International Journal of Construction Management

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tjcm20

An appraisal of barriers to digitalisation of construction industry in developing countries: perspective from India

Jamiu A. Dauda, Ninad N. Chavan, Abdullahi B. Saka, Saheed O. Ajayi & Adekunle S. Oyegoke

To cite this article: Jamiu A. Dauda, Ninad N. Chavan, Abdullahi B. Saka, Saheed O. Ajayi & Adekunle S. Oyegoke (11 Jun 2024): An appraisal of barriers to digitalisation of construction industry in developing countries: perspective from India, International Journal of Construction Management, DOI: 10.1080/15623599.2024.2362014

To link to this article: https://doi.org/10.1080/15623599.2024.2362014

Published online: 11 Jun 2024.

INTERNATIONAL JOURNAL OF CONSTRUCTION MANAGEMENT
https://doi.org/10.1080/15623599.2024.2362014

An appraisal of barriers to digitalisation of construction industry in developing countries: perspective from India

Jamiu A. Dauda, Ninad N. Chavan, Abdullahi B. Saka, Saheed O. Ajayi and Adekunle S. Oyegoke

School of Built Environment, Engineering and Computing, Leeds Beckett University, Leeds, UK

ABSTRACT

Digitalisation in the construction sector promises numerous benefits, yet its widespread adoption in India faces impediments. This study aims to identify and analyse critical barriers hindering the adoption of digitalisation within the Indian construction sector. The study adopts a multi-phase research approach, involving a literature review to identify potential barriers. Subsequently, a questionnaire was administered to 162 professionals in the Indian construction industry. The survey reveals a willingness within the Indian construction sector to embrace digitalisation, citing benefits such as enhanced productivity and revolutionary impacts on construction processes. Larger organizations exhibit greater proactivity, while smaller businesses face challenges in resources and knowledge, leading to slower adoption rates. The study identifies five key themes of barriers, including financial/resource constraints, cultural/organisational constraints, regional disparities, data security/privacy concerns, and awareness/capacity-building constraints. The implication of the study is to unveil crucial barriers and provide insights for tailored interventions, aiding stakeholders, policymakers, and researchers in navigating the evolving digital landscape of the Indian construction industry. This study contributes to the exploration of perceptions of construction professionals specifically in India on why digitalisation is not fully embraced in the Indian construction sector.

ARTICLE HISTORY
Received 25 December 2023
Accepted 22 May 2024

KEYWORDS
Barriers; construction; digitalisation; exploratory factor analysis; Indian construction industry

Introduction

Every country's economy depends heavily on the construction industry and India is no different. A report by Mahasua (2023) states that the Indian construction industry has a large multiplier impact of 250 associated industries and provides 8% of the net Indian GDP. The sector also has a cumulative Foreign Direct Investment (FDI) totalling US$25.66 billion between April 2000 and March 2020, making the Indian Construction sector the second-largest beneficiary of FDI in the fiscal year 2020–2021 (Rani et al. 2022). In 2023, the construction sector in India is anticipated to grow significantly and contribute 13% of the country's GDP to reach INR45,907 billion (Parwal 2023). Although some sectors of the construction industry face short-term difficulties, India's medium to long-term growth story is still positive. The growth trends within construction project planning, execution, and management could be sustained and enhanced through digitalisation, which would result in more effective operations, better collaboration, and environmentally friendly procedures (Gamil et al. 2020; Abbas et al. 2022). Alongside these benefits, a recent study from Ronaghi (2023) emphasised that the adoption of Artificial Intelligence and other technologies has positive effects on circular economy practices.

In acknowledgement of these prospects of digitalisation, the rate of technology adoption in the Indian construction sector is constantly increasing, although it varies across different parts of the business. While some businesses and initiatives are aggressively embracing digital technologies and cutting-edge practices, others are still in the early stages of technological adoption. The stakeholders in the Indian construction business have expressed conflicting opinions about digitalisation, not everyone feels confident enough to use the new technology first-hand (Musarat et al. 2022). This is in accordance with HT Brand Studio (2020) survey which reveals that developing digital competencies and skills throughout the organisation remains the top digital problem for 47% of construction companies in India. The survey also stated that 42% of the participants are having difficulty creating a strategic roadmap for digital investments while 41% are still finding it difficult to create the ideal organisational structure for digital transformation. Disturbingly, HT Brand Studio (2020) found that organisations in India only use digital solutions in 50% or less of their projects and in 5% of cases, they don't use them at all. Companies are reluctant to make technology investments despite the obvious associated benefits. In a similar study, Alva (2022) reported that only 3% of India's construction firms are currently undergoing technological transformation, however, more than 70% have only recently begun. A shift that has allowed between 1% and 3% of these companies' yearly revenue to be allocated to technology (Alva 2022).

The international market for construction 4.0 (digitalisation in construction) was estimated to be worth $9,786.9 million in 2019 and is anticipated to grow to $29,101.5 million by 2027

CONTACT Jamiu A. Dauda j.a.dauda@leedsbeckett.ac.uk School of Built Environment, Engineering and Computing, Leeds Beckett University, Leeds, UK.
Data available on request from the authors: The data that support the findings of this study are available from the corresponding author, [JD], upon reasonable request.

(Alva 2022). Therefore, investing in digital transformation, creating reliable workflows, and encouraging innovation will have major long-term benefits for the industry, the people it employs, and the nation. In addition to the financial gains from increased productivity, efficiency, quality, and teamwork, their adoption can help to improve safety and sustainability, which will help to improve the negative public perception of the construction sector as time passes (Smallwood and Allen 2022; Toyin and Mewomo 2023).

Numerous social, technological, environmental, economic, and political (STEEP) obstacles must be overcome to fully enjoy these advantages, especially in developing countries as submitted by the findings of (Oesterreich and Teuteberg 2016; Ronaghi and Ronaghi 2021). Understanding the factors that affect the adoption and execution of digitalisation is essential in the Indian context, where the construction industry is crucial to the nation's economic progress. The construction industry in India operates in a distinct socio-cultural and economic environment that is characterised by a fragmented ecosystem with numerous competitors, a wide range of project sizes, and varied technology readiness levels. Therefore, for effective implementation and long-term growth, a thorough investigation of the factors impeding digitalisation in this particular context is essential. As such, this study conducts an in-depth investigation to advance academic knowledge, educating industry stakeholders and policymakers for successful digitalisation implementation in India. The study aims to identify and analyse the barriers that hinder the widespread adoption of digital technologies within the Indian construction sector. The finding of this study will facilitate evidence-based decision-making steps toward crafting targeted interventions and strategies to promote the digitalisation of the Indian Construction sector.

Concept of digitalisation in Indian construction sector

The construction industry has continued to play a variety of roles in defining daily life because it includes provisions of houses, workplaces, and different modes of transportation. The broader relevance of construction projects comes with complexity, financial and time limitations, and quality issues that could be addressed through digitalisation (Alva 2022). The term digitalisation is a multifaceted concept that is often defined based on the context of application. In business, it refers to the application of digital technologies to enhance operations and customer experiences. While it is technologically referred to as the utilisation of tools for innovation and efficiency (Vaughan 2013). Specifically for construction, digitalisation is defined as the process of combining industrialised technical methods with digital technologies to boost profitability and enhance the sustainability of construction projects (Musarat et al. 2022). By changing operational procedures, enabling quick communication, increasing efficiency through system integration, improving asset productivity, lowering costs, and doing many other things, digitalisation can assist construction organisations in attaining their goals (Gamil et al. 2020; Maiti et al. 2020; Smallwood and Allen 2022).

Building Information Modelling (BIM), Internet of Things (IoT), Drones, Augmented Reality, Virtual Reality, Cloud Computing, and other technologies are all included in the term digitalisation. These technologies can change the way construction is carried out, improve collaboration, increase production, and make resource allocation more effective (Abbas et al. 2022). Previously, numerous studies, (Maiti et al. 2020; Paul et al. 2020; Parwal 2023) have looked at how the Indian construction industry is now adopting these digital technologies. The consensus of the studies revealed that there is widespread awareness of digitalisation across construction enterprises, but actual implementation varied greatly. Firm size, resource accessibility, and leadership support were found to be important barriers as per Maiti et al. (2020). In addition, a similar study by Kumari (2021) emphasised the uneven levels of digital maturity among Indian construction organisations, with bigger organisations being more developed in their digital transformation journey.

