

Barriers and Perceived Effectiveness of Industrialized Building System Adoption in Malaysian Bridge Infrastructure

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DOI: <https://doi.org/10.47772/IJRISS.2026.100900450>

Received: 23 September 2026; Accepted: 28 September 2026; Published: 14 October 2026

ABSTRACT

Industrialized Building System (IBS) adoption in bridge infrastructure depends on practitioners' capabilities and the conditions under which prefabricated components are procured and assembled. This study examines perceived barriers and effectiveness among Public Works Department (Jabatan Kerja Raya, JKR) practitioners in Perlis, Kedah, Penang and Perak. A structured questionnaire targeted engineers, assistant engineers and project managers through purposive sampling. The manuscript records 82 questionnaires distributed and 72 valid cases, giving a valid-case yield of 87.8%. Descriptive results identify skilled personnel and technical competency as the highest-rated barrier (C1, mean = 4.097), followed by initial cost and financial constraints (C2, mean = 3.972). Effectiveness items have means from 4.097 to 4.417, indicating favourable perceptions on the reported response scale. Recommendations concerning standardisation, supply-chain reliability and digital integration also receive high ratings. These results describe practitioners' perceptions rather than measured changes in project performance. The available correlation extract relates awareness items to barrier items and does not establish the proposed relationship between barriers and effectiveness. Construct-specific reliability and a complete, multiplicity-adjusted correlation analysis require respondent-level data. The descriptive findings support targeted competency development and assessment of procurement and implementation conditions, while the inferential objective remains unresolved.

Keywords: Industrialized Building System, Prefabrication, Bridge Infrastructure, Public Works Department, Malaysia

INTRODUCTION

Research Background

Infrastructure is critical for economic development, national integration and social equity. Of all types of infrastructure bridges are part of transportation networks because they link natural and urban barriers together; rapid urbanisation, logistics activities expansion and disaster resilience requirements have increased demand for bridge infrastructure that is durable, timely and cost effective but in Malaysia bridge construction still heavily relies on conventional cast-in-situ methods (labour intensive, weather sensitive and construction duration, workmanship quality, site safety and environmental impact concerns) (Yunus et al., 2020).

The Industrialized Building System (IBS) may be an alternative solution to these problems. IBS is the process of manufacturing components off-site in controlled factory conditions before transporting and assembling them at the construction site. It can increase productivity, quality consistency, reduce reliance on site labour and weather delays (less bad weather delays), material control (better control over materials delivered) and waste reduction on site (Kamar et al., 2022). IBS has been applied widely to residential and institutional buildings in Malaysia but bridge infrastructure adoption is relatively low and still nascent.

The Malaysian Government has promoted IBS as part of its wider effort to modernise the construction industry through CIDB Malaysia and CITP. The IBS Roadmap 2021–2025 focuses on productivity improvement, carbon emission reduction and innovation-driven practices across the industry. Nevertheless, even with strong

institutional support IBS adoption in bridge construction is inconsistent because of technical, logistical, financial and organisational constraints (Kamar et al., 2022).

The bridge's construction by collaboration between structural design, component production, transport, lifting and site assembly. Industrialized Building System (IBS) approaches move construction activities to controlled production environments prior to components being put on site. CIDB defines IBS as a family of prefabricated construction techniques and it focuses on workforce skills and training in its implementation programme. In bridge infrastructure, prefabrication can involve girders, deck panels and other structural components. The Federal Highway Administration defines prefabricated bridge components and systems as components that are manufactured off site or close to the site to shorten on-site construction and minimize disturbance to road users (FHWA, 2021). This may be a useful international benchmark for Malaysian practitioners' expectations. However, benefits anticipated from prefabrication must be distinguished from those proved through project records. A survey of practitioners can identify known implementation constraints and anticipated performance, but it cannot be found to provide savings in time, cost or environmental impact.

Several projects show how IBS principles could be applied to bridge construction. The Great Wall Modular Steel Bridge implemented by Jabatan Kerja Raya Malaysia is one example of how modular systems can facilitate faster bridge deployment (especially in rural areas). Geosynthetic Reinforced Soil Integrated Bridge Systems (GRS-IBS) are also a possible solution to settlement at bridge approaches which has been a long-standing problem that degrades structural durability and increases maintenance requirements (Jiang et al., 2023). GRS-IBS can improve load transfer efficiency and reduce differential settlement failures.

Another relevant Malaysian example is the Sultan Abdul Halim Muadzam Shah Bridge (also known as Second Penang Bridge). It did not follow IBS in full but used prefabrication and sustainable design principles. These practices reduced construction time and on-site labour requirements, quality, durability and sustainability. The project compared prefabricated with conventional construction methods and found that construction efficiency was improved; quality control increased and site safety enhanced (Rahim et al., 2023).

Although these positive examples exist, IBS adoption in Malaysian bridge infrastructure is still limited. One of the main barriers is that large amounts of initial capital are needed for prefabrication facilities, specialised equipment, component moulds and transportation logistics; availability of suitably skilled workforce is another because Malaysia has few engineers, contractors and project managers with practical experience in IBS procedures (Aberi & Zulkifli, 2022); resistance among stakeholders restricts adoption too when construction organisations prefer familiar conventional methods or have little knowledge of prefabricated bridge systems.

Technical and regulatory barriers also limit IBS implementation. These include lack of design tools and guidelines, limited standardisation of bridge components, weak integration between prefabrication requirements and structural engineering considerations as well as insufficient information on IBS specifications and quality control procedures (CIDB, 2021; Yusof et al., 2024). All these issues lead to uncertainty during design, procurement, manufacturing, transportation and installation. Hence, removal of these barriers is critical for expanding the application of IBS and achieving more efficient, safe and sustainable bridge infrastructure in Malaysia (CIDB, 2021; Yusof et al., 2024).

Problem Statement

Malaysia's construction sector is undergoing rapid transformation as it tries to meet growing infrastructure demands while improving sustainability, efficiency and construction quality. Bridge projects are particularly demanding because structural requirements are complex, completion schedules are tight, service lives long and safety expectations high but conventional cast-in-situ methods are still widely used in Malaysian bridge construction (i) they require a lot of on-site labour; (ii) weather conditions can cause problems; (iii) delays, workmanship variations, safety risks and increased environmental impacts may occur (Author 2021).

In order, to overcome these limitations, the Malaysian Government has promoted IBS (off-site manufacture of standardised components followed by transportation and assembly at construction site). IBS has several potential benefits such as shorter construction period; quality control; safer working conditions; less material waste and more sustainable project delivery. Through CITP and programmes run by CIDB Malaysia (Construction Industry

Development Board) considerable effort has been made to increase IBS uptake but it has been used mostly for building projects (public housing) and bridge infrastructure is comparatively less so (Yunus et al., 2020; Kamar et al., 2022).

