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BRIDGING AUTOMATION AND ROBOTICS IN INDUSTRIALIZED BUILDING SYSTEM (IBS): CHALLENGES, IMPACTS, AND STRATEGIES OF ADOPTIONS

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Graphical abstract



Abstract

The Industrialised Building System (IBS) was introduced in Malaysia in the early 1960s to address the growing demand for affordable housing, reduce reliance on foreign labour, and enhance the overall quality and productivity of the construction sector. Recently, the construction industry has begun integrating automation and robotics, aligning with the global shift towards the Fourth Industrial Revolution (IR 4.0). The Construction 4.0 Strategic Plan (2021–2025) further emphasises digitalisation, robotics, and automation to improve industry efficiency and sustainability. However, the construction industry has been slow to adopt these advancements, limiting the full benefits of automation in IBS. Persistent challenges, including resistance to change, high initial investment costs, a shortage of skilled personnel, and technical complexities, hinder widespread adoption. This research examines the integration of automation and robotics in IBS to enhance construction productivity. A questionnaire survey was used for the data collection exercise. The data collected were analysed using descriptive statistical methods utilising the Statistical Package for the Social Sciences (SPSS) software. The study is guided by three (3) objectives: (1) To identify barriers to the integration of automation and robotics in IBS, (2) To analyse the impact of automation and robotics on construction productivity compared to conventional IBS, and (3) To propose strategies to improve the adoption of these technologies. Findings reveal that the integration of automation and robotics in (IBS) faces significant barriers, primarily due to the high costs of investment. The main impact that automation offers is particularly in enhancing construction productivity by achieving higher levels of precision and quality compared to conventional IBS methods. The primary strategy to improve the adoption of these technologies is to reduce financial barriers through external support and strategic partnerships. The findings of this research were able to facilitate the transition towards a more efficient and sustainable construction industry, in alignment with Malaysia's Construction 4.0 Strategic Plan and Sustainable

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Development Goals (SDG) No. 9 to promote industrialisation and foster innovation.

Keywords: Industrialised Building System (IBS), SDG No. 9, Automation and Robotics, Fourth Industrial Revolution, Construction 4.0

Abstrak

Sistem Bangunan Berindustri (IBS) telah diperkenalkan di Malaysia pada awal 1960-an untuk menangani permintaan yang semakin meningkat untuk rumah mampu milik, mengurangkan pergantungan kepada buruh asing, dan meningkatkan kualiti dan produktiviti keseluruhan sektor pembinaan. Baru-baru ini, industri pembinaan telah mula menyepadukan automasi dan robotik, sejajar dengan peralihan global ke arah Revolusi Perindustrian Keempat (IR 4.0). Pelan Strategik Pembinaan 4.0 (2021–2025) lebih menekankan pendigitalan, robotik dan automasi untuk meningkatkan kecekapan dan kemampanan industri. Walau bagaimanapun, industri pembinaan telah lambat untuk menerima pakai kemajuan ini, mengehadkan faedah penuh automasi dalam IBS. Cabaran yang berterusan, termasuk penentangan terhadap perubahan, kos pelaburan permulaan yang tinggi, kekurangan kakitangan mahir dan kerumitan teknikal, menghalang penerimaan yang meluas. Penyelidikan ini mengkaji integrasi automasi dan robotik dalam IBS untuk meningkatkan produktiviti pembinaan. Tinjauan soal selidik telah digunakan untuk latihan pengumpulan data. Data yang dikumpul dianalisis menggunakan kaedah statistik deskriptif menggunakan perisian Statistical Package for the Social Sciences (SPSS). Kajian ini dipandu oleh tiga (3) objektif: (1) Untuk mengenal pasti halangan kepada penyepaduan automasi dan robotik dalam IBS, (2) Untuk menganalisis kesan automasi dan robotik terhadap produktiviti pembinaan berbanding dengan IBS tradisional, dan (3) Untuk mencadangkan strategi untuk menambah baik penggunaan teknologi ini. Penemuan mendedahkan bahawa penyepaduan automasi dan robotik dalam (IBS) menghadapi halangan yang ketara, terutamanya disebabkan oleh kos pelaburan yang tinggi. Impak utama yang ditawarkan oleh automasi adalah terutamanya dalam meningkatkan produktiviti pembinaan dengan mencapai tahap ketepatan dan kualiti yang lebih tinggi berbanding kaedah IBS tradisional. Strategi utama untuk menambah baik penggunaan teknologi ini adalah untuk mengurangkan halangan kewangan melalui sokongan luaran dan perkongsian strategik. Penemuan penyelidikan ini dapat memudahkan peralihan ke arah industri pembinaan yang lebih cekap dan mampan, sejajar dengan Pelan Strategik Pembinaan 4.0 Malaysia dan Matlamat Pembangunan Mampan (SDG) No. 9 untuk menggalakkan perindustrian dan memupuk inovasi.

***Kata kunci*:** Sistem Binaan Berindustri (IBS), SDG No. 9, Automasi dan Robotik, Revolusi Perindustrian Keempat, Pembinaan 4.0

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1.0 INTRODUCTION

The Industrialised Building System (IBS) was first introduced in Malaysia in the early 1960s when the Ministry of Housing and Local Government conducted study visits to several European nations to assess and adapt their housing development strategies for implementation in Malaysia. This initiative aimed to expedite construction timelines, deliver high-quality housing, and ensure affordability. As a result, the government launched the first IBS pilot project in 1964, marking a significant milestone in the country's housing development efforts. The introduction of IBS was primarily intended to address the increasing demand for affordable housing, reduce dependency on foreign labour, and enhance the overall quality, productivity, and reputation of Malaysia's construction sector, as supported by [1] Mohd Fateh & Nijar (2019) and [2] CIDB (2020).

In recent years, the rise of robotic machinery and automation has revolutionised global manufacturing processes, ushering in the era of the Fourth Industrial Revolution (IR 4.0). The construction industry has begun to integrate these advanced technologies, with IBS emerging as the most effective platform for implementing automation and robotics in Malaysia [3]. Following the Construction Industry Transformation

Programme (CITP) 2015–2020, the Construction 4.0 Strategic Plan 2021–2025 has further emphasised the adoption of digitalisation, robotics, and automation to transform the sector sustainably and efficiently [2]. Modern construction technologies, such as robotics and automated systems, hold immense potential to improve productivity, precision, and safety in construction processes. Robotic systems in manufacturing facilities enable materials to be produced according to exact specifications, reducing material waste while simultaneously increasing productivity and quality, as highlighted by [4] Anderson (2020). Such advancements underscore the critical role of IBS in leading the Malaysian construction industry toward a more efficient, sustainable, and technologically advanced future.

