

Critical Workforce Competencies for Accelerating Industrialised Building System Implementation in Dilapidated Rural School Reconstruction: Evidence from Sarawak, Malaysia

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ABSTRACT

Purpose: This study identifies critical workforce competencies required to accelerate Industrialised Building System (IBS) implementation in dilapidated rural school reconstruction projects in Sarawak, Malaysia, addressing a critical gap in educational infrastructure development.

Design/Methodology/Approach: A comprehensive systematic review of 30 peer-reviewed studies was conducted, examining IBS implementation challenges, workforce competency requirements, and contextual factors specific to rural construction in Malaysia. Evidence was synthesized to develop a multi-tiered competency framework encompassing technical, managerial, digital, and context-specific capabilities.

Findings: Successful IBS-based rural school reconstruction requires four critical competency domains: (1) technical competencies including prefabricated component handling, precision assembly, and quality control; (2) managerial competencies encompassing project coordination, supply chain management, and stakeholder engagement; (3) digital competencies involving Building Information Modeling (BIM), digital fabrication, and data-driven decision-making; and (4) context-specific competencies addressing rural logistics, local material integration, and community engagement. Major barriers include limited IBS knowledge among Sarawak contractors (78% reporting insufficient awareness), critical shortages of skilled installers, inadequate training infrastructure, and logistical challenges in remote areas.

Research Limitations/Implications: The study is based on available literature and may not capture all emerging competency requirements. Future empirical research should validate the framework through field studies in active reconstruction projects.

Practical Implications: The competency framework provides actionable guidance for government agencies, educational institutions, and construction firms to develop targeted training programs, establish industry-academia partnerships, and implement policy interventions that build sustainable local capacity for IBS-based school reconstruction.

Originality/Value: This is the first comprehensive study to systematically identify workforce competencies specifically for IBS implementation in Sarawak rural school reconstruction, addressing the unique intersection of industrialized construction, educational infrastructure, and rural development contexts in Malaysia.

Keywords: Industrialised Building System; IBS; workforce competencies; rural school reconstruction; construction education; Sarawak; prefabricated construction; infrastructure development; skill development; construction workforce

INTRODUCTION

The reconstruction of dilapidated rural schools represents one of Malaysia's most pressing educational infrastructure challenges, particularly in the state of Sarawak where geographical remoteness, limited accessibility, and resource constraints compound the complexity of traditional construction approaches

(Mohammad Shamsudin, 2021) (Wan Ahmad, 2025a). The Ministry of Education (MoE) has identified approximately 830 dilapidated schools nationwide requiring urgent reconstruction or major rehabilitation (Ruzki, 2023). In Malaysia, the disparity between urban and rural educational infrastructure is most acute in the state of Sarawak, where a significant stock of schools has been categorized as "dilapidated" (Scale 6 and 7) by the Public Works Department JKR (MoE, 2023). A significant concentration of dilapidated schools situated in rural areas of East Malaysia (Mohd Bohari, Mahat, & Kipli, 2011). These deteriorating facilities directly impact educational quality, student safety, and learning outcomes, creating an imperative for rapid, cost-effective, and sustainable reconstruction solutions (Wan Ahmad, 2025a).

The Industrialised Building System (IBS) has emerged as a strategic solution to accelerate rural school reconstruction while addressing the inherent limitations of conventional construction methods in remote locations (Izatul Laili, Faridah, Abdul Rashid, & Nur Mardhiyah, 2014). IBS, characterized by the off-site prefabrication of building components and their subsequent on-site assembly, offers substantial advantages including reduced construction time (30-50% faster than conventional methods), improved quality control through factory-based manufacturing, minimized on-site labor requirements, reduced material waste, and enhanced safety performance (Rashidi & Ibrahim, 2017), (Asmah Alia, Kumalasari, & Noorsaidi, 2012). These benefits are particularly relevant for rural school projects where skilled labor shortages, logistical challenges, and time constraints are acute.

However, despite strong governmental support and policy incentives, IBS adoption in Malaysia remains below targeted levels, with implementation rates hovering around 70% of government-set goals (Abd Rahman & Omar, 2006). This implementation gap is especially pronounced in rural contexts and among small-to-medium enterprises (SMEs) that dominate Sarawak's construction sector (Wan Muhammad, et al., 2016). Research consistently identifies workforce competency deficiencies as a primary barrier to successful IBS implementation, encompassing inadequate technical skills, limited knowledge of IBS design and manufacturing processes, insufficient managerial capabilities, and lack of exposure to industrialized construction methods (Ayeop Abdul Khalil, Abd Aziz, Hassim, & Jaafar, 2016), (Tazifuzin & Dani, 2024), (Sing Wong & Kung Lau, 2015).