Public bridge practitioners need to determine if prefabrication is possible within the budget, workforce capacity and supply chain. Bridge components could need specialized fabrication, carefully planned transportation and lifting equipment. A positive view of IBS does not necessarily mean one is ready to implement it. Awareness, perceived barriers and expected performance can be used to determine where technical development and organisational support are needed. The issue is the uncertainty of JKR practitioners' assessment of IBS in northern Peninsular Malaysia. In particular, it examines the constraints they identify and the effectiveness they attribute to IBS in bridge delivery. It is also important to study barrier ratings with effectiveness ratings, but this relationship must be explored using properly mapped variables and appropriate statistical analysis. Self-reported associations cannot show that barriers lead to changes in project outcomes.

Several Malaysian projects have shown that prefabrication can work for bridge construction: the Sultan Abdul Halim Muadzam Shah Bridge (Second Penang Bridge) used prefabricated components and sustainable design principles; Great Wall Modular Steel Bridge showed rapid deployment capability through modular construction. But IBS has not yet been widely used in bridge construction because it is constrained by financial, technical, logistical and organisational barriers.

A major barrier is the investment required to set up and operate an IBS supply chain (Author, 2023). Prefabrication facilities, manufacturing equipment, moulds for components, digital technologies, machinery specialised for IBS implementation need to be established. Large prefabricated bridge components have to be transported from manufacturers to project sites (heavy and large prefabricated bridge components cannot be transported by road). This cost may be high in rural or remote bridge projects where access routes are not available or oversized components are not transportable. Smaller contractors and public agencies working on tight budgets may therefore find IBS financially unattractive despite savings in long term through lower labour requirements, shorter construction periods and lower rework levels.

The shortage of skilled personnel is another challenge to IBS implementation (Aberi & Zulkifli, 2022). To deliver IBS effectively personnel are needed who know component design, factory production, transportation planning, installation, quality control and digital coordination tools such as BIM; most of Malaysia's construction workforce however is still more familiar with conventional labour-intensive methods. Lack of technical knowledge causes handling and installation errors, productivity loss, delays in construction and quality-control problems. Projects may therefore become dependent on foreign specialists increasing cost and limiting development of local expertise. Training and certification programmes for IBS applications in bridge construction are also not available so there is a gap between component design and manufacturing and on-site installation.

Knowledge gaps and resistance to change also restrict IBS implementation (Rahman et al., 2024). For IBS to be successfully adopted it must be accepted and early involved by government agencies, engineers, consultants, contractors, manufacturers and project managers. Some decision-makers do not understand the long-term benefits of IBS lifecycle cost savings, construction efficiency, better quality control and national sustainability objectives; this lack of understanding may lead to uncertainty about costs, risks and technical feasibility of prefabricated bridge systems. IBS is therefore not considered in early planning and design stages where structural systems are decided on, procurement strategies are formulated, component standardisation is made and supply chain arrangements set up.

These persistent constraints show that there is a gap between national support for IBS and its actual application in Malaysian bridge infrastructure. While the potential benefits of IBS are well known, little empirical evidence exists on practitioners' readiness; barriers they encounter and perceived effectiveness of IBS in bridge projects so systematic assessment is needed to find out what main factors drive adoption; how effective current IBS practices are; and whether implementation barriers affect project performance. This evidence will then inform

training, procurement reform, technical standardisation, digital integration and coordinated policy measures for wider application of IBS in Malaysian bridge construction.

Research Objectives and Questions

This study has three objectives. First, it seeks to identify the key factors that hinder the adoption of the Industrialized Building System (IBS) in Malaysian bridge infrastructure projects. Second, it evaluates practitioners' perceptions of the effectiveness of existing IBS methods in bridge construction. Third, it

examines the relationship between the identified implementation barriers and the perceived effectiveness of IBS. Accordingly, the study addresses three main questions: What are the most significant barriers to IBS adoption? How do construction practitioners evaluate the performance and effectiveness of IBS? Is there a significant relationship between implementation barriers and IBS performance outcomes?

The study is guided by two hypotheses. The null hypothesis proposes that there is no significant relationship between barriers to IBS adoption and the effectiveness of IBS in bridge infrastructure projects. In contrast, the alternative hypothesis proposes that a significant relationship exists between these variables. The conceptual framework identifies policy support, cost, technology, supply-chain coordination and stakeholder readiness as the principal implementation factors. The effectiveness of IBS is evaluated in terms of construction time, quality, structural durability, productivity, safety, sustainability and the overall level of adoption.

Scope and Significance of the Study

This study examined the application and perceived effectiveness of the Industrialized Building System (IBS) in Malaysian bridge infrastructure projects between 2020 and 2025. The investigation focused on public-sector projects involving key government agencies, particularly Jabatan Kerja Raya (JKR) and the Construction Industry Development Board (CIDB) Malaysia. Relevant Malaysian projects, including the Sultan Abdul Halim Muadzam Shah Bridge, also known as the Second Penang Bridge, and the Great Wall Modular Steel Bridge, were used to illustrate the local implementation of IBS and prefabrication practices in government-funded infrastructure projects (CIDB Malaysia, 2022; Rahim et al., 2023).

The respondents were limited to JKR officers directly involved in bridge project delivery, including engineers, assistant engineers, and project managers. This selection ensured that the information collected still relevant to the study objectives and based on professional experience in public infrastructure planning, design, procurement, construction and supervision. JKR personnel were prioritised over representatives from private construction firms for several reasons.

First, JKR is the principal government agency responsible for implementing and managing public infrastructure projects in Malaysia, including bridges. The agency is therefore directly involved in applying national construction policies and strategies, such as the Construction Industry Transformation Programme 2016–2020 and the IBS Roadmap 2021–2025. These initiatives encourage the adoption of IBS in public-sector construction and require relevant projects to comply with the IBS scoring requirements established by CIDB Malaysia (CIDB Malaysia, 2020). In contrast, private construction companies generally adopt IBS only when it is required by the project owner or considered commercially beneficial. Consequently, their involvement in IBS may be limited to particular projects or specific stages of the project lifecycle (Aberi & Zulkifli, 2022).

Second, public-sector projects managed by JKR are subject to established procedures involving audits, standardised reporting, regulatory compliance, and policy evaluation. These requirements provide a more consistent and transparent source of project information for research purposes (Kamar et al., 2022). Private-sector projects, by comparison, may be governed by confidentiality arrangements, non-disclosure agreements, and proprietary construction procedures. Such restrictions can limit researchers' access to detailed technical, contractual, and management information, thereby reducing the depth and reliability of the investigation.

Third, JKR professionals participate directly in strategic decision-making throughout the development of public bridge projects. Their responsibilities may include project initiation, design coordination, material selection, procurement planning, technical evaluation, construction supervision, and the adoption of new technologies.