Nevertheless, the construction industry has historically been slow to adopt emerging technological advancements. This hesitance has hindered the full integration of automation technologies, such as robotic construction systems and automated assembly processes, within IBS. As a result, the potential benefits of these technologies remain underutilised as reported by [5] Balogun et al. (2024). [6] CIDB (2017) also pointed out that the industry's persistent inefficiencies and low productivity underscore the urgent need for modernising existing practices through innovative technologies. Several challenges must be addressed before automation and robotics technologies can be fully integrated into IBS. [7] Bon-Gang et al. (2022) and [5] Balogun et al. (2024) underscored that the challenges that include resistance to change within the industry are the high initial investment costs associated with adopting advanced technologies, a shortage of skilled personnel, and various technical complexities. Overcoming these barriers is critical to unlocking the full potential of automation in IBS and enhancing the overall efficiency and productivity of the construction sector.

Based on the issues presented, this research examines the integration of automation and robotics into IBS to enhance productivity. Three objectives were set for the research: (1) to identify barriers to integrating automation and robotics in IBS (2) to analyse the impact of automation and robotics in IBS on construction productivity compared to conventional IBS and (3) to propose strategies for improving the integration of automation and robotics in IBS. The findings of the research aim to facilitate the adoption of advanced technologies within the construction sector, ultimately contributing to more sustainable and efficient building practices. This research provides a comprehensive framework to support the effective incorporation of automation and robotics in IBS in line with the aspiration of the Construction 4.0 Strategic Plan by the [8] Construction Industry Development Board Malaysia (2020) and is in line with the Sustainable Development Goals (SDG) No. 9, to promote industrialisation and foster innovation.

2.0 LITERATURE REVIEW

IBS represents a modern construction approach designed to enhance efficiency, reduce on-site construction time, and minimise labour demands while ensuring consistent quality. This is achieved by manufacturing building components in a controlled factory environment, transporting them to the construction site, and subsequently assembling them into the final structure, as reported by [9] Yusof et al. (2023). Common IBS components include precast concrete elements, steel frameworks, and modular units. The factory-based production process allows for greater control over material quality and precision, resulting in structures that adhere to stringent standards and specifications. The adoption of IBS offers numerous advantages, including shorter construction timelines, reduced material waste, and lower labour costs, making it an increasingly preferred method in many countries. By shifting component production off-site, IBS minimises weather-related delays and other on-site disruptions. Additionally, it promotes sustainability through waste reduction and material optimisation. Given its potential to significantly improve efficiency and quality, IBS is a highly viable alternative to conventional construction methods.

2.1 Automation and Robotics in the IBS Process

The integration of automation and robotics within IBS encompasses the use of advanced machinery, robotic arms, and sophisticated software systems. This technological advancement represents a transformative approach in the construction industry, aimed at enhancing productivity, increasing accuracy, and improving overall efficiency. [10] Oesterreich & Teuteberg (2016) emphasised that both government bodies and industry stakeholders have increasingly recognised the transformative potential of these technologies in modernising construction practices. Consequently, investments and supportive policies need to be in place to promote wider adoption. The evolution of automation and robotics in IBS is poised to revolutionise productivity while ensuring precision and efficiency in construction processes. The utilisation of automation technologies such as Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), and robotic assembly optimises the manufacturing process for various structural elements in IBS. This approach leverages automated manufacturing within a controlled factory environment, implementing advanced technologies to revolutionise the construction industry. Table 1 shows the comparison between Automation & Robotics and conventional IBS.

Table 1 Comparison Between Automation & Robotics and Conventional IBS

Aspects	Automation & Robotics	Conventional
Efficiency and Speed	• Performs tasks faster than manual methods. • Continuous operation without breaks.	• Relies heavily on manual labour. • Prefabrication speeds up some processes, but assembly is time-consuming.
Precision and Quality	• Ensures high precision and better quality. • Fewer defects and errors	• Depends on the worker's skill level. • Higher defect rates and inconsistencies.
Safety and Risk Reduction	• Reduces risk by handling hazardous tasks. • Fewer workplace accidents.	• Higher risk of injuries. • Safety measures are crucial but not foolproof.
Cost Implications	• High initial investment. • Long-term savings from reduced labour and rework.	• Lower initial costs. • High ongoing labour costs and rework expenses.
Time Implications	• Shortens project timelines. • More accurate scheduling with fewer delays.	• Longer project durations. • Variability in labour performance and delays
Quality Implications	• High precision and consistency. • Reliable quality control with fewer reworks.	• Variable quality based on worker skills. • Challenging quality control and more rework.
Environmental Impact	• Efficient material usage and less waste. • Lower environmental footprint.	• Higher material waste due to human error. • Larger environmental footprint.
Labour Impact	• Potential job displacement. • Opportunities for skilled labour. • Improved safety conditions.	• Provides broader employment opportunities. • Physically demanding and higher risk for workers.

2.1 Barriers of Automation and Robotics in IBS

Adopting new technologies and processes poses significant challenges, particularly for Malaysia's construction industry, including the Industrialised Building System (IBS) sector, which requires substantial adjustments to achieve transformative advancements. For the industry to align with the guiding principle of 'driving construction excellence together', this transition must be collectively supported by all stakeholders. While the adoption of advanced technologies and modern practices is expected to impact the industry positively, Malaysia's construction sector has yet to reach the technological maturity observed in developed nations, especially in the integration of automation and robotics, as informed by [11] Abd Rashid et al. (2018).

2.1.1 *Lack of Automation Literacy Among Workers*

The implementation of automation and robotics in IBS requires a workforce proficient in operating, maintaining, and troubleshooting advanced equipment. However, a significant skills gap persists in the construction industry, where many workers lack the requisite knowledge of robotics and automation systems [12] and [13]. This was echoed by [14] Stentoft et al. (2021), who underlined that a lack of technological understanding among workers is a primary barrier to adopting these technologies, as employees often struggle to familiarise themselves with automation strategies. [15] corroborates this, emphasising the challenges workers face in accepting and understanding automation and robotics integration within the construction process. The reluctance to embrace change is particularly pronounced among older industry practitioners, who represent a substantial proportion of the workforce. These individuals, having long relied on traditional construction methods, often resist new technologies due to their entrenched practices and the perceived disruption to established workflows. Furthermore, the learning curve associated with mastering new technologies demands significant time and effort, which older workers may find particularly burdensome compared to their younger counterparts.

[16] Ma et al. (2022) stated that for companies seeking to implement automation and robotics, employee training programmes are indispensable. Such programmes are not only costly and time-consuming but are essential for equipping workers with the skills necessary to operate and maintain complex automated systems. Effective training must encompass a broad spectrum of competencies, including robotic machinery operation, programming, maintenance, debugging, and the integration of automation technologies into routine construction tasks. Additionally, the rapid pace of technological advancements poses a continuous challenge to workforce education. As automation and robotics evolve, construction workers must engage in ongoing training to remain proficient with the latest tools, software, and machinery. This commitment to continuous learning is critical for maintaining productivity, ensuring safety standards, and fostering adaptability in the face of emerging technologies.