The adoption and integration of digital technologies are increasingly necessary for the construction industry to grow sustainably and remain competitive. As a result of digitalisation, businesses engage with interconnected systems at every stage of the value chain. With the construction industry undergoing technical and innovation improvements by replacing most manual construction operations with digital tools and automation, Industry 4.0 has the potential to necessitate a managerial paradigm shift. According to Obiso et al. (2020), the necessary managerial shift within the construction sector should address issues like ageing workforce, skill development, resource efficiency, clean production, and mass customisation. Addressing these issues will enable quick adoption and reaping of the numerous benefits of digital technologies within the construction sector (Maskuriy et al. 2019). These numerous advantages of quick digitalisation include enhanced stakeholder participation, better risk management, improved project results, improved productivity, simpler processes, cost savings, and improved project coordination (Jacobsson and Linderoth 2021). Understanding and calculating these advantages can help construction companies make more informed decisions by providing strong justifications for investing in digitalisation. Meanwhile, such investments and integration have been obvious issues for all SME businesses with those in the construction sector being the most affected (Jacobsson and Linderoth 2021). The implementation of digitalisation is seen to be hampered by significant barriers that have prevented the Indian construction sector from reaping the full potential of digitalisation. Studies such as Bajpai and Misra (2021) and Parwal (2023) show that the barriers facing the digitalisation of Indian construction industry loom large starting from the reluctance of stakeholders to adopt new technologies to the lack of digital competencies within organisations. In comparison to some other places, the adoption of digitalisation in the Indian construction industry has been somewhat delayed. The main causes of this delay or barrier to full digitalisation of the Indian construction sector have been studied in parts with most studies tend to focus on one sector of the industry at a time or even focusing on a certain group of stakeholders. This has been identified as a major gap in knowledge and as such, this study proposed to cover that by conducting a comprehensive study that will consider the barriers in the general sector including Architecture, Design, Engineering, Construction and Project management. The study also recruits participants at all levels within the sector, unlike many other studies that focus on either managers/policy makers or the end users. The details of such will be discussed in subsequent sections.

Research methodology

The current study is grounded in the positivist approach, a research philosophy that prioritises the utilisation of empirical data, scientific methodologies, and impartiality in the examination of social phenomena. Positivism is a philosophical stance that is founded on the epistemological assumption that

knowledge can be acquired through rigorous empirical observation, quantification, and rational deduction (Tsang 2016). The positivist paradigm prioritises the utilisation of Likert scale questionnaire as a precise instrument of measurement and quantifiable information, making this study quantitative. The utilisation of quantitative methods allows for the acquisition of impartial and measurable data, thereby promoting meticulous examination and statistical evaluation by researchers (Saunders et al. 2019). A three-stage multi-phase research approach as shown in Figure 1 is used in this study.

Stage I: - data construction

Reviewing the existing literature that is relevant to the topic under discussion is one of the most common processes of establishing variables to measure the constructs of questionnaires as conducted in the earlier study by Dauda and Ajayi (2022). Database of peer-reviewed articles such as Scopus, Google Scholars and Science Direct were searched using primarily the keyword "digitalisation in construction". The initial search resulted in 64,000 articles which was later reduced to 710 with the imposition of the Indian Construction sector as a compulsory inclusion criterion. Thereafter, other inclusion criteria such as barriers, hindrance and similar synonyms were imposed to narrow down the list of articles. After the screening procedure, 60 papers were chosen for a deeper examination. Upon review, the listed factors in Table 1 have been identified as potential barriers impacting the adoption of digitalisation in the construction industry and thus were used as a construct of the questionnaire in this study. This approach aligns with multiple theories related to technology or innovation adoption including the Technology Acceptance Model (TAM) proposed by Davis (1989) and the Unified Theory of Acceptance and Use of Technology (UTAUT) formulated by Venkatesh et al. (2003). Both TAM and UTAUT focus on identifying various factors influencing technology acceptance and ease of use. However, the critical review of technology theories is beyond the scope of this study because of the study's priority on the utilisation of empirical data to ensure a practical understanding of digitalisation barriers in the Indian construction industry.

Stage II: - data collection

The second stage involved developing and administering the questionnaire to collect data based on the initial potential barriers identified in Table 1. The survey used a five-point Likert scale, with responses that ranged from 1 to 5 representing strongly disagreed, disagreed, neutral, agreed, and strongly agreed. The questionnaire consists of 26 questions with questions 1 to 4 measuring the respondents' demographic data. Questions 6 – 26 examine respondents' degrees of agreement with several potential barriers to digitalisation within the Indian construction sector. The developed questionnaire was first piloted among professionals working in the Indian construction sector using personal contact networks. The pilot study avails the opportunity to make changes to some of the questions to remove any unclear information and improve respondents' understanding.

After completing the pilot study, the revised questionnaire was then electronically distributed to the interested respondents within the architecture/design, engineering, construction, and project management through an online survey platform by sending the URLs to the questions to business groups *via* email,

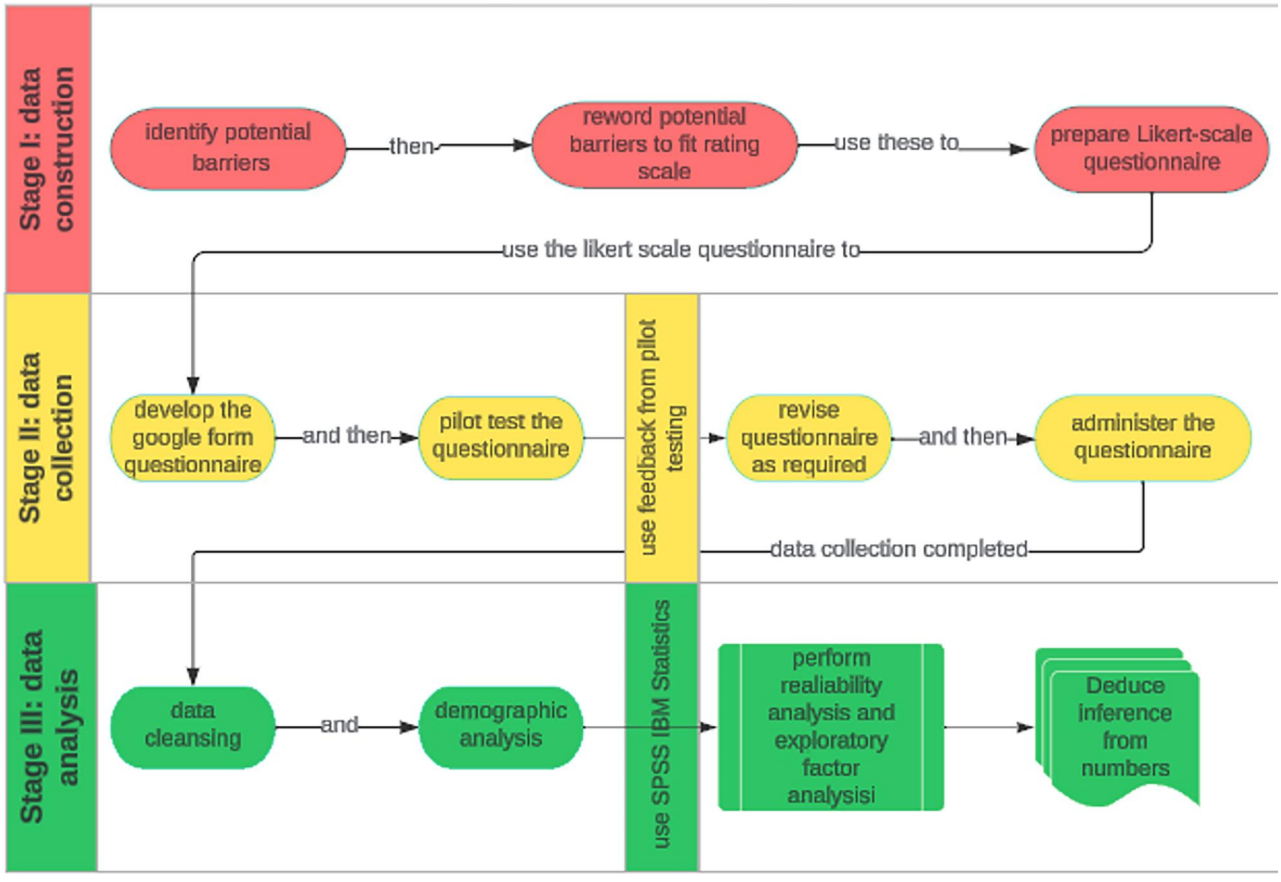

Figure 1. Illustration of the research methodology (source: Authors).

Table 1. Potential barriers to the adoption of digitalisation.