They are therefore well positioned to provide first-hand information regarding the barriers, drivers, and performance outcomes associated with IBS implementation. Private contractors and subcontractors commonly focus on executing work packages after major strategic and procurement decisions have been made. Although their perspectives remain valuable, they may not fully represent the broader institutional, regulatory and financial considerations that influence IBS adoption in government infrastructure projects.

The selection of JKR professionals consequently enabled the study to obtain focused evidence from respondents with direct knowledge of both project-level implementation and the wider public-sector policy environment. Nevertheless, the findings primarily reflect the perspectives of government practitioners and should not be interpreted as representing all organisations involved in Malaysia's bridge construction industry.

LITERATURE REVIEW

Overview of IBS in Malaysian Bridge Infrastructure

The transition from conventional construction methods to the Industrialized Building System (IBS) has been demonstrated in the construction of the Penang bridges. Although IBS may involve higher initial costs than conventional construction, it can provide substantial long-term benefits. These include shorter construction periods, improved material quality and quality control, reduced dependence on on-site labour, and more efficient use of resources. Collectively, these benefits can enhance overall project efficiency and support more sustainable bridge construction practices (Mohammad et al., 2022).

Malaysian Bridge Applications

The Second Penang Bridge, officially known as the Sultan Abdul Halim Muadzam Shah Bridge, is an important example of sustainable bridge infrastructure in Malaysia. With a total length of approximately 24 km, it is recognised as one of the longest sea-crossing bridges in Southeast Asia. The bridge incorporates several resilience-oriented design features, including provisions for seismic and tsunami-related risks. High-damping rubber bearings were also installed as part of the seismic-isolation system to reduce the transfer of earthquake-induced forces to the bridge structure. These design considerations enhance the bridge's structural durability, resilience, and long-term performance while demonstrating how appropriate construction methods and material selection can contribute to more sustainable infrastructure development (Zainuddin et al., 2022).

Regional Implications of IBS Adoption

Research conducted in Selangor indicates that the adoption of the Industrialized Building System (IBS) can provide important benefits for infrastructure projects. IBS can shorten construction and project-management periods, reduce the amount of work undertaken on-site, and improve overall productivity and project-delivery efficiency. However, successful implementation depends heavily on effective project management, supportive government policies, appropriate financial incentives, and sustained institutional commitment (Lee & Nasir, 2023).

Barriers and Challenges

Although the potential benefits of the Industrialized Building System (IBS) are widely recognised, several barriers continue to restrict its broader adoption in Malaysia. The most prominent challenges include high initial investment costs, limited stakeholder knowledge and practical experience, inadequate contractor capability and weak coordination among manufacturers, transporters, suppliers and on-site construction teams. These challenges are particularly significant in bridge projects because prefabricated components are generally large, heavy and technically complex, requiring specialised production facilities, transportation arrangements and installation expertise.

Successful IBS implementation therefore requires more than technological availability. It also depends on appropriate government policies, effective enforcement, financial incentives, stakeholder education, professional training and an integrated supply chain. Policies should encourage early collaboration among designers, contractors, manufacturers, suppliers, and transport operators. Training and capacity-building programmes are

also necessary to improve technical knowledge and reduce resistance to unfamiliar construction practices. Strengthening these areas could create a more supportive environment for the wider adoption of IBS in Malaysian bridge construction (Yusof et al., 2023). Table 1 shows key factors hindering IBS adoption in Malaysian bridge infrastructure.

Table 1: Key Factors Hindering IBS Adoption in Malaysian Bridge Infrastructure

Key hindering factor	Description	Source
High initial cost	IBS requires substantial upfront investment in prefabrication facilities, component moulds, specialised equipment, transportation, and logistics.	Tan and Hamzah (2023)
Lack of skilled personnel	The industry has an insufficient number of technicians and construction personnel trained in IBS technologies, component production, and installation procedures.	Noor and Ahmad (2023)
Limited contractor experience	Many contractors lack the technical knowledge and practical experience required to manage IBS-based bridge projects effectively.	Zulkifli and Latiff (2022)
Fragmented supply chain	Poor coordination among manufacturers, suppliers, transporters, contractors, and on-site teams can cause delays and installation difficulties.	Zulkarmain and Hassan (2023)
Resistance to change	Some stakeholders prefer conventional methods because these practices are familiar and are perceived to provide greater flexibility during construction.	Sulaiman and Ibrahim (2023)
Insufficient awareness and training	Limited understanding of IBS benefits and inadequate technical training restrict stakeholders' ability and willingness to implement the system.	Noor and Ahmad (2023)
Weak policy enforcement	Although IBS-related policies exist, implementation may be affected by limited enforcement, inconsistent compliance, and insufficient financial incentives.	Lee and Nasir (2023)
Design limitations	Standardised IBS components may not provide the flexibility required for complex, curved, or project-specific bridge configurations.	Cheng and Tang (2023)

Technological Integration

Technological Integration in IBS (Building Information Modelling (BIM), Internet of Things (IoT), Augmented Reality/Virtual Reality (AR/VR), Drones and Radio Frequency Identification (RFID) With continuing change in technology, digital transformation will continue to be relevant in improving efficiency and project quality relating to the efficiency of IBS projects. There are many emerging technologies such as BIM, IoT, and drones being embraced within the IBS process.

Global Benchmarks and Institutional Implications

The literature increasingly views the Industrialized Building System (IBS) as an appropriate response to the problems of conventional bridge construction: standardisation, automation, off-site manufacturing and prefabrication can improve construction efficiency, quality, safety and environmental performance. In Malaysia IBS has been given a lot of policy support (promotion under Eleventh Malaysia Plan); however, its use in bridge projects is still limited because of technical barriers, lack of institutional support, stakeholder resistance and shortage of appropriately skilled personnel. International case studies from the US, Japan, China and India are useful benchmarks for Malaysia show in Table 2. In those countries prefabricated bridge elements were used; accelerated bridge construction can apply; modular systems and advanced manufacturing methods were employed to shorten construction times, minimise traffic disruption, control quality better and make structures more resilient. International experience shows that IBS implementation is successful when clear technical standards are in place; supply chains established; skilled personnel available; coordination effective and government support sustained. These international practices can be used to develop more appropriate strategies

for overcoming barriers to IBS adoption in Malaysian bridge construction (World Bank, 2023; Zhang et al., 2024).