2.1.2 *High Cost for Robotic and Automation Technology*

The adoption of automation and robotics in the Industrialised Building System (IBS) requires substantial upfront investments to establish new processes and procure advanced equipment. As noted by [15] Mahbub (2008), the high initial costs and significant financial commitment necessary for research, development, and practical implementation pose a major challenge. The inherent risks of investment make it difficult to attract financiers willing to support these technologies. [17] Almatari et al. (2024) conveyed that construction companies often hesitate to incur such expenses due to uncertainty about the long-term financial benefits and return on investment. The cost of implementing automation and robotics is further exacerbated by the customisation required to meet specific construction needs. These efforts often involve prolonged programming, system integration, and hardware and software procurement, which can be potentially expensive [18]. Additionally, ongoing costs associated with maintenance, repairs, and upgrades of high-end automation systems present another financial burden. Regular upkeep is essential to maintain these systems in optimal condition and avoid costly downtimes that could disrupt construction activities and delay project timelines. [19] Khalid et al. (2021) added that another critical barrier is the lack of clear regulations and guidelines to govern the implementation of automation and robotics in IBS. The absence of such frameworks can affect safety, compliance, and operational efficiency, making it essential to establish comprehensive guidelines for companies intending to adopt these technologies. Organisational culture and resistance to change also pose significant challenges to the adoption of IBS automation and robotics. Successful implementation requires addressing deeply rooted traditions, conservative attitudes, and scepticism toward new technologies. As highlighted by [20] Love et al. (2011) and [21] Mohd Fateh et al. (2024), fostering a culture of innovation and increasing awareness of the benefits of change are critical for overcoming these obstacles.

2.1.3 *Unpredictable Nature of Works in Construction*

The integration of automation and robotics into the construction industry presents significant challenges due to uncertainties and unpredictable variables. The adoption of these technologies often involves unforeseen possibilities that complicate implementation. [22] Feldmann (2022) identified on-site construction as a critical factor impeding automation integration, a claim supported by [15] Mahbub (2008), which highlighted that location-specific factors, such as weather variability and the unstructured nature of construction sites, can hinder the functionality and reliability of robotic systems. Automation technologies, typically designed and tested in controlled environments, often struggle to adapt to the dynamic and unpredictable conditions of construction sites. For instance, autonomous machinery may face difficulties navigating congested or irregular terrains, while robotic arms may encounter challenges in executing precise tasks in unstable environments [23].

The inherent unpredictability of IBS projects further complicates the implementation of automation and robotics. IBS projects emphasise off-site prefabrication and on-site assembly, which, while standardising some components, introduce variability due to unique project-specific functional and design requirements, as pointed out by [24] Gravina da Rocha et al. (2022). Customisation often necessitates the production of bespoke components with complex geometries, varying sizes, and unique materials, posing significant challenges for automation systems. These systems, typically optimised for repetitive and standardised tasks, must overcome barriers in handling, assembling, and installing individualised components. As mentioned by [25] Licardo et al. (2024), robotic systems require advanced sensors, algorithms, and adaptive programming to accommodate these bespoke elements, such as adjusting to varying panel weights, dimensions, and connection methods. Furthermore, precise alignment and fitting tasks often exceed the current capabilities of many robotic systems, complicating their on-site integration.

The interaction between human workers and robotic systems adds another layer of complexity. Construction sites are inherently dynamic, with continuous activity, shifting conditions, and multiple trades operating simultaneously. Ensuring safe and efficient collaboration between human workers and robotic equipment is a significant challenge. [26] He et al. (2022) highlighted that robots must navigate environments influenced by human unpredictability, requiring advanced capabilities to respond in real-time to human actions. Workers' actions can be affected by habits, site conditions, or unforeseen events, further complicating human-robot interaction. For example, workers near automated machinery are at risk of accidents unless the machinery is equipped with advanced obstacle detection and avoidance technologies. Additionally, machinery must coordinate seamlessly with human labour to ensure effective task execution [10]. These challenges underscore the need for flexible and intelligent robotic systems that can adapt to the unique demands of the construction sector. Addressing these issues is crucial for the successful adoption of automation and robotics in the construction industry.

Table 2 summarises the literature review in the context of themes and the implications for the construction industry.

Table 2 Summary of Literature Review

Theme	Description	Benefits	Barriers	Implications for the Construction Industry
Industrialised Building System (IBS)	A modern construction approach involving the prefabrication of building components in a controlled factory environment, later assembled on-site.	• Shorter construction timelines • Reduced labour dependency • Consistent quality control • Enhanced sustainability through waste reduction	• Requires significant process transformation • Dependence on a skilled workforce for assembly	• Positions IBS as a foundation for automation adoption and construction modernisation
Automation and Robotics in IBS	Integration of advanced technologies such as CAD, CAM, and robotic assembly systems to enhance efficiency and precision.	• Increased productivity and accuracy • Improved safety and quality • Reduced material waste	• High setup costs • Limited industry readiness • Need for regulatory frameworks and investment incentives	• Accelerates the shift towards Construction 4.0 and smart manufacturing practices
Lack of Automation Literacy Among Workers	The workforce exhibits limited technical knowledge and a reluctance to adapt to robotic technologies.	• Training opportunities for skill enhancement • Potential to create a highly skilled workforce	• Skills gap and resistance to change, especially among older workers • High cost and time requirement for continuous training	• Necessitates long-term training strategies and organisational change management
High Cost of Automation and Robotics	Implementation involves substantial initial investment, customisation, and maintenance costs.	• Long-term cost savings through efficiency • Enhanced production scalability	• High capital expenditure • Uncertain return on investment • Lack of regulatory clarity and safety standards	• Requires government support, financial incentives, and standardisation to facilitate adoption
Unpredictable Nature of Construction Work	On-site variability and environmental unpredictability hinder robotic efficiency and adaptability.	• Development of adaptive, sensor-based robotics • Potential for hybrid human–robot collaboration	• On-site complexity and non-standard tasks • Human–robot safety concerns • Technical limitations in custom component handling	• Calls for AI-driven adaptive robotics and enhanced safety protocols for human–machine collaboration

3.0 METHODOLOGY

3.1 Population and Sampling

Selecting the appropriate target population and employing a suitable sampling method is critical for obtaining high-quality research data. The target population for this research consists of designers, engineers, and quantity surveyors working at IJM IBS Sdn. Bhd. and Gamuda Industrial Building System Sdn. Bhd. This selection aligns with the research objectives and ensures that relevant stakeholders actively engaged in IBS processes are included. The research focuses on executive personnel at two (2) prominent organisations, Gamuda Industrial Building System Sdn. Bhd. and IJM IBS Sdn. Bhd. IBS, which is actively involved in the IBS process. Both companies are located in Malaysia's Klang Valley, a key metropolitan area renowned for its construction activity. A total of 120 executive staff members from these organisations comprise the target population. Gamuda Industrial Building System Sdn. Bhd. and IJM IBS Sdn. Bhd. IBS were strategically selected for this study due to their leadership roles in the construction industry, particularly in the adoption and advancement of IBS technologies. These organisations have made significant investments in robotics and automation to enhance their IBS operations, providing a rich context for evaluating the impact of these innovations on productivity, operational efficiency, and project outcomes. Out of the 120 employees, a sample size of 96 executive team members was selected to gain a comprehensive understanding of IBS processes at these organisations. The executive level was chosen because they were the decision makers and involved in the high-level discussion. This sample size, representing 80% of the target population, is sufficient to ensure accurate and representative results.