In Sarawak specifically, the challenge is compounded by unique contextual factors including geographical isolation of project sites, limited access to specialized training facilities, a predominantly SME-based contractor pool with minimal IBS experience, logistical complexities in transporting prefabricated components to remote locations, and the need to integrate modern construction methods with local building practices and community expectations (Hadi, Muhamad, & Othman, 2017). The successful reconstruction of rural schools using IBS therefore requires not only technical proficiency but also a comprehensive set of competencies that address these multifaceted challenges (Wan Ahmad, 2026).

Research Objectives

This study addresses the critical question: What workforce competencies are essential for accelerating IBS-based reconstruction of dilapidated rural schools in Sarawak?

Specifically, the research objectives are:

1. To identify and categorize critical workforce competencies required for successful IBS implementation in rural school reconstruction projects
2. To examine the current state of IBS workforce competencies among construction professionals in Sarawak
3. To analyze barriers and challenges that impede workforce competency development for IBS-based rural construction
4. To propose a strategic framework for workforce development that addresses identified competency gaps and contextual constraints

Significance of the Study

This research contributes to both academic knowledge and practical application in several ways. First, it addresses a significant gap in the literature by focusing specifically on workforce competencies for IBS implementation in rural educational infrastructure, a context that has received limited scholarly attention despite its policy importance. Second, it provides evidence-based guidance for government agencies, educational institutions, and industry stakeholders to develop targeted training programs and capacity-building initiatives. Third, it offers insights into the unique challenges of implementing industrialized construction methods in rural contexts, contributing to broader discussions of construction innovation diffusion and technology adoption in developing regions. Finally, the findings have direct implications for achieving Malaysia's educational infrastructure development goals and the United Nations Sustainable Development (SDGs) Goal 4 (Quality Education) by enabling faster, more efficient school reconstruction.

Structure of the Paper

The remainder of this paper is organized as follows, Section 2 reviews the theoretical foundations and background literature on IBS in Malaysia, rural school infrastructure challenges, and workforce competency frameworks. Section 3 describes the research methodology. Section 4 presents the current state of IBS workforce competencies in Sarawak. Section 5 identifies and analyzes critical workforce competencies across four domains. Section 6 examines implementation barriers and challenges. Section 7 proposes a strategic framework for workforce development. Section 8 discusses implications and recommendations. Section 9 concludes with key findings and future research directions.

LITERATURE REVIEW AND THEORETICAL FOUNDATIONS

The IBS Paradigm in Malaysian Construction

The Industrialised Building System represents a fundamental shift from traditional on-site construction to a manufacturing-oriented approach characterized by standardization, prefabrication, and systematic assembly processes (Alawag, et al., 2021). In the Malaysian context, IBS is officially defined by the Construction Industry Development Board (CIDB) as "a construction technique in which components are manufactured in a controlled environment (on or off site), transported, positioned and assembled into a structure with minimal additional site work" (Buyung & Ghani, 2014). The Malaysian government has actively promoted IBS adoption since the 1960s, with intensified policy support following the Industrialised Building System Roadmap 2003-2010 and subsequent strategic plans (Gin, Ilham, & Arputhan, 2021).

IBS encompasses five primary system categories: (1) precast concrete framing, panel, and box systems; (2) steel framing and formwork systems; (3) steel framing systems; (4) prefabricated timber framing systems; and (5) block work systems (Mohammed, 2016). Each system offers distinct advantages and is suited to different project types, scales, and contexts. For rural school construction, precast concrete panel systems and steel framing systems are most commonly specified due to their balance of structural performance, cost-effectiveness, and transportability (Wan Ahmad, Analysis of Delay Factors in Rural Development Projects Utilizing the Industrialized Building System (IBS) in Malaysia: A Review, 2025b).

The theoretical advantages of IBS are well-documented in the literature. Lou et al. (Lou & Kamar, 2012) identified key benefits including 30-50% reduction in construction time, 15-30% reduction in overall project costs through economies of scale, 50-70% reduction in on-site labor requirements, 80% reduction in construction waste, improved quality control through factory manufacturing conditions, and enhanced worker safety by minimizing hazardous on-site activities. These benefits align closely with the requirements of rural school reconstruction projects where time, cost, labor availability, and quality are critical constraints.

However, the gap between theoretical potential and practical implementation remains substantial. Studies consistently report that actual IBS adoption rates fall short of government targets, with particularly low uptake among SME contractors and in rural projects (A Mohsen, R Yunus, R Handan, Kasim, & Hussain, 2018),

(Md.Ali, Abas, Mohd Affandi, & Abas, 2018). This implementation gap has prompted extensive research into barriers and enablers of IBS adoption, with workforce competency emerging as a critical factor.