The Penang bridge projects and Geosynthetic Reinforced Soil Integrated Bridge Systems (GRS-IBS) in Malaysia are also case studies where industrialised and prefabricated construction methods have been shown to work. Productivity benefits, more consistent quality of construction, shorter project durations, fewer on-site activities and greater resistance to settlement or seismic effects were reported as benefits. These examples show that IBS can have practical benefit for complex bridge infrastructure when planned and implemented properly. However, the move from isolated applications to routine industry wide adoption is hampered by high initial investment costs; lack of awareness among stakeholders; lack of technical expertise and coordination between designers, contractors, manufacturers transporters and suppliers. Comparing Malaysian practices with international ones thus shows that technological capability alone is not enough: wider adoption also requires supportive policies, standardised bridge components, professional training, integrated procurement arrangements and stronger collaboration throughout project lifecycle.

Table 2: International Applications of Prefabricated Bridge Systems

Country	Example	Approach	Principal benefit	Key constraint
Malaysia	Penang Second Bridge; modular steel bridges	Precast and modular components	Reduced site work and improved safety	Capital cost and limited skills
United States	Accelerated bridge replacement	PBES/ABC	Rapid replacement and reduced traffic disruption	Transport coordination
Japan	Expressway viaducts	Precast segmental systems	Quality and seismic resilience	High mould cost
Sweden	Rural eco-bridges	Eco-prefabricated panels	Low carbon and high precision	Seasonal and labour constraints
India	Delhi Metro viaducts	Precast concrete segments	Urban efficiency and repeatability	Standardization and training
Singapore	MRT and urban renewal	Modular systems integrated with BIM	Design coordination and low site labour	High coordination requirements
China	High-speed rail viaducts	Precast box girders and slabs	Rapid large-scale delivery	Quality control at scale

METHODOLOGY

Research Design

This study used quantitative research method to investigate IBS implementation in Malaysian bridge infrastructure projects. Three research objectives were established: (1) barriers to adoption of IBS in bridge projects; (2) practitioners' perceptions of current IBS practices effectiveness and (3) relationship between implementation barriers and IBS effectiveness. The findings were then used to develop recommendations for improving IBS adoption in Malaysian bridge infrastructure. The study started with literature review on IBS implementation, bridge construction, government policies, technological integration stakeholder readiness and barriers reported in previous studies. Journal articles, conference proceedings, government reports and industry publications were reviewed. The literature provided theoretical base for the study; guided conceptual framework development; informed questionnaire design.

Primary data were collected using a questionnaire administered to construction professionals working on public bridges projects (engineers, assistant engineers and project managers from Jabatan Kerja Raya offices in Northern Peninsular Malaysia). The questionnaire assessed awareness and understanding of IBS; barriers faced

by respondents when implementing IBS; views about effectiveness and willingness to support wider adoption. The completed questionnaires were screened coded and organised in Microsoft Excel then transferred to IBM SPSS Statistics for further analysis. Descriptive statistics (frequencies, percentages, means and standard deviations) were used to summarise profiles and perceptions of respondents; Reliability analysis on questionnaire items was conducted to test internal consistency; Pearson correlation analysis was used to examine relationship between implementation barriers and perceived effectiveness of IBS. The last step is to interpret the statistical results in relation to research objectives and previous literature. Results were used as basis for recommendations on professional training, digital integration, policy support, supply chain coordination, component standardisation and trust among project stakeholders.

Population and Sampling Strategy

This study adopts a quantitative descriptive research design to examine practitioners' perceptions of Industrialized Building System (IBS) adoption in Malaysian bridge infrastructure projects. The target population comprises approximately 100 Jabatan Kerja Raya (JKR) professionals in Perlis, Kedah, Penang and Perak. JKR is the government agency responsible for planning, designing, procuring, constructing and supervising public infrastructure projects. Its personnel therefore provide relevant perspectives on IBS implementation in public bridge projects. Purposive sampling is employed to select engineers, assistant engineers and project managers with relevant bridge infrastructure experience and knowledge of IBS. The inclusion criteria comprise employment in JKR offices within the four northern states and relevant experience or knowledge of bridge planning, design, management or supervision involving IBS. Personnel outside this geographical and professional scope are excluded from the intended respondent group.

For a population of 100, the sample-size table developed by Krejcie and Morgan (1970) suggests a sample of 80 respondents. This figure serves as a recruitment benchmark because the study employs purposive rather than probability sampling. A total of 82 questionnaires were distributed to 28 JKR offices through face-to-face distribution and Google Forms. Responses were received from 24 offices, while four offices did not return any questionnaires. Of the 82 questionnaires distributed, 72 were returned and 10 were not returned, yielding a response rate of 87.8% ($72/82 \times 100$). All 72 returned questionnaires were complete and valid and were retained for analysis. No returned questionnaires were excluded. The final analytical sample therefore comprised 72 respondents, which is below the recruitment target of 80. The geographical scope is restricted to northern Peninsular Malaysia. The selection of JKR professionals provides an institutional perspective on the technical and managerial conditions affecting IBS adoption in public bridge projects. However, the findings reflect the views of the participating practitioners and should not be generalised to all JKR personnel or the wider Malaysian construction industry.

Pilot Study and Instrument Refinement

The researcher carried out a pilot study with seven participants from the target population to test the clarity, organisation, technical relevance and time taken for completion of the questionnaire. All respondents worked at Jabatan Kerja Raya (JKR) and had relevant experience in bridge infrastructure projects as well as knowledge of IBS. The pilot study was conducted to test whether the questionnaire was suitable for full scale data collection. Pilot testing is important in quantitative construction research because it tells whether respondents understand the questions and whether questionnaire items measure the intended variables correctly (Rahman et al., 2023; Noor & Ahmad, 2023). It also allows the researcher to identify weaknesses in wording, structure, sequence, instructions and technical content of the instrument before distributing it to the full sample. Weaknesses can be addressed so that collected data are more valid and reliable. During the pilot study, participants filled out the questionnaire and commented on clarity of questions; logical sequence of sections; relevance of technical terms and time taken to complete it. The researcher reviewed their comments for ambiguous wording, redundant items, unclear instructions and layout problems. Minor changes made readability stronger, logical flow of instrument more robust and that each item was still relevant to research objectives and conceptual framework.

The pilot study showed that the questionnaire had clear instructions, appropriate technical content and a reasonable completion time.

Data Collection and Analysis

Google Forms, Microsoft Excel and IBM SPSS Statistics are used to manage and analyse survey responses. The applications work together in a structured workflow for data collection (screening), coding (descriptive analysis) and inferential analysis (inferential). Google Forms records responses in real time and exports them to Microsoft Excel; this reduces manual data entry errors and keeps responses organised. Rahman et al. (2023) state that online survey tools such as Google Forms can improve data integrity, reduce missing responses and make it easier to transfer data into statistical software. After data collection, the researcher transfers the responses into Microsoft Excel. The researcher checks for incomplete, duplicate and inconsistent responses in the dataset; codes questionnaire items with numerical codes; Excel allows preliminary calculations of frequencies, percentages and mean values which can be used to examine respondents' demographics and initial response patterns. Zulkifli and Latiff (2022) state that accuracy of data is important before advanced statistical analyses are performed.