Participants will be chosen using a simple random sampling method, which ensures that each executive employee has an equal chance of being included. This approach minimises sampling bias and enhances the generalisability of the findings.

3.1 Questionnaire Survey

Data for this study were collected using a structured questionnaire administered through Google Forms. The use of an online platform offered several advantages, including ease of distribution, accessibility, and efficient data management. To maximise response rates and ensure respondent convenience, the questionnaire link was disseminated through multiple channels. Initially, the link was shared with the administrative staff of Gamuda Industrial Building System Sdn. Bhd. and IJM IBS Sdn. Bhd. who facilitated its distribution to executive-level employees. The link was emailed individually to each executive staff member to ensure coverage of participants who may not actively use messaging platforms. The questionnaire was divided into four (4) sections as follows:

- **Section A:** Focuses on the demographic background of the respondents, encompassing details such as years of experience in the construction industry, designation, work setting and involvement in automation and robotics.
- **Section B:** Emphasises the impact of automation and robotics on productivity compared to conventional IBS, which includes the significant improvement in project timelines, the enhancement of the precision and quality of construction projects compared to the conventional IBS method, and the cost savings on the labour cost affected by implementing automation and robotics in IBS compared to conventional methods.
- **Section C:** Explores the barriers to the implementation of automation and robotics in IBS Construction, which include the primary financial barriers, the availability of skilled labour to operate and manage automation technologies in IBS and the resistance to change from employees, a challenge to adopting automation and robotics in IBS.
- **Section D**: Suggestions/recommendations for an organisation to explore to enhance the adoption of automation and robotics in IBS.

The Statistical Package for the Social Sciences (SPSS) software was used to analyse the questionnaire data using descriptive statistical methods, percentages and averages. The analysed data are visually represented through reader-friendly formats and tabulation forms to enhance clarity and ease of interpretation. The results and findings will be thoroughly discussed and elaborated on in the next section. The results derived from the data are summarised using average index analysis. The data are rated on a five-point Likert scale, ranging from Strongly Disagree (1) to Strongly Agree (5). The average index for each variable is calculated using a specified formula, providing a quantitative measure of the respondents' agreement levels.

4.0 RESULTS AND DISCUSSION

4.1 Reliability analysis & Response Rate

Reliability analysis was conducted to assess the internal consistency and item–total correlations of each measurement scale. According to prior research, a reliability coefficient exceeding 0.70 indicates an acceptable level of reliability [27] . In this study, the reliability coefficients for all variables surpassed this threshold. The overall Cronbach's alpha value was 0.80, reflecting a high level of internal consistency. Therefore, the instrument used in this study can be considered highly reliable for measuring the intended constructs.

Out of the targeted 120 respondents, 91 completed the survey, yielding a response rate of 76%. This significantly surpasses the typical response rates of 30–40% for self-administered questionnaires in the built environment research domain, as noted by [27] Fateh et al. (2024). Potential challenges such as busy schedules or communication gaps might have prevented some individuals from participating. Table 3 summarises the response rate of the questionnaire survey.

Table 3 Response Rate of the Questionnaire Survey

Organization	Target Respondents	Completed Responses	Response Rate (%)
Gamuda Industrial Building System Sdn. Bhd.	60	47	78.3
IJM IBS Sdn. Bhd.	60	44	73.3
TOTAL	**120**	**91**	**75.8**

4.2 Respondent's Demographic Background

This section presents the demographic and professional characteristics of the respondents, with a particular focus on their involvement in automation and robotics within the Industrialised Building System (IBS) sector. The background information collected includes organisational designation, years of experience in the construction industry, current workplace setting, awareness of automation and robotics implementation, and extent of participation in such initiatives. As shown in Table 4, the sample comprised a balanced representation of professional roles: engineers formed the largest group with 33 respondents (36.3%), followed by quantity surveyors

(31 respondents, 34.1%) and designers (27 respondents, 29.7%). This composition ensures comprehensive insights from key technical and managerial perspectives central to automation and robotics adoption in IBS. Table 5 summarises respondents' experience in the construction industry. The majority, 39 respondents (42.9%), had between 1–3 years of experience, followed by 33.0% with 4–7 years and 14.3% with over 8 years of experience. Nine respondents (9.9%) had less than one year of experience. This distribution indicates a workforce that is predominantly early- to mid-career, representing the emerging generation of professionals most likely to engage with and adapt to automation technologies. Next, Table 6 details respondents' work settings, with 57 individuals (62.6%) based in office environments, 22 (24.2%) working on-site, and 12 (13.2%) in factory settings. The predominance of office-based personnel highlights the strong emphasis on design integration, digital planning, and project management—core functions in the automation-driven IBS workflow. Lastly, Table 7 outlines respondents' experience with automation and robotics in their organisations. Nearly half (49.5%) reported 1–3 years of involvement, followed by 29.7% with 4–7 years, 16.5% with less than one year, and only 4 respondents (4.4%) with over 8 years of experience. These findings reflect a growing engagement with automation and robotics technologies within the IBS sector, with most professionals actively participating in the early stages of technological integration.

Table 4 Distribution of Respondents by Designation

Designation	Number of Respondents	Percentage (%)
Engineers	33	36.3
Quantity Surveyors	31	34.1
Designers	27	29.7
TOTAL	**91**	**100.0**

Table 5 Respondents' Years of Experience in the Construction Industry

Years of experience	Number of Respondents	Percentage (%)
Less than 1 year	9	9.9
1–3 years	39	42.9
4–7 years	30	33.0
More than 8 years	13	14.3
TOTAL	**91**	**100.0**

Table 6 Respondents' Work Setting

Work setting	Number of Respondents	Percentage (%)
Office	57	62.6
Site	22	24.2
Factory	12	13.2
TOTAL	**91**	**100.0**

Table 7 Respondents' Involvement in Automation and Robotics

Years of involvement	Number of Respondents	Percentage (%)
Less than 1 year	15	16.5
1–3 years	45	49.5
4–7 years	27	29.7
More than 8 years	4	4.4
TOTAL	**91**	**100.0**

The demographic composition underscores the technologically progressive nature of the IBS industry. The dominance of engineers, quantity surveyors, and designers—many of whom possess early to mid-level experience—suggests that the sector is driven by a younger, innovation-oriented workforce. The prevalence of office-based roles and increasing exposure to automation and robotics further demonstrate the industry's strategic shift towards digitalisation, precision manufacturing, and technology-enabled productivity enhancement.