S/No	Barriers	References
1	High initial investment for implementing digitalisation tools and technologies	(Bajpai and Misra 2020)
2	Limited financial resources of most small and medium-sized enterprises (SMEs) within the construction sector	(Akinradewo et al. 2022)
3	Insufficient awareness among construction industry stakeholders regarding digitalization concepts and available technologies.	(Perera et al. 2023)
4	Gaps in understanding the practical aspects of how to integrate digital technologies into construction workflows.	(Chen et al. 2022)
5	Cultural norms, hierarchical structures, and resistance to change within organizations	(Oesterreich and Teuteberg 2016)
6	Constant need for upskilling and reskilling of the workforce to effectively use and leverage digital technologies	(Aghimien et al. 2019)
7.	Prevalence of older and less tech-savvy workforce within the construction sector who may struggle with the learning curve.	(Singh et al. 2023)
8	The complexity and diversity of construction projects in India, including various building types, materials, and construction practices	(Perera et al. 2023)
9	Regional Disparities in the availability and quality of digital infrastructure across different regions in India	(Bajpai and Misra 2021)
10	Disparities in the overall success of digitalisation initiatives causing discouragement to further implementation	(Parwal 2023)
11	Data security and privacy, as construction projects involve sensitive information.	(Obiso et al. 2020)
12	Resources intensive need for continuous upgrades, maintenance, and support for long-term sustainability	(Taher 2021)
13	Daunting challenges of scalability of digital technologies within construction projects that are often unique.	(Omrany et al. 2023)
14	Fragmentation between industry stakeholders, including government bodies, construction companies, technology providers, and research institutions	(Maskuriy et al. 2019)
15	Lack of sufficient alternatives for affordable and user-friendly digitalisation solutions	(Maiti et al. 2020)
16	Lack of bespoke solutions specifically tailored to the needs and challenges of the Indian construction industry.	(Chen et al. 2022)
17	Inadequate data-driven analysis and case studies to overcome initial uncertainty and encourage organisations to adopt digital technologies	(Babaeian and Sutrisna 2022)
18	Lack of detailed documentation on ROI and cost-saving possibilities of digitalisation concerning specific examples from the Indian Construction industry.	(Bajpai and Misra 2021)
20	Irregular industry-wide campaigns and awareness programs	(HT Brand Studio 2020)
21	Secrecy of information that hinder inspiration and informed decisions about embracing and investing in digital technologies.	(Yap and Toh 2020)
22	Limited training and educational programs on digitalisation concepts within Indian Construction Sector	(Won et al. 2013)

LinkedIn, and WhatsApp. This type of sampling is referred to as convenient/opportunity sampling which allows any willing participant to respond to the questionnaire. The main criteria to be considered as valid respondents is that the respondents must be working in the Indian construction sector. Targeting respondents exclusively from the Indian construction sector enhances the relevance and industry-specific insights. However, it limits the study perspectives and sample sizes, hence limiting the generalisability of the study outcome. In total, 162 responses were received which is deemed appropriate because most studies require a sample size of at least 30 (Memon et al. 2020; Ajayi et al. 2022).

Stage III: - data analysis

The demographic data of the respondents was first analysed and presented in Figure 2 to show (a) the percentage variation across architecture/design, construction, engineering, and project management sectors, (b) the percentage number of respondents based on years of experience, and (c) number of respondents from each sector that currently adopt specific technology in their work. In addition, the collected data were analysed using the five-level Likert scales often referred to as summative scales for comparing respondent's answers across their different categories. This analysis is necessary to reveal the different opinions and levels of agreement of respondents in different categories to the identified potential barriers. To do that, the mean responses of all the 11, 36, 95, and 20 respondents for architecture/design, construction, project management and engineering respectively were estimated. After establishing the mean scores, equations 1 & 2 were used to obtain the scale index which is then used to determine the final level of agreement or disagreement of each measuring potential barriers according to the respondents from each group as shown in Table 2.

$$Scale\ index = Low\ Mean\ score + scale\ Index\ interval \quad (1)$$

$$Scale\ index\ interval = (Highest\ Mean\ score - Lowest\ Mean\ Score) / \text{Total Scale Usage} \quad (2)$$

Reliability analysis

The data collected were subjected to reliability analysis to evaluate their integrity and determine whether any factor did not significantly contribute to the general reliability of the data collected. Tuan et al. (2005) suggested that poor test construction or confusing instructions might contributed to the unreliability of data. Thus, recommended that any data found not contributing to the overall reliability of the response should be declared unsuitable for further analysis and should be eliminated from the data before conducting exploratory factor analysis. Since Likert scale was employed in the survey data, Cronbach Alpha coefficient recommended by Field (2013) which is the the most common measure of internal consistency or reliability was used. Cronbach Alpha quantifies the extent to which a set of items in a scale or

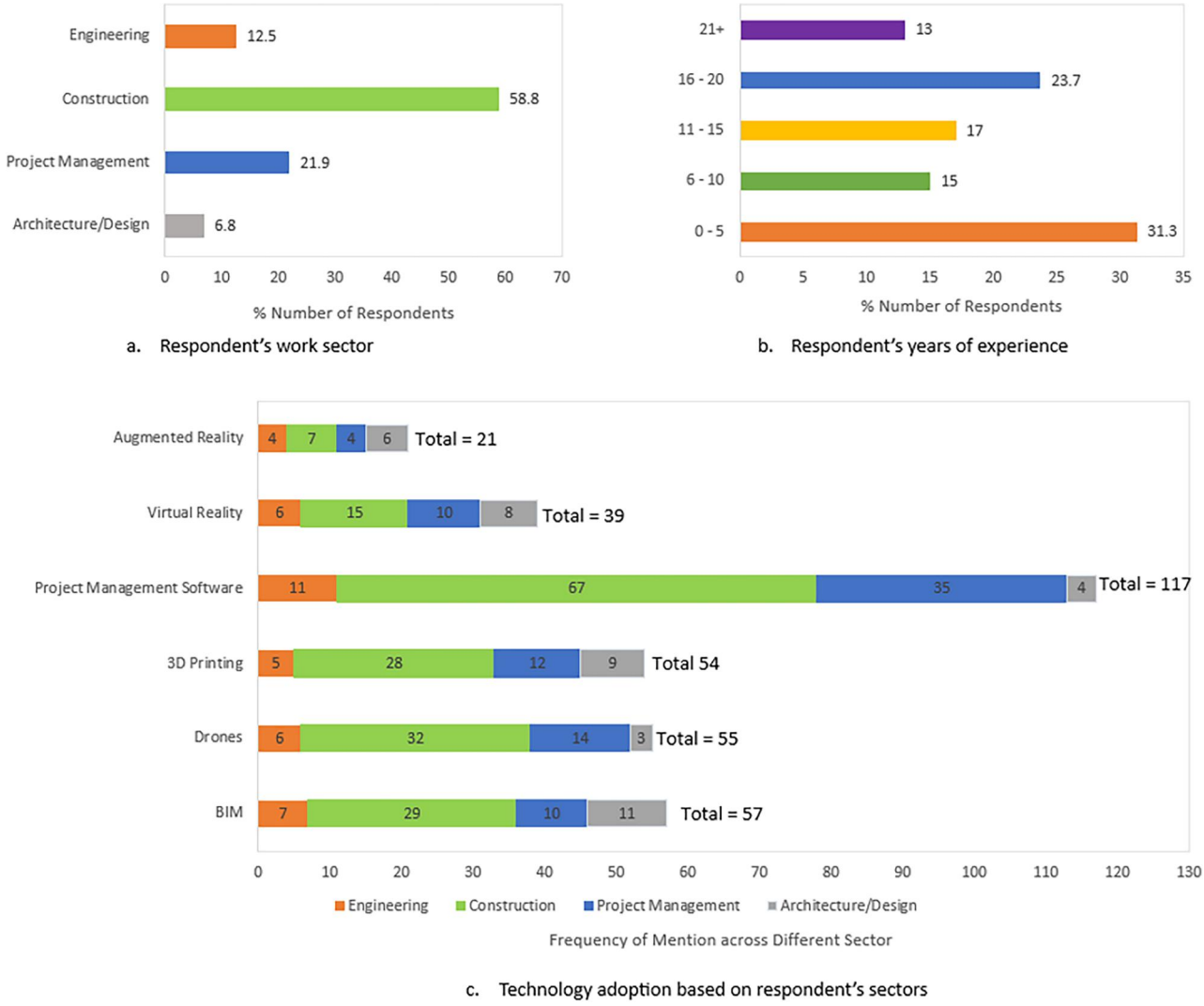

Figure 2. Demographic data analysis (source: Authors).

questionnaire measures a single latent construct or dimension (Taber 2018). The Cronbach Alpha coefficient has a value between 0 and 1, with a value over 0.7 suggesting an acceptable amount of internal consistency and a value above 0.8 indicating a high-level internal consistency (Cho and Kim 2015). The Cronbach Alpha coefficient for this study is 0.922, which indicates that the data gathered is extremely reliable and internally consistent. However, Taber (2018) suggested that a further analysis known as Cronbach Alpha coefficient if item deleted is recommended in identifying problematic items that may weaken the overall reliability of the data. Statistically, Cho and Kim (2015) argued that every variable that produces an individual Cronbach Alpha coefficient more than the overall Cronbach Alpha coefficient for this study (0.922) should be regarded as unreliable. However, before the removal of any items in this study, the flagged items were further considered against the items where the level of agreement of the respondents from each sector is less than 3.72 as shown in the scale of index under Table 2. The 3.72 represent either neutral responses, disagree or strongly disagree. As such, BAR 6, BAR8, and BAR 20 with Cronbach's Alpha values of 0.927, 0.936, and 0.929, respectively and a mean index of less than 3.72 across all sectors except BAR 6 where the responses from the Engineering sector is a narrow agreed of 3.75 were eliminated before the exploratory factor analysis.