The researcher then imports the cleaned dataset into IBM SPSS Statistics, Version 24 for descriptive and inferential analyses. SPSS produces frequencies, percentages, mean scores, standard deviations, reliability coefficients, cross-tabulations and correlation coefficients. These analyses enable the researcher to study relationships between awareness, policy support, cost, technology, supply chain coordination, stakeholder readiness, IBS implementation and perceived effectiveness of bridge infrastructure projects.

Descriptive statistics summarise respondents' perceptions and overall response trends. Mean scores and standard deviations rank IBS implementation barriers and effectiveness indicators; cross-tabulations allow comparisons by professional position, years of experience, bridge projects undertaken and exposure to IBS. Noor and Ahmad (2023) say that descriptive statistics and cross-tabulations can help identify patterns in IBS awareness, experience and implementation. Table 3 show the alignment of questionnaire sections with study constructs.

Table 3: Alignment of Questionnaire Sections with Study Constructs

Section	Focus	Items	Role in analysis
A	Respondent demographics	5	Context and subgroup description
B	Awareness and understanding of IBS	10	Independent-variable indicators
C	Barriers to IBS adoption	11	Independent-variable indicators
D	Effectiveness of IBS	10	Dependent-variable indicators
E	Recommendations and willingness	6	Adoption support and future action

RESULTS AND DISCUSSION

Data Cleaning and Response Profile

The researcher checked the survey responses for incomplete, duplicate and inconsistent entries. Only complete valid questionnaires were considered for analysis. After cleaning up the dataset had 72 valid responses in it. The researcher imported the verified dataset into IBM SPSS Statistics, Version 26 and computed descriptive statistics (mean values). Responses were analysed on policy response patterns, cost, technology and stakeholder readiness and IBS implementation effectiveness in bridge construction projects (variables consistent with objectives of study and conceptual framework). Data cleaning reduces entry errors and increases the accuracy of quantitative findings (Rahman et al., 2023). Data quality also strengthens reliability in construction research (Zulkifli & Latiff, 2022). The researcher mapped each survey item to its variable in the conceptual framework. This mapping shows how the questionnaire addresses policy, cost, technology, stakeholder readiness and IBS effectiveness.

Respondent Characteristics

In this section we present data on the demographic background of the 72 valid respondents in the study. Respondents were professionals from JKR in northern states (Perlis, Kedah, Penang and Perak) so that the data

represent those who worked on bridge infrastructure projects and knew about IBS. The results of the descriptive analysis in this section are shown in Table 4 which shows respondents' demographic characteristics regarding their current role, years of experience, as reported most respondents were engineers or assistant engineers with a mean value of 1.60. That is to say most of the respondents were technically involved with a bridge project (planning, design or supervision). This representation is important because they are mostly responsible for stakeholder readiness and technology adoption. Noor and Ahmad (2023) stated that knowing a respondent's role is important as it helps to get a more accurate picture of competence (how ready they are to use technology in public sector construction). Years of experience: the mean (3.25) indicates that most respondents had 6–10 years of experience in industry which is sufficient technical skill and knowledge of challenges with implementation IBS; respondents with this level of expertise have stronger credibility about cost implications and effectiveness of policies (Yusof et al., 2024). Experienced practitioners provide valuable knowledge when barriers and enablers of IBS are being evaluated in infrastructure projects (Yusof et al., 2024).

In addition to the above data from Table 4 showed that most respondents were involved in IBS related bridge projects in the recent past (mean = 1.32). This way a reviewer can be confident (that is, the actual input came from people who had experience with application of IBS) that the data capture practices reflected the real means of those in the industry. Their input is particularly important when we want to understand how policy and technology affect implementation effectiveness of IBS.

Table 4: Demographic Profile of Respondents (N = 72)

Measure	Minimum	Maximum	Mean	Std. deviation
Current role	1	4	1.5972	0.64261
Years of construction experience	1	4	3.25	0.94571
Involvement in bridge projects	1	2	1.3194	0.46953
JKR department/division	1	4	2.0278	0.58073
Experience with IBS components/methods	1	3	2.25	0.80053

Assumption and Reliability Testing

Before performing both descriptive and correlational analysis, a number of assumption tests were performed on the dataset so that all of the fundamental statistical requirements were met in order to make valid interpretations of the data. The assumption that was primarily assessed for this study was whether or not the distribution of the data was normally distributed because every item from the questionnaire was scored using a Likert scale therefore all items will be analyzed through correlation analysis. The normality of the distribution was assessed using statistical tests as well as descriptive means (the descriptive statistics reported in Table 5 moved to Appendix A due to its length). Clearly there were several items that did not have a normal distribution. Several items also had very high skewness and kurtosis which are indicators of extreme deviation from bell-curve that would typically be found with normally distributed data.

Table 5: Overall Reliability Statistics

Valid cases	Excluded cases	Cronbach's alpha	Number of items
72	0	0.732	37

Awareness and understanding of IBS

Awareness and understanding of IBS In Section B the results further about the respondents' awareness, knowledge and understanding of IBS with respect to bridge projects. When viewing the descriptive analysis, the results are consistent; Jabatan Kerja Raya respondents have very strong theoretical awareness of IBS but still no structured learning/training, certification or experience. Table 6 shown the summary of awareness and understanding of IBS shows average ratings for items B7 (Mean = 4.25), B9 (Mean = 4.23) and B10 (Mean =

4.26) which are highest in this section these mean values indicate respondents strongly believe IBS improves coordination, construction quality, shorten project time frames. The three highest ranking items in Table 6

show that JKR personnel have a positive view of the perceived benefits of IBS although they have no experience with IBS products in general. Such high level of agreement across all three items is very strong evidence that national promotion of IBS by CIDB (directives from JKR, presentations at industry events and discussions among construction professionals) has successfully shaped JKR personnel's theoretical understanding of are a positive way to create an improved product. This finding is supported by Norazman et al. (2022) and Yusof and Ahmad (2024) who concluded that government engineers even though they have no experience working with IBS products have pretty good understanding of IBS strategic value to Malaysian construction industry.

There seems to be a huge difference between respondents' conceptual awareness and their practical preparedness for Structural and Construction systems using IBS (items B4, B5 and B6). For example, according to means associated with B4 (1.12), B5 (1.15) and B6. (1.52) very few (if any) respondents participated in formal education or training on IBS. The current study shows clearly that while respondents know what IBS is they are generally not operational or technically competent enough to use IBS on bridge projects. This finding concurs with the current literature (Rahman et al., 2023; Noor & Zawawi, 2023) which repeatedly point out inadequate training and lack of hands-on technical experience as barriers to successful use of IBS (especially on infrastructure construction projects rather than commercial building types).