4.3 The Barriers to Integration of Automation and Robotics in IBS

The findings underscore the multifaceted challenges hindering the adoption of automation and robotics in IBS, ranging from financial constraints and workforce limitations to technical and environmental barriers. Addressing these issues requires a concerted effort from all stakeholders, including industry players, policymakers, and researchers, to create a more conducive ecosystem for innovation. Enhanced policies, targeted workforce development, and ongoing technological advancements are essential in overcoming these barriers and unlocking the potential of automation in the construction industry. These barriers are grouped into three major themes: *Cost of Robotic and Automation Technology*, *Lack of Automation Literacy Among Workers*, and *Unpredictable Nature of Work in Construction*. Table 8 presents the findings on the identification of barriers in the integration of automation and robotics in IBS.

Table 8 The barriers to integration of automation and robotics in IBS (N = 91)

THEME	BARRIERS	MEAN SCORE	STD. DEV.	AV. MEAN SCORE
Cost for Robotic and Automation Technology is High	The maintenance and repair costs of advanced robotic systems and automation technology are prohibitive for many construction companies.	4.66	0.477	4.586
	The adoption of IBS automation and robotics requires a	4.62	0.489	

	significant upfront investment.			
	Comprehensive regulatory frameworks are necessary to mitigate risks and ensure the responsible implementation of automation and robotics in IBS.	4.48	0.524	
Lack of Automation Literacy Among Workers	Conventional building methods are deeply ingrained among older workers, making it hard for them to adapt to new technologies.	4.54	0.501	4.428
	Continuous training programs are essential to upskill and keep construction workers updated latest advancements in automation and robotics.	4.40	0.492	
	Workers in the construction industry lack the necessary understanding of robotics and automation systems.	4.35	0.480	
Unpredictable Nature of Works in Construction	Robotic systems tested in controlled environments may not be sufficiently prepared for chaotic construction site conditions.	4.35	0.524	4.311
	Robotic systems must be extremely flexible and adaptive to handle customized parts in construction projects.	4.30	0.527	
	The unknown risks connected with automation and robotics make their integration into construction projects challenging.	4.29	0.523	

The findings emphasise the significant financial and regulatory challenges perceived by respondents as major barriers to adopting automation and robotics in IBS. The mean score of 4.586 for cost-related aspects not only highlights the prominence of financial concerns but also reflects a striking consensus among respondents, as evidenced by the low standard deviation. This reinforces the criticality of cost barriers as a key deterrent to technological advancements in the construction sector. These results align closely with prior studies, [28] Demirkesen & Tezel (2022) and [29] Barykina (2019), which highlights the construction industry's reluctance to invest in expensive technologies when faced with uncertain long-term financial returns and potential risk.

Furthermore, results also indicate that while initial capital investments often dominate discussions on cost barriers, maintenance and repair costs are equally prohibitive. This suggests that stakeholders in the construction industry are concerned not only about the acquisition of advanced technologies but also about the financial burden of sustaining these systems over time. The study by [30] Hui et al. (2019) corroborates these findings, emphasising the disruptive consequences of inadequate maintenance and repair of automation systems. The previous findings argue that poorly maintained systems lead to operational inefficiencies, project delays, and increased costs, thereby creating cascading challenges that affect project timelines and profitability. This aligns with the current study's observations, underscoring the need for strategic planning to address these barriers in construction projects utilising automation and robotics.

The second theme of the significant barrier to the integration of automation and robotics in IBS processes is a lack of automation literacy among construction industry personnel. The mean score of 4.428 indicates strong agreement among respondents regarding the severity of this issue, while the very low standard deviation highlights a high degree of consensus. This underscores that the lack of understanding and familiarity with automation technologies is a widespread and critical challenge for the construction sector. This finding aligns with the studies of [31] Oke et al. (2024) and [32] Regona et al. (2022), which both emphasise that a significant skills gap in the construction industry impedes the adoption of advanced technologies such as automation and robotics. They assert that the lack of trained personnel capable of understanding, operating, and maintaining these systems remains one of the foremost barriers to technological transformation. Similarly, [33] Akmam Syed Zakaria & Amtered El-Abidi (2021) provide insights into how deeply ingrained conventional building methods among older workers further exacerbate this skills gap, as many rely heavily on established practices and are resistant to adopting modern technologies.

The unpredictable and dynamic nature of construction projects is the last theme barrier to the implementation of automation and robotics in IBS. With a mean value of 4.311, respondents strongly agree that the inherent variability and uncertainty in construction projects complicate the adoption of these advanced technologies. The low standard deviation suggests a strong consensus among respondents on this issue. These results indicate that, while automation and robotics hold great potential for improving construction processes, adapting them to the ever-changing conditions of construction sites remains a critical challenge. This finding aligns with

existing literature, which emphasises the complexity and variability of construction projects as a major challenge to automation. [34] Melenbrink et al. (2020) and [35] Pan & Zhang (2021) highlight that construction sites are dynamic, with unpredictable changes in weather, ground conditions, and project timelines, which can disrupt the performance of automated systems. Unlike controlled manufacturing environments, where processes are uniform and repeatable, construction projects demand flexibility and adaptability, often beyond the current capabilities of robotic systems.

There were findings from the optional open-ended survey question that provided valuable insights into additional barriers to implementing automation and robotics in IBS that were not captured in the quantitative section of the study. Despite the limited number of responses, the themes identified highlight nuanced issues that merit deeper consideration. One respondent pointed to "hidden costs" as a significant barrier to the implementation of automation and robotics in IBS. These are costs not accounted for during the initial feasibility study, such as unforeseen expenses related to customisation, integration, training, or system upgrades over time. This aligns with the findings of [35] Pan & Zhang (2021), who emphasised the importance of accounting for all lifecycle costs in construction projects, particularly those involving emerging technologies. Hidden costs can disrupt project budgets, lead to financial strain, and potentially reduce the return on investment. Moreover, the respondent raised concerns about the "future-proofing" of automation and robotics systems, questioning whether current technologies will remain relevant or become obsolete as new advancements emerge. This sentiment resonates with the work of [10] Oesterreich & Teuteberg (2016), who highlighted that rapid technological evolution poses a risk to long-term investments in construction automation, necessitating continuous updates and adaptability.