Exploratory factor analysis

The study confirmed 18 of the 21 identified potential barriers as barriers to digitalisation in the Indian construction industry and the exploratory factor analysis (EFA) was utilised to determine the inherent correlations between the measured variables. In essence, it is used to identify a collection of latent notions that underline several measurable variables given in the provided questionnaire. The three separate steps of the factor analysis were the appropriateness of data test, factor extraction, and factor rotation as described by Field (2013) and Frost (2022) In the first step, the Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity were used to determine the adequacy of the data collected. Field (2013) suggested that the KMO value must be more than 0.5 and the Small Bartlett's test of sphericity value must be less than 0.05 for data sampling to be considered appropriate. Bartlett's test of sphericity seeks some redundancy between the variables that can be added by a small number of elements by comparing an observed correlation matrix to the identity matrix. In this study, the analysis yields a KMO value of 0.90 and Bartlett's test of sphericity value of 2.98E-007, both values falling inside the appropriate upper and lower bounds, proving that the data can be used for factor analysis. An analysis of the anti-imaging matrix was conducted to find any variables with a diagonal value less than 0.5 and

Table 2. Demographic analysis of responses and reliability analysis.

ID/S.No	Barriers	Overall Responses by Sector				Cronbach's Alpha	Cronbach's Alpha if Item Deleted
		Architecture & Design	Project Management	Construction	Engineering		
BAR1	High initial investment required for implementing digitalisation tools and technologies	4.18	4.53	4.20	4.15	0.488	0.919
BAR2	Limited financial resources of most small and medium-sized enterprises (SMEs) within construction sector	4.00	4.28	3.99	3.95	0.479	0.918
BAR3	Insufficient awareness among construction industry stakeholders regarding digitalization concepts and available technologies.	3.82	4.25	3.80	4.10	0.568	0.917
BAR4	Gaps in understanding the practical aspects of how to integrate digital technologies into construction workflows.	4.27	4.14	4.20	4.25	0.572	0.918
BAR5	Cultural norms, hierarchical structures, and resistance to change within organizations	4.55	4.36	4.09	3.85	0.564	0.92
BAR6*	Constant need for upskilling and reskilling of the workforce to effectively use and leverage digital technologies*	3.64	2.97	3.02	3.75	0.297	0.927
BAR7	Prevalence of older and less tech-savvy workforce within construction sector who may struggle with the learning curve.	3.55	2.89	3.82	3.65	0.489	0.921
BAR8*	The complexity and diversity of construction projects in India, including various building types, materials, and construction practices*	3.18	3.33	2.87	3.05	0.49	0.936
BAR9	Regional Disparities in the availability and quality of digital infrastructure across different regions in Indian.	4.55	4.44	4.20	4.05	0.554	0.918
BAR10	Disparities in the overall success of digitalisation initiatives causing discouragement to further implementation	4.27	4.28	4.48	3.90	0.578	0.918
BAR11	Data security and privacy, as construction projects involve sensitive information.	4.73	4.50	4.09	4.15	0.572	0.919
BAR12	Resources intensive need for continuous upgrades, maintenance, and support for long term sustainability	4.45	4.33	4.06	3.95	0.541	0.919
BAR13	Daunting challenges of scalability of digital technologies within construction projects that are often unique.	3.91	4.22	3.96	3.90	0.556	0.917
BAR14	Fragmentation between industry stakeholders, including government bodies, construction companies, technology providers, and research institutions	4.09	4.69	4.20	4.00	0.648	0.917
BAR15	Lack of sufficient alternatives for affordable and user-friendly digitalisation solutions	4.18	4.25	4.67	4.05	0.701	0.916
BAR16	Lack of bespoke solution specifically tailored to the needs and challenges of the Indian construction industry.	4.36	4.39	3.99	3.95	0.628	0.918
BAR17	In adequate data-driven analysis and case studies to overcome initial uncertainty and encourage organisations to adopt digital technologies	4.09	4.19	3.94	4.30	0.689	0.917
BAR18	Lack of detail documentation on ROI and cost-saving possibilities of digitalisation with respect to specific example from Indian Construction industry.	4.55	4.03	4.20	3.85	0.654	0.919
BAR19	Irregular industry-wide campaigns and awareness programs	4.18	3.17	4.08	4.25	0.752	0.917
BAR20*	Secrecy of information that hinder inspiration and informed decisions about embracing and investing in digital technologies*	2.73	3.08	2.34	3.10	0.303	0.929
BAR21	Limited training and educational programs on digitalisation concepts within Indian Construction Sector	4.36	4.31	4.21	4.10	0.717	0.917

Cronbach's Alpha – 0.922, Strongly disagree: $2.18 \leq$ Mean Index ≤ 2.69, Disagree $2.69 \leq$ Mean Index ≤ 3.20, Neutral: $3.20 \leq$ Mean Index ≤ 3.71, Agree: $3.71 \leq$ Mean Index ≤ 4.22, Strongly agree: $4.22 \leq$ Mean Index ≤ 4.73.
*Excluded from further analysis.

deleted such as suggested by Field (2013) and implemented in a previous study by Ajayi et al. (2022). All variables in this study have anti-imaging values over 0.5, indicating that the data are suitable for further investigation and a scree plot of all factors has been presented in Figure 3.

After that, the Principal Component Analysis (PCA) was used to do a factor extraction to uncover common data patterns and create suitable themes using Rotated Component Matrix (PCA's Equamax with Kaiser Normalisation) to represent the factors that belong to the same group. Factor extraction could be carried

out based on Eigenvalues greater than 1 or based on a fixed number of factors (Frost 2022). As per the rule stated by Field (2013), an extraction based on Eigenvalue greater than 1 was first carried out and three factor groups emerged as shown in Figure 4a. However, the rotated component matrix in Figure 4a shows the extraction of too many factors which are difficult to theme together in group 1. This observation is in line with the earlier concerns of Costello and Osborne (2005) and Frost (2022) which submitted that extraction with Eigenvalues greater than 1 often tends to extract too many/little factors in most cases. Thus, recommending extraction with a fixed number of factors using insights from the theory and subject-area knowledge to adjust the number of factors. In this study, the well-known STEEP framework (Social, Technological, Economic, Environmental, and Political factors) and the Information and Communication Technology (ICT) Adoption and Implementation framework were adopted. Both frameworks have five distinct themes and as such extraction based on 5 fixed number of factors was carried out as shown in Figure 4b. This produces a much better grouping with identified patterns that can facilitate the naming of each theme as done in the subsequent section (Discussion of Result). In addition, the retrieved total variance from the 5 fixed number of factors extraction is 70% compared to the 59% from the extraction based on Eigenvalues greater than 1. The 70% is significantly higher than the recommended cut-off point of 60% (Field 2013). As a result, extraction based on 5 fixed number of factors offered here is accurate and the analysis's findings can be trusted. Table 3 displays the summary of the factor analysis (extraction and rotation), along with the eigenvalue and percentage of variance for each group.