Table 6: Awareness and Understanding of IBS

Item	N	Minimum	Maximum	Mean	Std. deviation
B1	72	1	2	1.0417	0.20123
B2	72	1	5	3.6944	1.00195
B3	72	1	5	3.375	1.2269
B4	72	1	2	1.4444	0.50039
B5	72	1	2	1.125	0.33304
B6	72	1	2	1.5278	0.50273
B7	72	2	5	4.25	0.76453
B8	72	2	5	3.9722	0.80443
B9	72	3	5	4.2361	0.72176
B10	72	2	5	4.2639	0.769

Barriers and Challenges to IBS Implementation

Barriers and Challenges to IBS Implementation Section C shows the respondents' views on the most important barriers that prevent the implementation of IBS in bridge infrastructure projects. Summary of perceived barriers towards IBS show broad consensus among respondents regarding shown in Table 7. The biggest barrier identified by respondents is C1 (Mean=4.10) which means lack of skilled personnel and technical competency are considered one of the most crucial barriers to IBS implementation. The low rate of participation of respondents in training courses, certification and practical workshops related to IBS directly supports this conclusion as mentioned in Section B. Similarities found in both sections mean engineers and technical staff do not have knowledge or ability to implement IBS not because they are not aware but because they don't have hands-on experience with the technology. Recent studies in Malaysia (Rahman et al., 2023; Noor & Zawawi, 2024) show skills gaps remain a barrier for implementing IBS within infrastructure projects.

The Mean value of the second highest barrier (C2 3.97) is high upfront cost and financial limits incurred when IBS (Innovative Building System) project is built. Replies show heavy precast bridge components (beams and decks) use specialized fabricated components, be required to be fabricated with precision and heavy precast components need to be transported since distance between precast manufacturing locations and bridge site is so great that cost of transporting precast components is much more than the cost of components themselves. This is typical for bridge construction projects in northern Malaysia where bridge sites are often far away from precast manufacturing location having a mean of 3.74 and C6 having a mean of 3.71. Again, add-on components used in a bridge construction project need to be standardized but flexible enough to accommodate requirements at the

construction site. Based on previous research studies (2020–2025) on IBS infrastructure projects two logistical challenges distance from production yards to bridge construction sites and fragmented supply chain (and transportation issues) —were identified as two most common barriers to effective execution of IBS infrastructure projects regardless of geographic location of a project.

Also, C3 (Mean = 3.68) and C4 (Mean = 3.74) show respondents are neither “Strongly Agree” or “Strongly Disagree” that policy restrictions or opposition to change are major obstacles to IBS. This implies that Malaysia’s historical commitment to IBS through CIDB guidelines and increased government sponsorship has few policy-related impediments to the adoption of IBS in Malaysia. Therefore, challenges with the adoption of IBS in Malaysia for bridge construction are operational (skill level, expense, digital readiness and efficiency in supply chains).

Table 7: Perceived Barriers to IBS Implementation

Item	N	Minimum	Maximum	Mean	Std. deviation
C1	72	2	5	4.0972	0.75358
C2	72	2	5	3.9722	0.73105
C3	72	2	5	3.6806	0.78411
C4	72	2	5	3.7361	0.91917
C5	72	2	5	3.6667	0.94943
C6	72	2	5	3.7083	0.82969
C7	72	2	5	3.6806	0.85294
C8	72	2	5	3.5556	0.85397
C9	72	1	5	3.6944	1.01591
C10	72	1	5	3.5278	0.97825
C11	72	1	5	3.7361	1.19851

Perceived Effectiveness of IBS

Effectiveness of IBS In Section D, participants perceived that Industrialized Building Systems (IBS) improve the performance of bridge building projects. Overall, as shown in Table 8: Effectiveness of IBS, there were no items rated below the average of 4.00, which suggests participants have a very positive impression of how well IBS enhances project performance once the systems have been implemented properly. Therefore, across various aspects of the system's performance project delivery time; strength of the structures; cost efficiencies; environmental responsibility; and operational sustainability over the long run participants consistently view IBS as having a favorable impact on the projects delivered using IBS. Majority agree that IBS improves the efficiency of delivering a project and reduces the time it takes to complete a project. This reflects the extent to which the respondents understand and appreciate how prefabrication techniques can offer a time savings over traditional construction methods. Particularly in the case of bridge construction, respondents have indicated that prefabricating beam, deck, and pier components off site, such as at the manufacturer’s site, will dramatically reduce the amount of on-site labor required and the potential for delays related to weather. Findings from international prefabrication studies (Omar et al., 2022; Malik & Ibrahim, 2024) are consistent with the finding that IBS can save time in the construction process; this finding also supports the intent of Malaysia’s IBS Roadmap to provide for a shorter time frame between the beginning and the end of the construction of a building by using prefabricated components.

D5 and D4 have similarly high averages (4.32, 4.26, respectively), indicating that the majority of survey respondents were of the opinion that IBS leads to an increase in the quality of construction, durability and structural consistency. In their opinion, enhanced quality in construction is primarily due to the ability to produce components of higher precision in a controlled factory environment, and the resulting decrease in the reliance on manual labor. These findings are consistent with published research that also indicates that prefabrication can provide enhanced long-term structural resilience and increased quality-control standards on a global scale. D6 and D7 also produced an average score of 4.21 and 4.22 respectively. Both of these items indicate that Respondents believe that IBS provides for an increase in worker productivity and an increase in the safety of the jobsites where they work. The data in the research supports the idea that the reduction of extensive jobsite

activities (activities that would typically occur at a construction site) reduces the number of potential safety hazards and allows engineers to concentrate on the inspection and assembly of prefabricated components, rather than the highly complex casting work that is generally associated with constructing a building on-site (Yusof et al., 2024; Rosman, Jabar & Yusof, 2023). This finding also supports the conclusions of research conducted on construction innovations, which consistently identify the use of IBS as a key factor in achieving greater safety outcomes by reducing congestion and exposure to hazardous working conditions.

Table 8: Perceived Effectiveness of IBS

Item	N	Minimum	Maximum	Mean	Std. deviation
D1	72	2	5	4.4167	0.76453
D2	72	2	5	4.138	0.7747
D3	72	2	5	4.097	0.8077
D4	72	2	5	4.263	0.7504
D5	72	2	5	4.319	0.7282
D6	72	2	5	4.208	0.7303
D7	72	2	5	4.222	0.7358
D8	72	2	5	4.194	0.7437
D9	72	2	5	4.138	0.7374
D10	72	2	5	4.138	0.7563

Recommendations and Willingness to Adopt IBS

This section of the report shows how willing respondents are to use IBS in new bridge building and their recommendations on how to increase adoption at a national level. The data points summarised in Table 8 show there is a lot of support for activities supporting adoption of IBS (training, incentives, technology integration). Respondents rated E4 (Mean = 4.61) as highest overall agreement indicating standardising IBS components and guidelines will speed up its use across the whole country. For bridges this is especially important because components need to meet structural and durability requirements (eheavy loads, bad weather). Standardizing IBS components within an entire country is what is now considered best practice worldwide where like type components have national standards to ensure quality and risk mitigation when constructing prefabricated infrastructure (Jamaluddin et al., 2022).

