automation" (B22) reflects persistent operational inefficiencies, as many automated systems lack the precision needed for certain tasks, requiring manual touch-ups and diminishing automation's overall effectiveness.

4.3.5 Human-Related Barriers

Finally, human-related barriers are deeply rooted in India's socio-economic context. The "Easy access to low-wage labour" (B3) reflects a fundamental barrier to automation adoption (Delgado et al., 2019; Pradhananga et al., 2021). With abundant and inexpensive labour readily available, many contractors see little incentive to invest in costly automation technologies that replace manual work. "Job loss concerns" (B7) further deter automation adoption. The fear of widespread unemployment due to automation is a significant concern in a country with high labour dependency. Stakeholders often prioritize social stability over technological advancement, choosing to maintain traditional practices that ensure job security for unskilled and semi-skilled workers (Delgado et al., 2019; Tafazzoli et al., 2024).

In summary, the barriers identified across industrial, economic, technical, operational, and human dimensions present a comprehensive view of the multifaceted challenges facing automation in Indian construction. Recognizing and addressing these barriers is crucial for developing effective strategies to foster wider technology adoption and drive industry transformation.

5. CONCLUSIONS

The present study critically explored the barriers to the adoption of automation in Indian construction through a mixed-methods approach involving literature review, semi-structured interviews, and a questionnaire survey. A total of 23 distinct barriers were identified and grouped into five core categories: industry-related, economic, technical, operational, and human-related. Among these, the most significant barriers were the need for training and retraining, high initial costs, low stakeholder awareness, and lack of skilled operators. These findings reveal the complex interplay of challenges faced by a traditionally operated industry, where socio-economic diversity and infrastructural limitations continue to impede technological adoption.

The research contributes theoretically by offering a structured, empirically validated framework tailored to India's unique construction landscape. While studies including Delgado et al. (2019) and Mahbub (2008) have assessed global contexts, the present study localizes those findings, accounting for India's infrastructural and policy environment. Practically, it delivers insights regarding construction automation for stakeholders across the sector. Top-ranked barriers, such as high costs and inadequate government support, suggest the need for incentives like subsidies and public-private partnerships. R&D and modular automation can address technical gaps, whereas awareness campaigns can reduce resistance among workers and decision-makers.

The sample, though diverse, may not fully capture regional disparities or micro-level project complexities, representing a limitation. While PCA effectively grouped barriers into themes, it did not examine causal relationships, which future studies could address using SEM or system dynamics. Further research could explore sector-specific automation, cross-country comparisons, and the integration of emerging technologies like AI, BIM-robotics, and digital twins. Overall, a holistic approach addressing technological, economic, operational, and human factors is essential. This study offers a foundation for steering India's construction industry toward a more automated, efficient, and future-ready paradigm.

6. REFERENCES

Aghimien, D., Ikuabe, M., Aghimien, L. M., Aigbavboa, C., Ngcobo, N., & Yankah, J. (2024). PLS-SEM assessment of the impediments of robotics and automation deployment for effective construction health and safety. *Journal of Facilities Management*, *22*(3), 458-478. https://doi.org/10.1108/JFM-04-2022-0037

Bademosi, F., & Issa, R. R. (2021). Factors influencing adoption and integration of construction robotics and automation technology in the US. *Journal of Construction Engineering and Management*, *147*(8), 04021075. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002103

Bartlet, M. (1954). A note on multiplying factors for various chi-squared approximations. *Journal of the Royal Statistical Society*, *16*, 296-298. https://www.jstor.org/stable/2984057

Bock, T. (2015). The future of construction automation: Technological disruption and the upcoming ubiquity of robotics. *Automation in Construction*, *59*, 113-121. https://doi.org/10.1016/j.autcon.2015.07.022

Boya, A., Akinradewo, O., Aigbavboa, C., & Ramabodu, M. (2022, June). Implementation of automation and robotics: Benefits to the construction industry. In A. O. Windapo, A. O. Aiyetan, N. Umeokafor & C. S. Okoro (Eds), *Proceedings of the construction business and project management conference* (pp. 78-87). University of Cape Town. http://researchgate.net/publication/363196463_Implementation_of_automation_and_robotics_Benefits_to_the_construction_industry

Chen, Q., de Soto, B. G., & Adey, B. T. (2018). Construction automation: Research areas, industry concerns and suggestions for advancement. *Automation in Construction*, *94*, 22-38. https://doi.org/10.1016/j.autcon.2018.05.028

Davis, M. (2022, January 06). *What is construction automation, and how will it drive the future of building?*. Autodesk. https://www.autodesk.com/design-make/articles/construction-automation

Delgado, J. M. D., Oyedele, L., Ajayi, A., Akanbi, L., Akinade, O., Bilal, M., & Owolabi, H. (2019). Robotics and automated systems in construction: Understanding industry-specific challenges for adoption. *Journal of Building Engineering*, *26*, 100868. https://doi.org/10.1016/j.jobe.2019.100868

Espinoza, M. S. R., Contreras, M. A. C., Estela, K. M. A., Varillas, C. J. N., & Torpoco, G. F. R. (2023, October). *Robotics in building construction: Advantages and barriers*. 2023 Congreso Internacional de Innovación y Tendencias en Ingeniería (CONIITI), Colombia. http://dx.doi.org/10.1109/CONIITI61170.2023.10324131