Discussion of result

The findings of the study were addressed based on the main goal of this research, which is to identify the barriers to digitalisation in the Indian construction industry. Although the questionnaire examined 21 factors, the results of the exploratory factor analysis following extraction and rotation supported 18 of them and categorised them into five different themes as shown in Figure 5. The theme naming in this study was based on insights from both the well-known STEEP framework (Social, Technological, Economic, Environmental, and Political factors) and the Information and Communication Technology (ICT) Adoption and Implementation framework. The STEEP framework emanated from the ETPS taxonomy (Economic, Technical, Political, and Social) credited to Aguilar (1967) while the ICT adoption and implementation framework includes categories of factors that are extracted from TAM (Davis 1989) and UTAUT (Venkatesh et al. 2003) discussed earlier. Although the STEEP framework offers a broad categorisation of external factors influencing technology adoption and implementation, it overlooks specific nuances and complexities. As such, this study integrates insights from the ICT Adoption and Implementation framework with the STEEP to provide more tailored novel themes for the understanding of challenges. The integration of these frameworks enables this study to establish a balanced picture of the current state of digitalisation within the Indian construction sector with novel themes which is the main purpose of this study. The novel theme names presented in Figure 5 highlighted unique dimensions of constraints in the digitalisation of the construction industry in India. This novel theme-naming approach allowed for a granular analysis driven by the need for a comprehensive understanding of barriers to digitalisation of the Indian construction industry beyond the broad categorisation provided by the STEEP and ICT adoption framework. The themes were then used to discuss the main findings of the study as follows.

Financial and resources constraints

Financial and resource constraints comprising three items; BAR1, BAR2 and BAR12 are unanimously agreed by the participants from all four sectors with all having a scale index of more than 3.95 to show the level of agreement as agreed or strongly agreed. This consensus accentuates the pivotal role finance and resources play in shaping the digitalisation landscape within the construction industry. The factor analysis reported an eigenvalue of 2.890 and a percentage variance of 16.056 further underlining the significant impact of these constraints on the broader process

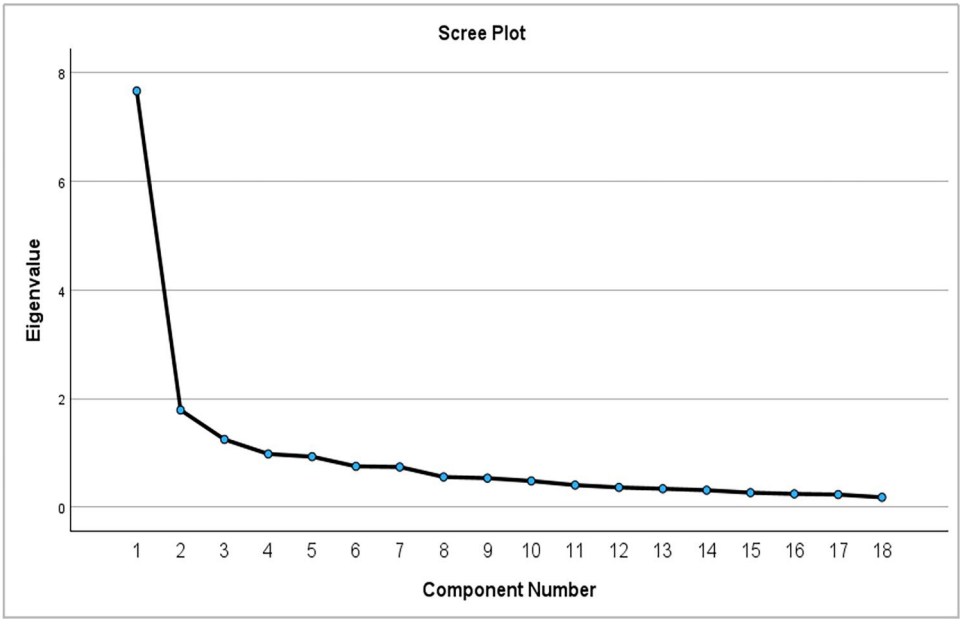

Figure 3. Scree plot showing components' eigenvalue (source: Author).

(a)

Total Variance Explained

Component	Initial Eigenvalues Total	% of Variance	Cumulative %	Extraction Sums of Squared Loadings Total	% of Variance	Cumulative %	Rotation Sums of Squared Loadings Total	% of Variance	Cumulative %
1	7.666	42.586	42.586	7.666	42.586	42.586	4.660	25.890	25.890
2	1.788	9.934	52.520	1.788	9.934	52.520	3.584	19.909	45.799
3	1.246	6.925	59.444	1.246	6.925	59.444	2.456	13.645	59.444
4	.978	5.436	64.880						
5	.929	5.160	70.040						
6	.751	4.170	74.210						
7	.739	4.105	78.315						
8	.555	3.081	81.396						
9	.533	2.961	84.357						
10	.481	2.673	87.030						
11	.405	2.251	89.281						
12	.362	2.010	91.291						
13	.338	1.877	93.168						
14	.311	1.728	94.896						
15	.265	1.474	96.370						
16	.243	1.349	97.719						
17	.231	1.281	98.999						
18	.180	1.001	100.000						

Extraction Method: Principal Component Analysis.

Rotated Component Matrix[a]

	Component 1	2	3
VAR00001			.511
VAR00002			.634
VAR00003	.806		
VAR00004	.572		
VAR00005	.613		
VAR00007	.719		.573
VAR00009	.714		
VAR00010	.693		
VAR00011	.689		
VAR00012	.584		
VAR00013	.701		
VAR00014		.643	
VAR00015			
VAR00016		.720	
VAR00017		.712	
VAR00018		.696	
VAR00019		.787	
VAR00021			.744

Extraction Method: Principal Component Analysis.
Rotation Method: Equamax with Kaiser Normalization.
a. Rotation converged in 5 iterations.

(b)

Total Variance Explained

Component	Initial Eigenvalues Total	% of Variance	Cumulative %	Extraction Sums of Squared Loadings Total	% of Variance	Cumulative %	Rotation Sums of Squared Loadings Total	% of Variance	Cumulative %
1	7.666	42.586	42.586	7.666	42.586	42.586	2.890	16.056	16.056
2	1.788	9.934	52.520	1.788	9.934	52.520	2.717	15.095	31.151
3	1.246	6.925	59.444	1.246	6.925	59.444	2.647	14.705	45.856
4	.978	5.436	64.880	.978	5.436	64.880	2.240	12.447	58.304
5	.929	5.160	70.040	.929	5.160	70.040	2.112	11.736	70.040
6	.751	4.170	74.210						
7	.739	4.105	78.315						
8	.555	3.081	81.396						
9	.533	2.961	84.357						
10	.481	2.673	87.030						
11	.405	2.251	89.281						
12	.362	2.010	91.291						
13	.338	1.877	93.168						
14	.311	1.728	94.896						
15	.265	1.474	96.370						
16	.243	1.349	97.719						
17	.231	1.281	98.999						
18	.180	1.001	100.000						

Extraction Method: Principal Component Analysis.

Rotated Component Matrix[a]

	Component 1	2	3	4	5
VAR00001	.511				
VAR00002	.634				
VAR00003					.806
VAR00004					.572
VAR00005		.613			
VAR00007		.719			
VAR00009			.714		
VAR00010			.693		
VAR00011				.689	
VAR00012	.584				
VAR00013			.701		
VAR00014		.643			
VAR00015					.728
VAR00016			.720		
VAR00017				.712	
VAR00018				.696	
VAR00019				.787	
VAR00021					.677

Extraction Method: Principal Component Analysis.
Rotation Method: Equamax with Kaiser Normalization.
a. Rotation converged in 8 iterations.

Figure 4. Output showing extraction based on (a) eigenvalue greater than 1 (b) fixed number of factors.
(Source: Authors)

of digitalising construction practices. The inference from this study supports the earlier findings of Gundes et al. (2019) that highlighted that construction companies, especially smaller ones, often face challenges in allocating significant funds upfront for adopting digital tools. This financial burden impedes the integration of technologies that could enhance efficiency, communication, and overall project management. While the overall level of agreement to the three items under financial and resource constraints is agreed, the respondents for the project management sector strongly agreed all through. This is consistent with Bajpai and Misra (2020) assertion that project management SMEs typically operating on tighter budgets may find investing in the latest digital technologies difficult. This limitation affects their competitiveness and hinders the industry's overall progress toward a more digitally integrated future (Bajpai and Misra 2020). Aiyetan and Das (2023) submitted that ongoing financial commitments are necessary to keep digital tools up to date, maintain their functionality, and provide necessary support. Meanwhile, the respondents in this study have agreed that the demand for continuous resources may strain the finances of construction companies, leading to potential hesitancy or cutbacks in digital adoption.

The high financial and resource requirements identified as a barrier in this study are in line with several earlier studies including (Aghimien and Aigbavboa 2021; Aiyetan and Das 2023; Solanki et al. 2023; Alalade et al. 2024) that have argued that stakeholders including architects, designers, and subcontractors may be deterred from engaging in the maintenance stage of digitalisation implementation due to the associated costs. As such, this study confirmed that financial and resource constraints encompassing both the initial investment and ongoing resource requirements pose substantial challenges to the construction sector's efforts to embrace digital technologies and integrate them into operational processes.