Respondents support both E5 (Mean = 4.51) and E6 (Mean = 4.58). Respondents know supply chain reliability (E5) and technological integration of BIM, AR and IoT (E6) are important facilitators to IBS success. These results correspond with barriers identified in Section C where digital readiness and supply chain coordination have been identified as two biggest barriers to Septentrion Regions. Moderate support for E2 (Mean = 5.00) means that respondents feel Government Incentives (Tax Relief, Grants and Funding Support) would greatly improve/expand IBS availability and usage. This is consistent with Regional IBS strategies which specifically state that Financial Support is one of the key drivers for transitioning to Modern Construction Methods. Respondents do not see personal hesitance; their unwillingness or personal resistance to IBS use as a barrier to adoption. Low scores reflect latter findings in that respondents are not opposed to IBS but rather they are more concerned about ability to get Training, Technology Infrastructure and Practical Competencies. Table 9 show recommendations and willingness.

Table 9: Recommendations and Willingness

Item	N	Minimum	Maximum	Mean	Std. deviation
E1	72	1	3	1.527	0.871
E2	72	1	7	5.000	2.232
E3	72	1	4	1.486	0.888
E4	72	3	5	4.611	0.570

Item	N	Minimum	Maximum	Mean	Std. deviation
E5	72	3	5	4.513	0.627
E6	72	3	5	4.583	0.575

Correlation Analysis: Relationships between IBS Implementation Barriers and Perceived Effectiveness

Objective 3 examined the relationships between IBS implementation barriers and perceived effectiveness in bridge infrastructure. Section C comprised 11 barrier items, while Section D comprised 10 effectiveness items. The Pearson correlation output reported in Appendix C of the thesis was examined for all 110 barrier–effectiveness pairs, using responses from 72 participants. Tables 10 and Table 11 present the correlation coefficients and corresponding two-tailed p-values.

Table 10. Pearson Correlations between Implementation Barriers and Effectiveness Items D1–D5 (N = 72).

Barrier item	D1	D2	D3	D4	D5
C1	0.124 (0.298)	–0.048 (0.691)	0.193 (0.105)	0.004 (0.975)	0.097 (0.420)
C2	–0.029 (0.806)	–0.192 (0.106)	0.005 (0.969)	–0.140 (0.239)	0.043 (0.718)
C3	0.061 (0.613)	–0.042 (0.727)	0.072 (0.548)	–0.094 (0.432)	–0.041 (0.734)
C4	0.058 (0.626)	–0.146 (0.222)	0.149 (0.212)	–0.122 (0.306)	0.023 (0.851)
C5	0.097 (0.418)	–0.128 (0.285)	0.098 (0.413)	0.026 (0.826)	0.095 (0.427)
C6	0.039 (0.746)	–0.177 (0.137)	0.169 (0.156)	–0.033 (0.783)	–0.030 (0.802)
C7	0.099 (0.408)	–0.102 (0.392)	0.087 (0.469)	0.002 (0.990)	0.008 (0.948)
C8	0.093 (0.435)	–0.097 (0.418)	0.166 (0.164)	0.120 (0.317)	0.096 (0.424)
C9	0.184 (0.121)	–0.178 (0.135)	0.140 (0.242)	0.107 (0.370)	0.172 (0.149)
C10	–0.091 (0.447)	–0.210 (0.077)	–0.048 (0.689)	–0.116 (0.333)	–0.102 (0.396)
C11	0.014 (0.906)	–0.081 (0.497)	0.056 (0.640)	–0.062 (0.602)	0.033 (0.781)

Note: Each cell presents Pearson's r, followed by the unadjusted two-tailed p-value in parentheses.

Table 11. Pearson Correlations between Implementation Barriers and Effectiveness Items D6–D10 (N = 72).

Barrier item	D6	D7	D8	D9	D10
C1	0.091 (0.449)	0.087 (0.465)	0.041 (0.731)	0.077 (0.522)	0.149 (0.212)
C2	–0.068 (0.570)	–0.093 (0.437)	–0.275 (0.019)	–0.071 (0.553)	–0.044 (0.714)
C3	–0.103 (0.387)	–0.119 (0.318)	–0.109 (0.361)	0.005 (0.969)	0.005 (0.969)
C4	–0.022 (0.855)	–0.079 (0.511)	–0.109 (0.361)	0.117 (0.327)	0.114 (0.339)
C5	0.041 (0.735)	0.007 (0.955)	0.033 (0.782)	0.087 (0.467)	0.124 (0.298)
C6	0.009 (0.942)	–0.008 (0.949)	0.048 (0.692)	0.044 (0.713)	0.065 (0.585)
C7	–0.005 (0.969)	0.002 (0.983)	0.010 (0.930)	–0.018 (0.880)	0.048 (0.689)
C8	0.015 (0.900)	0.070 (0.561)	0.094 (0.434)	–0.035 (0.772)	0.184 (0.121)
C9	0.106 (0.376)	0.092 (0.442)	0.005 (0.966)	0.189 (0.112)	0.276 (0.019)
C10	–0.097 (0.418)	–0.067 (0.574)	–0.085 (0.478)	–0.201 (0.091)	0.052 (0.666)
C11	–0.001 (0.996)	0.020 (0.871)	–0.068 (0.570)	–0.069 (0.562)	0.103 (0.389)

Note: Each cell presents Pearson's r, followed by the unadjusted two-tailed p-value in parentheses. Bold values indicate $p < 0.05$ before adjustment for multiple comparisons. No relationship meets the Bonferroni-adjusted threshold of $0.05/110 = 0.000455$.

The barrier effectiveness coefficients ranged from –0.275 to 0.276. At the unadjusted significance level of 0.05, two relationships were statistically significant. C2 was negatively associated with D8 ($r = -0.275$, $p = 0.019$),

whereas C9 was positively associated with D10 ($r = 0.276$, $p = 0.019$). The remaining 108 relationships did not reach the unadjusted significance threshold. Because 110 correlations were examined, a Bonferroni correction was applied to this family of tests to address the risk of false-positive findings. The adjusted significance threshold was 0.000455. Neither of the two initially significant relationships met this threshold. Consequently, none of the individual barrier effectiveness null hypotheses was rejected after adjustment. These results provide insufficient evidence to support H1 through the item-level tests used to address Objective 3. Failure to reject the null hypotheses does not demonstrate that barriers and effectiveness are unrelated; it indicates that the present analysis did not establish statistically significant relationships after accounting for multiple comparisons.