The second respondent underscored the lack of government incentives as a critical barrier to the adoption of automation and robotics in IBS. They highlighted that most implementations are driven by private companies' initiatives rather than supported by public funding or policy frameworks. This was echoed by [28] Demirkesen & Tezel (2022), who emphasise the pivotal role of government intervention in promoting technological innovation in the construction sector. Incentives such as grants, tax reliefs, or subsidies could significantly alleviate the financial burden on companies, especially small and medium enterprises (SMEs), enabling broader adoption. Without such support, private companies bear the full weight of financial and operational risks, which can stifle innovation and limit scalability.

Among all three themes mentioned in this section, the biggest impact that hinders the implementation of automation and robotics in IBS, according to the participants, is the high cost of implementation. With the average mean value of 4.5861, this suggests a prevalent view that financial barriers are a significant concern for the construction industry. Abs that accept automation and also robotics need to make a considerable ahead-of-time financial investment to purchase sophisticated tools plus place brand-new treatments in position. A research study by [15] Mahbub (2008) that highlights the considerable costs as well as monetary dedication needed for research study and growth, coupled with functional application, could be made use of to sustain this. Given that these financial investments lug a high degree of risk, it can be testing to draw in enrollers, specifically when building business doubt regarding the lasting economic returns.

According to [10] Oesterreich & Teuteberg (2016), the initial costs may total up to numerous bucks and also require not just the purchase of equipment and software programs but additionally adjustment for specific buildings and construction requirements that demand considerable shows as well as combination. Covering it up with continual maintenance repair work together with improvements enhances the expense. Automated arms as well as drones are instances of state-of-the-art tools that call for regular upkeep to prevent pricey downtime because even little mistakes can create hold-ups together with interrupting tasks. Comprehensive governing structures are needed because of poor as well as disjointed regulations, specifically in IBS posture concerns concerning security and conformity along with moral usage, as reported by [36] Wong et al. (2020).

4.4 The Impact of Automation and Robotics IBS on Construction Productivity Compared to Conventional IBS

This section focuses on the impact of automation and robotics in IBS on construction productivity compared to conventional IBS. The findings hold immense potential to revolutionise the construction industry and unlock new opportunities for growth and innovation. Table 9 summarises the findings based on four (4) themes: (1) ***Precision and Quality***, (2) ***Efficiency and Timeliness***, (3) ***Labour and Safety***, and (4) ***Cost and Environmental Impact***.

Table 9 The impact of automation and robotics in IBS on construction productivity compared to conventional IBS (N = 91)

Theme	Impact	Mean	Std Dev.	Av. Mean Score
Precision and Quality	Robotic systems in IBS ensure a high level of precision in construction processes compared to Conventional IBS.	4.69	0.464	4.64
	Automation and robotics in IBS significantly enhance construction quality compared to	4.59	0.516	

	conventional IBS methods.			
Efficiency and Timelines	Automation and robotics significantly enhance the efficiency of construction processes in IBS compared to Conventional IBS.	4.53	0.502	4.53
	Automation and robotics in IBS significantly improve project timelines compared to conventional IBS methods.	4.53	0.502	
Labour and Safety	Automation and robotics in IBS have a positive impact on the labour market compared to conventional IBS methods.	4.45	0.563	4.43
	The integration of automation and robotics in IBS enhances safety during the construction processes compared to Conventional IBS.	4.40	0.514	
Cost and Environmental Impact	The efficiency of automated systems in IBS results in lower operational costs over time compared to Conventional IBS.	4.38	0.573	4.37
	Automation and robotics in IBS significantly reduce the environmental impact of construction projects compared to conventional IBS methods.	4.36	0.548	

Precision and Quality ranked as the main theme with an average mean score of 4.64. Most respondents perceived that robotic systems in IBS provide a higher level of precision than conventional methods. This high mean points to a belief that automated systems can achieve greater accuracy, reducing errors and improving the quality of the final product. It underscores a strong confidence in the precision capabilities of robotics in construction. Such strong agreement suggests that precision is a standout benefit of automation and robotics, which could translate to higher-quality buildings and structures with fewer defects and reworks. These technologies help create higher-quality and better-built structures. A strong advantage of improved quality is that it can result in fewer flaws, more longevity, and a better reputation for builders who use cutting-edge technologies. This can be supported by [37] Neuroject (2024), which stated that automation and robotics technologies can reduce errors in work because these systems are programmed to perform tasks with exact specifications. For example, robotic bricklayers can place each brick with millimetres of accuracy, ensuring uniformity and structural integrity [39].

Compared to conventional IBS methods, quality control is more challenging due to the reliance on manual inspections and supervision. Variations in worker performance can lead to defects and irregularities in the construction [40]. The findings align with [40] Jin (2020), which reported that robots operate with consistent efficiency and accuracy, ensuring that each component meets the required specifications. This consistency reduces the need for inspections and rework, improving overall project outcomes and customer satisfaction. The high precision and reliability of automation and robotics contribute to superior quality in IBS construction, which leads to better quality control in conventional IBS. It is more complex due to the variability in worker performance and the potential for human error, as emphasised by [41] Chan & Wang (2019) and [42] Gan et al. (2017).

Secondly is the *Efficiency and Timelines* theme with an average mean score of 4.53. Respondents show high agreement that automation and robotics shorten project durations, which further supports the perceived time-saving benefits. These technologies have the potential to expedite the construction process, resulting in earlier project completion dates. Quick project turnaround times can give businesses a significant competitive edge by allowing them to finish more tasks in a given amount of time and increase client satisfaction. On top of that, automation and robotics significantly enhance the efficiency of construction processes in IBS compared to conventional methods. This indicates a perception that automated systems streamline operations, reduce delays, and optimise workflow.

The consensus reflects a broad recognition of efficiency gains, implying that these technologies are reliably seen as beneficial for operational speed and effectiveness. This strong agreement suggests that industry practitioners see clear and tangible benefits in adopting automation and robotics, potentially leading to faster project completion and more efficient use of resources. This can be supported by [43] Masjaya Eco Construction Sdn. Bhd. (2023), which notes that robots can operate continuously without the need for breaks, which speeds up the completion of building stages. With the automation and robotics system, the manual tasks that would take weeks may be completed in days, significantly reducing project durations. The project duration can be longer because of the manual assembly and the reliance on human labour in conventional IBS methods [45]. It will lead to project delays and extended project timescales due to variability in worker performance.

According to [45] Jacobsson & Linderoth (2021), automation and robotics significantly enhance the efficiency and speed of construction processes. Robots can work 24/7, unlike human labour, which is limited by working hours and physical fatigue. [46]

Aghimien et al. (2018) added that robotic bricklayers can lay bricks with high precision and at speeds that far exceed human capabilities, resulting in quicker completion of construction projects. This was agreed by [47] Kaiv (2024), who indicates that human workers, unlike robots, require rest and are susceptible to fatigue, which can slow down the pace of construction. Additionally, manual labour is more prone to delays due to factors such as weather conditions, worker availability, and physical constraints.