Cultural and organisational constraints

This factor has an eigenvalue of 2.717 and a percentage variance of 15.095% indicating that cultural and organisational influence cast significant shadows on the path toward digital transformation in the Indian construction industry. While the theme comprises three items; BAR5, BAR7 and BAR14, the analysis revealed BAR5: the influence of entrenched cultural norms, hierarchical structures, and resistance to change and BAR14: fragmentation between industry stakeholders are formidable cultural barriers. This is because the responses from all four sectors indicated an agreed level with the project management sector again showing strong agreement. However, the response to BAR7: prevalence of an older and less tech-savvy workforce is somehow inconsistent across all sectors with the project management sector disagreeing, both the Architecture and Engineering sectors are somehow neutral and only the construction sector narrowly

Table 3. Results of exploratory factor analysis.

	Extracted and rotated components	Factor loading	Eigen value	% of variance
Theme 1 - Financial and Resources Constraints			**2.890**	**16.056**
BAR1	High initial investment required for implementing digitalisation tools and technologies	0.511		
BAR2	Limited financial resources of most small and medium-sized enterprises (SMEs) within the construction sector	0.634		
BAR12	Resources intensive need for continuous upgrades, maintenance, and support for long-term sustainability	0.584		
Theme 2 - Cultural and Organisational Constraints			**2.717**	**15.095**
BAR5	Cultural norms, hierarchical structures, and resistance to change within organizations	0.613		
BAR7	Prevalence of older and less tech-savvy workforce within construction sector who may struggle with the learning curve.	0.719		
BAR14	Fragmentation between industry stakeholders, including government bodies, construction companies, technology providers, and research institutions	0.643		
Theme 3- Regional Disparities and Inequality Constraints			**2.647**	**14.705**
BAR9	Regional Disparities in the availability and quality of digital infrastructure across different regions in Indian.	0.714		
BAR10	Disparities in the overall success of digitalisation initiatives causing discouragement to further implementation	0.693		
BAR13	Daunting challenges of scalability of digital technologies within construction projects that are often unique.	0.701		
BAR16	Lack of bespoke solution specifically tailored to the needs and challenges of the Indian construction industry.	0.720		
Theme 4 - Data Security and Privacy Constraints			**2.240**	**12.447**
BAR11	Data security and privacy, as construction projects, involve sensitive information.	0.689		
BAR17	In adequate data-driven analysis and case studies to overcome initial uncertainty and encourage organisations to adopt digital technologies	0.712		
BAR18	Lack of detail documentation on ROI and cost-saving possibilities of digitalisation with respect to specific example from Indian Construction industry.	0.696		
BAR19	Irregular industry-wide campaigns and awareness programs	0.787		
Theme 5 - Awareness and Capacity Building Constraints			**2.112**	**11.736**
BAR3	Insufficient awareness among construction industry stakeholders regarding digitalization concepts and available technologies.	0.806		
BAR4	Gaps in understanding the practical aspects of how to integrate digital technologies into construction workflows.	0.572		
BAR15	Limited training and educational programs on digitalisation concepts within Indian Construction Sector	0.728		
BAR21	Lack of sufficient alternatives for affordable and user-friendly digitalisation solutions	0.677		

agreeing to that. Although the factor analysis did not unearth this barrier and included it in the analysis, the analysis of individual responses discovered that this is not a major barrier to the digitalisation of the Indian construction industry. This finding is in line with the articles of Dutta (2022) that submitted that 66% of the registered workers in the Indian construction sector are in the age group of 16 – 40 years.

Therefore, the main findings of this study are that entrenched cultural norms and the leadership styles that evolve from cultural elements often lead to fragmentation between industry stakeholders. This causes challenges of collaboration and coordination which are the main cultural and organisation constraints impacting the digitalisation of the construction sector. This is in accordance with Babaeian and Sutrisna (2022) submission that there is a need for a cohesive approach to align cultural and organisational priorities across stakeholders in order to overcome fragmentation to promote the digitalisation of the construction industry.

The construction industry, known for its resistance to innovations and new technologies exhibits rigidity and a lack of adaptability among its employees as noted by Bajpai and Misra (2021) and Dauda et al. (2023). Employee concerns, particularly regarding job security in the face of automation emerge as a substantial barrier to the full digitalisation of the construction sector. Acceptance becomes a crucial success factor and employee resistance stemming from these concerns poses a significant obstacle. A report by Bajpai and Misra (2021) highlights that digitalisation encounters challenges due to resistance to change rooted in various factors such as the one discussed under the cultural and organisation constraints.

Regional disparities and inequality constraints

This constraint has been identified as a significant barrier to digitalisation in the Indian construction sector, with an eigenvalue of 2.647 and a variance of 14.705. Within this theme is BAR9 which highlights disparities in digital infrastructure quality and availability across Indian regions. All the responses from architecture, construction and project management strongly agreed to BAR9 with a minimum index of more than 4.22 while the participants from the Engineering sector just agreed. The inference from this study is in agreement with the presence of digital divide in the construction sector where some areas have advanced access while others lag. This unequal distribution

Figure 5. Themes of barriers emerged from the study.

aggravates inequality, hindering regions with inadequate infrastructure from effectively implementing digital solutions as submitted by the earlier study of Abbas et al. (2022). In addition, the theme acknowledges BAR10, BAR13 and BAR16 as supported by the level of agreement across all the sectors participating in this study. Omrany et al. (2023) and Chen et al. (2022) had earlier acknowledged that discrepancies in the success of digitalisation initiatives, and scalability challenges can discourage further implementation, creating a domino effect and impeding technological advancement across the construction sector. There is a strong level of agreement among respondents that the inability to scale digital solutions efficiently across varied projects impedes the sector's widespread digitalisation benefits and this is evident in the earlier study of Bajpai and Misra (2020). BAR16 emphasises the lack of bespoke solutions tailored to the Indian construction industry's specific needs widening the gap between generic digital solutions and nuanced Indian requirements. This thereby perpetuates regional disparities that have been identified in this study as a major drawback to the digitalisation of the construction sector in India.

These regional disparities are further worsened by challenges in digital infrastructure as highlighted by Oesterreich and Teuteberg (2016). Several studies including Akinradewo et al. (2022) and Bajpai and Misra (2021) have submitted that the construction industry's reliance on information and communication technologies necessitates a quick and dependable Internet connection. However, unstable broadband connectivity or lack of availability of high-bandwidth connectivity for collaborative apps poses a significant hurdle. This challenge is particularly pronounced in fairly isolated rural locations, where mobile phone use and internet access are limited or non-existent (Akinradewo et al. 2022).

Data security and privacy constraints

Four items; BAR11, BAR17, BAR18 and BAR19 have been affirmed to be barriers impacting the digitalisation of Indian construction sectors in this study. The barriers are grouped under the data security and privacy constraint's theme with an eigenvalue of 2.240 and a percentage variance of 12.447% indicating a significant contribution of the factors in hindering the digitalisation of the Indian construction sector. The respondents from the architecture, design and project management sector rated BAR11: data security concern of the sensitivity of the information involved in construction projects as strongly agreed. Of all the items listed in the questionnaire, this particular barrier has the highest scale index of 4.73 which shows the concern of construction partners on the effect of the vulnerability of their project data is a critical concern for the adoption of digital technology in the construction sector. This is in line with the earlier study of Kumari (2021) that highlighted that the fear of unauthorised access, data breaches, and potential misuse of sensitive information acts as a major deterrent to the widespread adoption of digital tools and technologies in the construction industry. In addition to this, BAR17 and BAR18 which highlight the lack of adequate data-driven analysis and case studies documentation on the return on investment (ROI) as unanimously agreed by respondents across all sectors as major barriers to the digitalisation of the Indian construction sector. This finding further supported the earlier claim of Chen et.al (2022) and Rajhans and Bhavsar (2023) that organisations are reluctant to invest in digital technologies without a clear understanding of the financial gains, especially when potential risks, including those related to data security, are not thoroughly addressed. BAR19 underscores the impact of irregular industry-wide campaigns and awareness programs on the adoption of digital technologies, and this was agreed to by all sectors except for the project management sector which disagrees with this factor. This indicates a lack of consistent efforts in the diffusion and adoption of digital technologies across every sector of the construction industry as highlighted by Abbas et al. (2022). This inconsistency is attributed to the intricate nature of the construction value chain, highlighting the need for tailored strategies to overcome these challenges and promote a smoother transition towards digitalisation as earlier submitted by Singh et al. (2023).