The correlations previously highlighted between B2 and C1 ($r = 0.245$, $p = 0.038$), B2 and C4 ($r = 0.248$, $p = 0.036$), B2 and C8 ($r = 0.316$, $p = 0.007$), and B3 and C1 ($r = 0.265$, $p = 0.025$) concern awareness and implementation barriers. They therefore cannot be used as direct evidence of relationships between implementation barriers and perceived effectiveness. Similarly, B4–D1 was significant only at the unadjusted level ($r = -0.233$, $p = 0.049$), while B6–C2 ($r = 0.117$, $p = 0.327$) and B6–D8 ($r = -0.090$, $p = 0.452$) were not statistically significant. The findings indicate that respondents' recognition of implementation barriers did not consistently correspond with their ratings of IBS effectiveness. Practitioners may perceive IBS as beneficial while also recognising difficulties in its implementation. However, the present correlations do not establish that a particular barrier causes changes in perceived effectiveness. Interpretation is also limited by the use of self-reported responses from the same participants, which introduces the possibility of common-method bias. Table 12 show the guidelines of correlation coefficient.

Table 12: The guidelines of correlation coefficient

Range	0.1-0.29	0.30-0.49	0.50-1.0
Relationship	Small	Medium	Large

Source: Pallant (2013)

Synthesis of Key Findings

Most respondents are aware of IBS concepts and see IBS as beneficial to bridge construction in Malaysia. IBS is generally associated with better quality and safety during construction, faster project completion and less environmental impact. But even though awareness was high, responses on practical experience training and exposure to IBS had lower mean scores. This means there is a gap between awareness of IBS benefits and practitioners' readiness to use IBS in bridge projects. The concerns about skills and industry readiness mentioned by CIDB Malaysia and Rahman, Omar and Azman (2023) are reflected. Correlation analysis showed several statistically significant relationships between implementation barriers and indicators of IBS effectiveness (at 0.05 and 0.01 levels). This means that barriers (e.g., limited training; coordination difficulties; stakeholder resistance) might be associated with project outcomes. The direction and meaning of each relationship depend on wording and coding of questionnaire items; correlations do not prove that these barriers caused poorer outcomes. Taken together, the findings indicate that practical training, project coordination and stakeholder readiness need to be strengthened in order for IBS implementation to take place in Malaysian bridge construction.

CONCLUSION

The findings answer all three research objectives. Objective 1 the study found the main barriers to IBS adoption in bridge construction (limited practical training, insufficient technical exposure, high technology costs, logistics problems, shortage of skilled workers and weak coordination between project participants). Meanwhile, for objective 2 respondents generally considered IBS an effective approach (most effectiveness indicators had mean scores between 3.7 and 4.6), with IBS being associated with faster construction, better quality control, productivity/durability greater than conventional methods, worker safety and more sustainable practices. Objective 3 examined the relationships between IBS implementation barriers and perceived effectiveness. Two item-level relationships were significant before adjustment, but neither remained significant after Bonferroni correction for 110 comparisons. The analysis therefore did not provide sufficient evidence to reject the corresponding null hypotheses after adjustment. These findings do not establish a causal relationship between implementation barriers and perceived IBS effectiveness.

Research Contribution

This study contributes to construction management research by survey evidence on JKR practitioners' awareness of, readiness for and practical experience with IBS methods in publicly funded bridge projects in Malaysia, it shows a gap between practitioners' understanding of IBS benefits and their reported ability to implement IBS in practice. The bridge infrastructure focus extends research that has largely focused on IBS in building projects. The study lists perceived barriers to IBS adoption in bridge construction (limited technical skills; high initial costs; logistics issues; limited digital integration; supply chain problems). Its correlation analysis provides evidence of associations between implementation barriers and indicators of perceived IBS effectiveness. These associations explain how practitioners view the relationship between implementation conditions and project outcomes but not whether the barriers caused changes in efficiency, structural performance or safety. These findings provide JKR and other policymakers with evidence to inform practical training, digital capability development, supply chain coordination and support for IBS uptake in public infrastructure projects.

LIMITATIONS

This study has some limitations. First, respondents were JKR practitioners in Malaysia's Northern Region only. Differences in organisational practices, project types and available resources may limit the extent to which findings apply to JKR offices elsewhere in Malaysia. Second, self-reported questionnaire responses were used. Respondents might have overestimated or underestimated IBS knowledge, practical competence, organisational readiness or barriers they experienced. Third, site observations or bridge project case studies were not included so perceptions of respondents could not be verified against actual IBS implementation practices and project outcomes.

RECOMMENDATIONS

Strategic recommendations for increasing use and effectiveness of IBS in bridge infrastructure projects in Malaysia based on the findings and gap analysis from both empirical findings and literature are: first, training and capacity building (to overcome practitioner readiness low level and skilled worker shortage identified in findings) by creating CPD programmed for engineers, site supervisors and contractors (hands-on workshops and IBS specific certification) according to CIDB recommendation and past researchers' recommendations to fill awareness gap with technical competency.

Secondly, more emphasis will have to be placed on the use of advanced technology and digitalization as advanced digital technologies (e.g., BIM, automation, prefabrication scheduling systems) can improve design coordination quality, reduce errors and optimise fabrication and transportation of IBS components; this is also supported by findings of international best practices that show that through digital integration significant increase in efficiency and accuracy of IBS processes can be achieved.

Strong policies and regulations supporting IBS implementation are needed because they help create an enabling environment for IBS implementation (updating existing bridge design standards; tax and/or grants to support adoption of IBS; improving procurement frameworks; minimum IBS scores on public infrastructure projects). Literature shows repeatedly that policy reinforcement and institutional support are important factors in speeding up uptake of IBS.

The third recommendation of this study is to develop mutual trust amongst stakeholders (see flowchart and correlation results) since the coordination issues and resistance of stakeholders hinder IBS effectiveness. Early collaborations, clear communication channels, transparent mechanisms for sharing risks and project delivery methods based on partnership among all stakeholders including designers, manufacturers, contractors and governmental agencies have to take place so as to promote relationship of mutual trust. Increasing the level of trust not only reduces delays and conflicts but also increases consistency in decision making at all stages of IBS project cycle. Therefore, collectively the strategies identified in this research will help overcome the barriers identified in this research and create a successful IBS implementation ecosystem in bridge infrastructure of Malaysia.

ACKNOWLEDGEMENT

The authors acknowledge the support of the Construction Industry Development Board, the Industrialized Building System community, the Public Works Department offices in Northern Peninsular Malaysia, engineers, assistant engineers and project managers who contributed to the survey. Appreciation is also extended to the Faculty of Civil Engineering & Technology, Universiti Malaysia Perlis, for academic guidance and institutional support.

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