Next, a mean score of 4.43 denotes agreement that robotics and automation improve the employment market and safety. These technologies have the potential to upskill the workforce, open up new career opportunities, and enhance working conditions. The integration of automation and robotics technologies creates new opportunities for skilled labour in areas such as programming, operating, and maintaining automated systems [49]. Additionally, automation improves working conditions by reducing exposure to hazardous tasks and enhancing worker safety and well-being. The integration of automation and robotics is also able to enhance safety during construction processes. The perception of improved safety is crucial for the adoption of these technologies, as it highlights their role in protecting workers and reducing accidents, which can be a significant factor for companies prioritising occupational health and safety.

Moreover, these technologies can mitigate risks, reduce human error, and create safer working environments. [49] Rahim et al. (2020) highlighted that the conventional IBS methods rely heavily on manual labour, providing employment opportunities for a wide range of skill levels, but the physical demands and safety risks associated with manual labour can lead to lower job satisfaction and a higher turnover rate. This was backed by [50] R. Ahn et al. (2019), who noted that robots can perform dangerous tasks such as heavy lifting, working at heights and handling toxic materials. Thus, the integration of automation and robotics in IBS significantly improves safety by taking over dangerous tasks that put human workers at risk. Furthermore, findings from [51] Xiao et al. (2022) underscored that the use of automation and robotics systems can reduce the incidence and risk of long-term health issues because it can reduce physical strain on labour. A more productive workforce and healthier labour can improve the safety conditions in construction.

The theme *Cost and Environmental Impact* placed last from the respondents' point of view, with an average mean score of 4.37. The respondents agree that the efficiency of automated systems results in lower operational costs over time compared to conventional IBS methods. The moderate range of replies shows some variation, indicating that although most people agree, opinions on the amount of cost reductions vary. For those making decisions about the long-term financial effects of investing in automation and robots, this perceived cost benefit is important. Such investments may have a strong argument due to the long-term cost reductions. Automation can lead to cost savings through reduced labour, minimised errors, and optimised resource use. In addition, automation and robotics have less influence on the environment compared to conventional IBS. Although there are some differences in opinion about the degree of environmental advantages, there is a general tendency towards agreement, as indicated by the modest variability.

The advantages for the environment can play a big role in encouraging automation and robotics, which is in line with the growing emphasis on sustainability and green building practices in corporate social responsibility and regulation. These technologies may result in more environmentally friendly building methods, such as decreased waste and better material use. It was supported by [52] Attalla et al. (2023) that automated solutions shorten project schedules, minimise the need for manual labour, and minimise the likelihood of rework because there are fewer errors, all of which contribute to overall cost savings. According to [53] Tilley (1997), the automated systems' accuracy and efficiency over time reduced operating expenses because machinery can run constantly and usually requires less maintenance, which maximises output and reduces downtime. Compared to conventional IBS, depending so heavily on physical labour results in increased fixed costs, particularly in areas where labour costs are high. Furthermore, conventional IBS methods' increased risk of errors and rework results in greater costs and longer project schedules, as reported by [44] Sibs AB (2022). [54] Wu et al. (2019) mentioned that the automated and robotics systems accuracy ensures that resources are used effectively, with little surplus and waste. Moreover, automation and robotics systems can lessen noise pollution and minimise emissions, and this is possible to follow the environment-friendly construction method programme [56].

4.5 Strategies to improve the implementation of automation and robotics in IBS

This section underscores the strategies required for successfully adopting automation and robotics in IBS. The strategies were grouped into four (4) themes: (1) *Financial Aspects*, (2) *Workforce Development and Training*, (3) *Technology and Employment Adaptability*, and (4) *Risk Mitigation and Phased Adoption*. Table 10 summarises the strategies to improve the implementation of automation and robotics in IBS to further elaborate on the interplay between these themes in the construction industry transformation.

Table 10 Strategies to improve the implementation of automation and robotics in IBS (N = 91)

Theme	Strategies	Mean	Std Dev.	Av. Mean Score
Financial Aspects	Exploring financing options and government incentives is crucial for alleviating the financial burden of adopting automation and robotics technologies.	4.73	0.449	4.72
	Forming strategic partnerships and collaborations can significantly reduce the cost barrier and enhance innovation in automation technologies.	4.70	0.459	
Workforce Development and Training	Organizations should invest in comprehensive training programs to enhance employees' understanding and skills related to automation technologies.	4.58	0.496	4.55
	Fostering a culture of continuous learning and investing in comprehensive training programs are crucial strategies for improving the implementation of automation and robotics in IBS.	4.51	0.503	
Technology and Employment Adaptability	Organizations should focus on developing adaptable and flexible robotic systems that can handle varying tasks and environments.	4.40	0.594	4.36
	Involving employees in the early stages of automation projects is beneficial for the successful integration of automation and robotics in IBS.	4.31	0.662	
Risk Mitigation and Phased Adoption	Using a phased approach and conducting pilot projects before full-scale deployment is an effective strategy to mitigate risks and optimise the integration of automation technologies.	4.23	0.668	4.23

The first theme of strategies to improve the implementation of automation and robotics in IBS emphasises reducing financial barriers through external support and partnerships. The mean score of 4.72 across the items indicates strong agreement among respondents that financial incentives and strategic collaborations are essential for promoting automation in IBS. Financing aid resources could aid in improving the assimilation of automation as well as robotics in IBS. It may be as a reward, support mechanisms or financing choices to lessen the economic problem connected with carrying out automation as well as robotics innovations. This reveals that respondents think that having monetary aid is necessary to make fostering much easier. Financial support mechanisms, such as tax incentives or grants, could be pivotal in encouraging small and medium-sized enterprises (SMEs) to adopt these technologies.

Additionally, partnerships between organisations and research institutions can foster innovation while sharing costs and risks, thus promoting wider adoption. Practical applications include advocating for more targeted government policies and creating industry consortia to pool resources and expertise, thereby reducing financial burdens and accelerating technological implementation. Respondents agreed that producing calculated collaborations as well as interacting might decrease expenses along with cultivating development in modern automation technology. This shows confidence in the capability of teamwork to progress objectives and divided expenditures. These findings align with research by [29] Barykina (2019) and [28] Demirkesen & Tezel (2022), which highlight the critical role of government incentives and industry partnerships in alleviating the high initial and operational costs associated with advanced technologies. [56] Rashid et al. (2019) stated that collaboration in construction can spread the implementation wider and also boost advancement and expertise. This was echoed by the respondents who answered the open-ended question, revealing the need for federal policies and incentives to encourage the adoption of automation and robotics in IBS. This finding reflects the broader industry perception that government support is critical for addressing barriers such as high initial costs and lack of technical expertise, which can hinder the widespread adoption of advanced technologies. The *Workforce Development Strategies* placed second, with an average mean score of 4.55, reflecting the importance of equipping employees with the skills necessary for managing automation and robotics in IBS. Findings suggested that respondents unanimously agree on the importance of comprehensive training initiatives. This agreement highlights the recognition that employees require structured and substantial training to understand and effectively utilise automation technologies. The low variability in responses further emphasises a shared perception of the critical role that employee training plays in ensuring successful technology integration. This theme aligns with findings by [31] Oke et al. (2024) and [32]

Regona et al. (2022), which emphasise that the success of automation heavily relies on the availability of a skilled workforce. Automation literacy gaps remain a significant challenge in the construction industry, as outlined in previous studies, and addressing this issue requires comprehensive training programmes that cater to both technical and operational aspects of robotics. The importance of training is consistent with the findings of [57] Maity (2019), which emphasized that organisations must invest in robust training programmes to equip employees with both technical knowledge and practical skills. Such initiatives bridge the skill gaps that often impede the adoption of advanced technologies. By doing so, organisations can reduce operational inefficiencies, mitigate resistance to change, and maximise the potential of automation systems.