Awareness and capacity building constraints

This study identified four barriers related to awareness and capacity-building constraints with 2.112 Eigenvalue from the study analysis. In the context of the digitalisation of the Indian construction sector, these barriers; BAR3, BAR4, BAR15 and BAR21hinder the seamless integration of digital technologies. Insufficient awareness among construction industry stakeholders regarding digitalisation concepts and available technologies (BAR3) poses a significant challenge, as key decision-makers may not fully grasp the potential benefits or understand how these technologies can enhance the sustainability of the construction sector (Maiti et al. 2020). Moreover, gaps in understanding the practical aspects of integrating digital technologies into construction workflows (BAR4) exacerbate the issue, as there is a disconnect between conceptual knowledge and practical implementation (Alva 2022). The limited training and educational programs on digitalisation concepts within the Indian Construction Sector (BAR21) further impede progress, inhibiting the development of necessary skills and expertise. Addressing these awareness and capacity-building constraints is crucial for unlocking the full potential of digitalisation in the Indian construction sector, fostering a more sustainable and efficient approach to construction (Rajhans and Bhavsar 2023).

A lack of understanding of the benefits of digital technology can contribute to aversion of using them as identified by (Abbas et al. 2022; Alva 2022; Parwal 2023) and supported by the findings

from this study. This lack of awareness affects participants from all four sectors comparatively with all having a scale index of more than 4.0. The finding of this study corroborated Maiti et al. (2020) submission that highlighted the lack of training for government employees in charge of e-governance as another barrier standing in the way of successful digitalisation. While some areas in India have seen remarkable success in e-governance projects, the absence of expertise and properly trained staff members, along with a scarcity of training, impacts the successful application of digital technology. Meanwhile, Many SMEs recognise the benefits of improving the skills of employees towards digitalisation but fear that skilled employees become more appealing to competitors, making retention a significant concern for SME construction businesses (Dauda et al. 2023). Hence, it is difficult for them to invest in capacity building which causes the extent of the awareness and capacity building Constraints that impact the digitalisation of the Indian construction industry.

Implications of findings

The adoption of a novel framework culled out from STEEP and ICT adoption framework to name the emerged themes enables the findings from this research to reveal detailed insights that extend beyond basic interpretations, offering substantial implications for researchers, stakeholders, including the government, and the broader population within the Indian construction industry. The varying pace and extent of digitalisation adoption across different segments within the Indian construction sector indicate a need for strategic decision-making, particularly for project management and construction SMEs that are facing resource and knowledge gaps. Policymakers can leverage these insights to refine government programs like "Digital India" and "Smart Cities," ensuring they address the challenges faced by different segments within the construction industry. This study underscores the key barriers to digitalisation of the Indian construction sector, necessitating an ecosystem fostering innovation, affordable digital solutions, and skill development. Educational and training initiatives, guided by researchers and industry stakeholders, become crucial in addressing identified skill gaps and knowledge limitations, supporting effective technology integration. The acknowledgement of the transformative potential of digital technologies in promoting sustainability within the construction industry by the study's participants points to an opportunity for researchers and industry leaders to drive innovation and digital technologies in construction in eco-friendly practices. Public awareness and perception play a role in the societal impact of technology integration into construction practices, requiring collaborative efforts to communicate the advantages of digitalisation. This study emphasises the importance of creating a supportive ecosystem beyond financial support, involving collaboration between construction enterprises, technology providers, research institutes, and educational authorities to accelerate the integration of digital technologies. In essence, these implications offer a roadmap for collaborative action, guiding stakeholders, researchers, and policymakers toward strategic steps that will propel the Indian construction industry into a future characterised by efficiency, sustainability, and global competitiveness.

Conclusion

Despite numerous benefits of digitalisation on construction including productivity, improved collaboration, better decision-making, increased safety, and enhanced competitiveness, its adoption has been slowed by some barriers. Using a multi-phase research approach, this study has identified and analysed the critical barriers that hinder the widespread adoption of digitalisation within the Indian construction sector. The study's holistic approach involved conducting a literature review to uncover some potential barriers to digitalisation in the construction sector. The potential barriers identified were then used to construct a questionnaire administered to 162 professionals working within the construction industry in India.

The survey conducted established that the Indian construction sector is willing to move towards the global trend of technology integration into construction procedures. Many of the participants upheld that digital transformation holds promise for improving productivity and revolutionising every aspect of the construction sector, from personalized customer demands to sustainable building designs. The study indicates a steady rise in the adoption and implementation of digitalisation in the Indian construction industry, albeit with variations across different segments and companies. Engineering and design sectors demonstrate greater proactivity, leveraging financial capabilities and ample resources to embrace digital technologies. In contrast, project management and construction businesses that are characterised by smaller and medium-sized businesses face challenges in resources and knowledge, leading to slower adoption rates. The responses from the study specifically reveal the increasing integration of technologies such as building information modelling (BIM), virtual reality, drones, IoT sensors, and cloud-based project management tools in construction projects.

Meanwhile, the results of the Exploratory Factor Analysis produced five themes of barriers comprising a total of 18 specific barriers that are considered impediments to the digitalisation of the Indian construction sector. These are financial and resource constraints; cultural and organisational constraints; regional disparities and inequality constraints; data security and privacy constraints and awareness and capacity-building constraints. This study has been able to explore the perception of construction professionals within the Indian construction sector on what are the main barriers impeding digitalisation of the Indian construction sector. This is very important because it will allow tailored and India-focussed interventions on how digitalisation can be promoted within the Indian Construction Industry. However, it is important to point out that the main limitation of this study is the relatively small sample size and lack of focus on the size of the company which would have unveiled how different the barriers are due to company sizes. Despite this limitation, this study still contributes to significant issues of exposing the key barriers to digitalisation of the Indian construction sector in general. This study provides the barriers that could be used to get further information and suggestions to assist industry stakeholders, policymakers, and researchers in their efforts to navigate the rapidly changing landscape of digitalisation and redefine the future of construction in India as the Indian construction sector sets out on its digital transformation journey.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Abbas MA, Ajayi SO, Oyegoke AS, Alaka H. 2022. A cloud-based collaborative ecosystem for the automation of BIM execution plan (BEP). JEDT. doi: 10.1108/JEDT-02-2022-0128.