Fellows, R., & Liu, A. M. (2012). Managing organizational interfaces in engineering construction projects: Addressing fragmentation and boundary issues across multiple interfaces. *Construction Management and Economics*, *30*(8), 653-671. https://doi.org/10.1080/01446193.2012.668199

Field, A. (2013). *Discovering statistics using IBM SPSS statistics* (6th ed.). Sage Publications Limited. https://uk.sagepub.com/en-gb/eur/discovering-statistics-using-ibm-spss-statistics/book285130

Get It Right Initiative UK. (2024). *The use of digital technology on site to reduce errors in construction*. https://getitright.uk.com/reports/giri-research-report-the-use-of-digital-technology-on-site-to-reduce-errors-in-construction

Groover, M. P. (2016). *Automation, production systems, and computer-integrated manufacturing* (4th ed.). Pearson Education India. https://miemagazine.com/sample/IT/IT301-400/IT358/sample-Automation%20Production%20Systems%20and%20Computer-Integrated%20Manufacturing%204th%204E.pdf

Huang, Z., Mao, C., Wang, J., & Sadick, A. M. (2022). Understanding the key takeaway of construction robots towards construction automation. *Engineering, Construction and Architectural Management*, *29*(9), 3664-3688. https://doi.org/10.1108/ECAM-03-2021-0267

Jäkel, J. I., Rahnama, S., & Klemt-Albert, K. (2022). Construction robotics excellence model: A framework to overcome existing barriers for the implementation of robotics in the construction industry. In T. Linner, B. G. de Soto, R. Hu & I. Brilakis (Eds.), *Proceedings of 39th international symposium on automation and robotics in construction* (pp. 605-613). ISARC. https://doi.org/10.22260/isarc2022/0085

Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika, 39*(1), 31-36. https://doi.org/10.1007/BF02291575

Kamaruddin, S. S., Mohammad, M. F., & Mahbub, R. (2016). Barriers and impact of mechanisation and automation in construction to achieve better quality products. *Procedia-Social and Behavioral Sciences*, *222*, 111-120. https://doi.org/10.1016/j.sbspro.2016.05.197

Kruskal, W. H., & Wallis, W. A. (1952). Use of ranks in one-criterion variance analysis. *Journal of the American Statistical Association*, *47*(260), 583-621. https://doi.org/10.2307/2280779

Liu, Y., AH, A., Haron, N. A., NA, B., & Wang, H. (2024). Robotics in the construction sector: Trends, advances, and challenges. *Journal of Intelligent & Robotic Systems*, *110*(2), 72. https://doi.org/10.1007/s10846-024-02104-4

Mahbub, R. (2008). *An investigation into the barriers to the implementation of automation and robotics technologies in the construction industry* [Doctoral dissertation, Queensland University of Technology]. QUT ePrints. https://eprints.qut.edu.au/26377

McKinsey Global Institute. (2017). *Reinventing construction through a productivity revolution*. https://www.mckinsey.com/capabilities/operations/our-insights/reinventing-construction-through-a-productivity-revolution

Nunnally, J., & Bernstein, I. (1994). *Psychometric theory* (3rd ed.). MacGraw-Hill, New York. https://journals.sagepub.com/doi/abs/10.1177/014662169501900308

Oesterreich, T. D., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry*, *83*, 121-139. https://doi.org/10.1016/j.compind.2016.09.006

Oke, A. E., Aliu, J., Fadamiro, P., Leo-Olagbaye, F., Jamir Singh, P. S., & Samsurijan, M. S. (2023). Evaluating the drivers for the implementation of automation techniques in the Nigerian construction sector. *Built Environment Project and Asset Management*, *13*(6), 913-928. https://doi.org/10.1108/BEPAM-04-2023-0085

Olanrewaju, O. I., Chileshe, N., Babarinde, S. A., & Sandanayake, M. (2020). Investigating the barriers to building information modeling (BIM) implementation within the Nigerian construction industry. *Engineering, Construction and Architectural Management*, *27*(10), 2931-2958. https://doi.org/10.1108/ECAM-01-2020-0042

Pradhananga, P., ElZomor, M., & Santi Kasabdji, G. (2021). Identifying the challenges to adopting robotics in the US construction industry. *Journal of Construction Engineering and Management*, *147*(5), 05021003. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002007

Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, *52*(3-4), 591-611. https://doi.org/10.1093/biomet/52.3-4.591

Tafazzoli, M., Shrestha, K., & Dang, H. (2024). Investigating barriers to the application of automation in the construction industry. In J. S. Shane, K. M. Madson, Y. Mo, C. Poleacovschi & R. E. Sturgill (Eds.), *Construction research congress 2024: Advanced technologies, automation, and computer applications in construction* (pp. 941-950). ASCE Publishing. https://doi.org/10.1061/9780784485262.096

US Bureau of Labor Statistics. (2024). *National census of fatal occupational injuries in 2023*. https://www.bls.gov/news.release/pdf/cfoi.pdf

Waqar, A., Alrasheed, K. A., & Benjeddou, O. (2024). Enhancing construction management outcomes through the mitigation of robotics implementation barriers: A sustainable practice model. *Environmental Challenges*, *16*, 100989. https://doi.org/10.1016/j.envc.2024.100989

Williams, B., Onsman, A., & Brown, T. (2010). Exploratory factor analysis: A five-step guide for novices. *Australasian Journal of Paramedicine*, *8*, 1-13. https://doi.org/10.33151/ajp.8.3.93