Practical implications for IBS companies include designing tailored training sessions that focus on both theoretical concepts and hands-on applications, such as robotics operation, maintenance, and troubleshooting. Furthermore, promoting continuous learning received strong consensus among the respondents. This strategy underscores the necessity for organisations to establish a learning-oriented culture that encourages employees to stay updated with evolving technologies. Continuous learning fosters adaptability, a vital quality for employees working in a fast-changing technological environment. The emphasis on continuous learning aligns with the study by [58] Al-Shammari (2023), which found that organisations that prioritise long-term knowledge acquisition and skill development are better positioned to maintain competitive advantage in technology-driven industries. The findings highlighted that fostering a learning culture ensures that employees are not only capable of adapting to current technologies but also prepared for future advancements. This approach also enhances employee engagement and morale, as workers feel valued and supported in their professional growth.

The *Technology and Employment Adaptability* theme is positioned third with a mean score of 4.36; respondents agree on the importance of developing adaptable and flexible robotic systems to handle diverse tasks and dynamic environments in IBS. The higher standard deviation (0.594) indicates varying opinions, possibly reflecting differences in organisational priorities or technological readiness. This aligns with [34] Melenbrink et al. (2020), who reasoned that current robotic systems often struggle to adapt to the unpredictable conditions of construction sites. By focusing on modular and scalable system designs, companies can enhance flexibility while maintaining efficiency. These systems should be capable of addressing site-specific challenges such as varying project sizes, labour availability, and environmental constraints. Respondents demonstrated agreement on the importance of designing robotic systems that are adaptable and capable of handling diverse tasks and environments. It underscores the critical need for flexible automation solutions to cater to the dynamic nature of construction projects.

The findings resonate with the work of [59] Parascho (2023) and [60] Naghshbandi et al. (2021), emphasising that the unpredictable and ever-changing conditions of construction sites necessitate the use of robotics that can adapt to varying tasks, scales, and environments. The adaptability in robotic systems not only enhances operational efficiency but also reduces downtime caused by mismatches between robotic capabilities and on-site requirements. For example, modular robotic systems that can be reconfigured for different tasks—such as assembling structural components, plastering, or painting—offer significant advantages in the IBS context.

Furthermore, the strategy of involving employees early in automation projects indicates an agreement among respondents regarding its importance [57]. The results align with findings from [56] Rashid et al. (2019) that demonstrated that early involvement of employees in automation initiatives fosters a sense of ownership, reduces resistance to change, and ensures smoother integration of new technologies. Employees' input during the planning and implementation stages is invaluable for identifying potential challenges and developing practical solutions. This participatory approach not only improves buy-in but also leverages the tacit knowledge and on-the-ground expertise of workers to optimise the automation process.

The last theme on the list is *Risk Mitigation and Phased Adoption*, with the lowest average mean score of 4.23, reflecting moderate agreement on the effectiveness of phased approaches and pilot projects. Implementing automation technologies in stages allows organisations to evaluate their performance, identify operational challenges, and make necessary adjustments before committing to full-scale implementation. [61] Bughin et al. (2017) highlighted that implementing automation technologies in stages allows organisations to evaluate their performance, identify operational challenges, and make necessary adjustments before committing to full-scale implementation. The importance of incremental and adaptive strategies for successful technology adoption. The phased adoption approaches allow companies to align automation efforts with organisational goals while mitigating risks associated with sudden changes. Similarly, the emphasis on pilot projects aligns with broader recommendations in the construction technology literature, which advocate for using small-scale implementations to identify potential technical or logistical issues before scaling up.

All in all, the study reveals four strategic themes crucial for enhancing the adoption of automation and robotics in IBS. Reducing financial barriers through incentives and strategic partnerships emerged as the highest priority, as these mechanisms alleviate costs and foster innovation. Equally important is workforce

development, emphasising comprehensive training and continuous learning to bridge automation literacy gaps and ensure employee adaptability. Furthermore, designing flexible robotic systems capable of handling dynamic environments and involving employees early in automation projects fosters smoother integration and operational efficiency. Lastly, adopting phased approaches and pilot projects mitigates risks, allowing organisations to refine processes before full-scale implementation.

5.0 CONCLUSION

In conclusion, the implementation of automation and robotics in IBS remains limited, with insufficient government support and several barriers hindering its widespread adoption. The integration of advanced technologies in IBS faces challenges such as high initial investment costs, prohibitive maintenance expenses, and the lack of automation literacy among workers, particularly older employees accustomed to conventional construction methods. Furthermore, the unpredictable nature of construction sites and external factors like weather variations pose additional difficulties.

Despite these barriers, the research highlights the substantial impact of automation and robotics on enhancing productivity, including improved efficiency, precision, safety, and environmental sustainability. These technologies reduce project timelines, operational costs, and risks while also improving construction quality and labour market dynamics. To overcome existing challenges and accelerate adoption, the study proposes strategies such as exploring financial incentives, forming strategic collaborations, and implementing comprehensive training programmes. Additionally, fostering a culture of continuous learning and involving employees early in automation projects can facilitate smoother integration. A phased approach with pilot projects and the development of adaptable robotic systems further ensures the effective deployment of these technologies, ultimately enabling improved productivity and innovation in IBS construction.

Moving forward from this research, expanding the population is essential to enhance the strength as well as the generalisability of future research studies on the combination of automation and also robotics in IBS. This involves a larger range of specialists from various construction-related functions, consisting of designers, engineers, job supervisors and also employees. In addition, the research study should have a more comprehensive geographical emphasis, incorporating different states and countries. This larger worldwide protection assures that the outcomes take regional distinctions right into account and also supply a much more extensive understanding of the characteristics as well as problems dealing with business.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics declaration

Formal ethical approval was not obtained for this study. However, the authors confirm that the research was conducted in accordance with established ethical principles and good research practices, with due consideration given to participant rights, informed consent, confidentiality, and responsible data handling.

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