Aghimien DO, Matabane K, Aigbavbo C, Oke AE. 2019. Industry 4.0 diffusion in the South African construction industry – Construction professionals' perspective. 13th Built Environment Conference; Durban, South Africa.
Aghimien DO, Aigbavboa C. 2021. Construction digitalisation: a capability maturity model for construction organisations. New York: Routledge.
Aguilar FJ. 1967. Scanning the business environment. New York: MacMillan Co.
Aiyetan AO, Das DK. 2023. Use of drones for construction in developing countries: barriers and strategic interventions. Int J Construct Manage. 23(16):2888–2897. doi: 10.1080/15623599.2022.2108026.
Ajayi SO, Lister N, Dauda JA, Oyegoke A, Alaka H. 2022. Influencing subcontracted operatives' attitudes and behaviours towards improved health and safety culture in construction. ECAM. doi: 10.1108/ECAM-03-2022-0265.
Akinradewo O, Aigbavboa C, Edwards D, Oke A. 2022. A principal component analysis of barriers to the implementation of blockchain technology in the South African built environment. JEDT. 20(4):914–934. doi: 10.1108/JEDT-05-2021-0292.
Alalade O, Dauda JA, Saka AB, So A, Oyegoke A. 2024. An in-depth analysis of facility management approaches in Nigeria's ailing healthcare sector. J Facil Manage. Inpress.
Alva L. 2022. Construction Industry: technology based innovation is sparking a revolution. Online. [accessed 2023 November 27]. https://etinsights.et-edge.com/construction-industry-technology-based-innovation-is-sparking-a-revolution/.
Babaeian JM, Sutrisna M. 2022. Guest editorial: working smarter by applying advanced technologies in construction: enhancing capacity and capability in construction sector for infrastructure project delivery. JEDT. 20(4):861–865. doi: 10.1108/JEDT-08-2022-744.
Bajpai A, Misra SC. 2020. Assessment of success determinants for implementing digitalization in Indian construction industry. In 2020 IEEE International Conference on Engineering, Technology, and Innovation (ICE/ITMC); Cardiff, IEEE.
Bajpai A, Misra SC. 2021. Analyzing key barriers for adoption of digitalization in Indian construction industry: a case study. Singapore: Springer; p. 683–693.
Brand Studio HT. 2020. How digital transformation in India's construction sector can be a game changer. Online. [accessed 2023 November 17]. https://www.livemint.com/brand-stories/how-digital-transformation-in-india-s-construction-sector-can-be-a-game-changer-11596170012701.html.
Chen X, Chang-Richards A, Pelosi A, Jia Y, Xuesong S, Mohsin K, Siddiqui N. 2022. Implementation of technologies in the construction industry: a systematic review. ECAM. 29(8):3181–3209. doi: 10.1108/ECAM-02-2021-0172.
Cho E, Kim S. 2015. Cronbach's coefficient alpha: well-Known but poorly understood. Organizational Res Methods. 18(2):207–230. doi: 10.1177/1094428114555994.
Costello A, Osborne J. 2005. Best practices in exploratory factor analysis: four recommendations for getting the most from your analysis. Practical Assess Res Eval. 10:7.
Dauda JA, Ajayi SO, Omotayo TS, Oladiran OO, Ilori OM. 2023. Implementation of lean for small- and medium-sized construction organisational improvement. SASBE. 13(3):496–511. volume doi: 10.1108/SASBE-10-2022-0233.
Dauda JA, Ajayi SO. 2022. Understanding the impediments to sustainable structural retrofit of existing buildings in the UK. J Build Engin. 60:105168. doi: 10.1016/j.jobe.2022.105168.
Davis FD. 1989. Perceived usefulness, perceived ease of use, and user acceptance. MIS Quarterly. 13(3):319–340. doi: 10.2307/249008.
Dutta T. 2022. India's invisible female construction workers: underpaid and overworked. Online. [accessed 2024 March 11]. https://www.thenationalnews.com/world/2022/03/07/hold-indias-invisible-female-construction-workers-underpaid-and-overworked/.
Field A. 2013. Discovering statistics using IBM SPSS statistics. 5th ed. London, UK: Sage edge.
Frost J. 2022. Factor analysis guide with an example. Online. [accessed 2024 April 19]. https://statisticsbyjim.com/basics/factor-analysis/.
Gamil Y, Abdullah MA, Rahman IA, Asad MM. 2020. Internet of things in construction industry revolution 4.0: recent trends and challenges in the Malaysian context. JEDT. 18(5):1091–1102. doi: 10.1108/JEDT-06-2019-0164.
Gundes S, Atakul N, Buyukyoran F. 2019. Financial issues in construction companies: bibliometric analysis and trends. Can J Civ Eng. 46(4):329–337. doi: 10.1139/cjce-2018-0249.
Jacobsson M, Linderoth H. 2021. Newly graduated students' role as ambassadors for digitalisation in construction firms. Construct Manage Econ. 39(9):759–772. doi: 10.1080/01446193.2021.1955398.
Kumari I. 2021. Digital transformation in construction industry. Delhi: Delhi Technological University.
Mahasua K. 2023. COVID-19 and its impact on Indian construction industry: an event study approach. Construct Manage Econ. 41(5):428–444. doi: 10.1080/01446193.2022.2164789.
Maiti D, Castellacci F, Melchior A. 2020. Digitalisation and development: issues for India and beyond. 1st ed. Singapore: Springer.
Maskuriy, Selamat, Maresova, Krejcar, Olalekan. 2019. Industry 4.0 for the construction industry: review of management perspective. Economies 7(3):68. doi: 10.3390/economies7030068.
Memon M, Ting H, Cheah J, Ramayah T, Chuah F, Cham T. 2020. Sample size for survey research: review and recommendations. JASEM. 4(2):i–xx. doi: 10.47263/JASEM.4(2)01.
Musarat MA, Sadiq A, Alaloul WS, Wahab MA. 2022. A systematic review on enhancement in quality of life through digitalization in the construction industry. Sustainability. 15(1):202. doi: 10.3390/su15010202.
Obiso JA, Himang CM, Ocampo LA, Bongo MF, Shirley AA, Caballes DA, Custer CD, Roberto P, Rosein AJ. 2020. Management of Industry 4.0–reviewing intrinsic and extrinsic adoption drivers and barriers. Int J Construct Manage. 81(3–4):210–257.
Oesterreich TD, 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. Comput Ind. 83:121–139. doi: 10.1016/j.compind.2016.09.006.
Omrany H, Al-Obaidi K, Husain A, Ghaffarianhoseini A. 2023. Digital twins in the construction industry: a comprehensive review of current implementations, enabling technologies, and future directions. Sustainability. 15(14):10908. doi: 10.3390/su151410908.
Parwal U. 2023. India construction industry: current status & trend analysis. [accessed 2024 March 6]. https://equipmenttimes.in/india-construction-industry-current-status-trend-analysis/.
Paul M, Upadhyay P, Dwivedi Y. 2020. Roadmap to digitalisation of an emerging economy: a viewpoint. Transforming government. People, Process and Policy. 14(3):401–415.
Perera S, Jin X, Samaratunga M, Gunasekara AK. 2023. Drivers and barriers to digitalisation: a cross-analysis of the views of designers and builders in the construction industry. ITcon. 28:87–106. doi: 10.36680/j.itcon.2023.005.
Rajhans K, Bhavsar V. 2023. Impending need of sustainable human resource management practices in construction industry: evidence from India. Int J Construct Manage. 23(13):2249–2259. doi: 10.1080/15623599.2022.2050569.
Rani HA, Farouk AM, Anandh KS, Almutairi S, Rahman RA. 2022. Impact of COVID-19 on construction projects: the case of India. Buildings. 12(6):762. doi: 10.3390/buildings12060762.
Ronaghi M, Ronaghi MH. 2021. Investigating the impact of economic, political, and social factors on augmented reality technology acceptance in agriculture (livestock farming) sector in a developing country. Technol Soc. 67:101739. doi: 10.1016/j.techsoc.2021.101739.
Ronaghi MH. 2023. The influence of artificial intelligence adoption on circular economy practices in manufacturing industries. Environ Dev Sustain. 25(12):14355–14380. doi: 10.1007/s10668-022-02670-3.
Saunders M, Lewis P, Thornhill A. 2019. Chapter 4: understanding research philosophy and approaches to theory development. In Research methods for business students. 8th ed. London, UK: Pearson.
Singh A, Kumar V, Verma P, Kandasamy J. 2023. Identification and severity assessment of challenges in the adoption of Industry 4.0 in Indian construction industry. Asia Pacific Manage Rev. 28(3):299–315. doi: 10.1016/j.apmrv.2022.10.007.
Smallwood J, Allen C. 2022. Practitioners' perceptions of the potential impact of Industry 4.0 on construction health and safety. JEDT. 21(2):486–501. doi: 10.1108/JEDT-11-2021-0635.
Solanki A, Sarkar D, Kapdi P. 2023. Evaluation of key performance indicators of internet of things and cloud computing for infrastructure projects in Gujarat, India through consistent fuzzy preference relations approach. Int J Construct Manage. 24(7):707–721. doi: 10.1080/15623599.2022.2114060.
Taber KS. 2018. The use of Cronbach's Alpha when developing and reporting research instruments in science education. Res Sci Educ. 48(6):1273–1296. doi: 10.1007/s11165-016-9602-2.
Taher G. 2021. Industrial revolution 4.0 in the construction industry: challenges and opportunities. MSES. 6(4–3):109–127. doi: 10.12816/0060000.
Toyin JO, Mewomo MC. 2023. An investigation of barriers to the application of building information modelling in Nigeria. JEDT. 21(2):442–468. doi: 10.1108/JEDT-10-2021-0594.
Tsang EWK. 2016. The philosophy of management research. 1st ed. London: Routledge.
Tuan HL, Chin CC, Shieh SH. 2005. The development of a questionnaire to measure students' motivation towards science learning. Int J Sci Educ. 27(6):639–654. doi: 10.1080/0950069042000323737.

Vaughan J. 2013. Technological Innovation: perceptions and definitions. In Chapter 2, Defining technological innovation. Reprint. Chicago, IL: American Library Association; p. 10.

Venkatesh V, Morris MG, Davis GB, and Davis FD. 2003. User acceptance of information technology: toward a unified view. MIS Quarterly. 27(3): 425–478. doi: 10.2307/30036540.

Won J, Lee G, Dossick C, Messner J. 2013. Where to focus for successful adoption of building information modeling within organization. J Constr Eng Manage. 139(11):04013014. doi: 10.1061/(ASCE)CO.1943-7862.0000731.

Yap J, Toh H. 2020. Investigating the principal factors impacting knowledge management implementation in construction organisations. JEDT. 18(1): 55–69. doi: 10.1108/JEDT-03-2019-0069.