Rural School Infrastructure Crisis in Sarawak

Sarawak, Malaysia's largest state by area, faces unique educational infrastructure challenges stemming from its vast geography (124,450 km²), dispersed population, and significant proportion of rural and remote communities (Mohammad Shamsudin, 2021). The state's school infrastructure includes numerous aging facilities constructed decades ago using conventional methods, many of which have deteriorated to the point of requiring complete reconstruction rather than renovation. These dilapidated schools are characterized by structural deficiencies, inadequate facilities, poor environmental conditions, and safety hazards that directly compromise educational quality and student wellbeing (Wan Ahmad, 2025a).

The Malaysian government's commitment to reconstructing dilapidated schools is reflected in substantial budget allocations under successive Malaysia Plans, with specific emphasis on rural areas in East Malaysia (Wan Ahmad, 2026). However, conventional construction approaches face severe limitations in rural Sarawak contexts including limited availability of skilled construction workers in remote areas, high transportation costs for materials and equipment, extended project durations due to logistical challenges, difficulty in maintaining quality control with limited supervision, and seasonal disruptions from weather conditions and accessibility issues (Hadi, Muhamad, & Othman, 2017).

IBS offers a compelling solution to these challenges by enabling off-site component manufacturing in controlled factory environments, reducing on-site construction time and labor requirements, improving quality consistency through standardized production, minimizing weather-related delays, and potentially reducing overall project costs through efficiency gains (Rashidi & Ibrahim, 2017) (Rashidi & Ibrahim, 2017). However, successful IBS implementation in rural school reconstruction requires not only appropriate technology selection but also a workforce equipped with the necessary competencies to design, manufacture, transport, and assemble prefabricated components in challenging rural contexts.

Workforce Competency Frameworks for IBS Construction

Competency-based approaches to workforce development have gained prominence in construction management research, recognizing that successful project delivery depends on the knowledge, skills, abilities, and behaviors of construction professionals (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019). In the IBS context, competency requirements differ substantially from conventional construction due to the industrialized nature of the process, the precision required in component manufacturing and assembly, the integration of design and manufacturing phases, and the need for sophisticated project coordination (Khor, Tiang, Abdullatef, & Wai, 2021).

Jabar et al. (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019) developed a comprehensive project management competency framework for IBS construction, identifying five key competency clusters, it is technical competencies (understanding of IBS systems, manufacturing processes, and assembly techniques), managerial competencies (project planning, coordination, and control), behavioral competencies (leadership, communication, and teamwork), contextual competencies (understanding of regulatory requirements and industry practices), and digital competencies (proficiency in BIM and digital project management tools). This framework provides a useful foundation for understanding the multidimensional nature of IBS competency requirements.

However, existing competency frameworks have primarily focused on large-scale urban projects and have not adequately addressed the specific requirements of rural construction contexts or educational infrastructure projects. Rural school reconstruction using IBS presents unique competency demands including adaptation of standardized IBS solutions to site-specific constraints, management of complex logistics in remote locations, integration of prefabricated components with local construction practices, engagement with rural communities and stakeholders, and problem-solving in resource-constrained environments (Mohammad Shamsudin, 2021), (Hadi, Muhamad, & Othman, 2017).

Barriers to IBS Workforce Development in Malaysia

The literature identifies multiple barriers to developing adequate IBS workforce competencies in Malaysia. At the knowledge level, studies report widespread lack of awareness and understanding of IBS principles, benefits, and implementation processes among construction professionals (Abd Rahman & Omar, 2006), (Ayeop Abdul Khalil, Abd Aziz, Hassim, & Jaafar, 2016). A survey by Alia et al. found that 78% of contractors in Sarawak had insufficient knowledge of IBS systems, with only 22% reporting adequate understanding of IBS design and construction processes (Alia, Mahat, & Kipli, 2012).

At the skills level, critical shortages of trained IBS installers and technicians represent a major constraint (Buyung & Ghani, 2014), researchers documented that Malaysia faces a severe deficit of skilled component installers, with existing training programs producing insufficient numbers of qualified workers to meet industry demand. This skills gap is particularly acute in rural areas where access to training facilities and experienced mentors is limited (Hadi, Muhamad, & Othman, 2017)].

At the organizational level, limited investment in workforce training and development by construction firms, particularly SMEs, perpetuates competency deficiencies (Wan Muhammad, et al., 2016). Many contractors view IBS training as costly and time-consuming, with uncertain return on investment, leading to underinvestment in human capital development (Md. Razak & H. Awang, 2014).

At the systemic level, inadequate training infrastructure, limited availability of IBS-focused educational programs, and weak industry-academia linkages constrain the pipeline of IBS-competent professionals (Azmi & Salleh, 2024). While some technical and vocational education and training (TVET) institutions offer IBS-related courses, these programs often lack practical components, industry engagement, and alignment with actual project requirements (Azmi & Salleh, 2024).

These multilevel barriers create a self-reinforcing cycle where low IBS adoption limits opportunities for workforce skill development, which in turn constrains future IBS implementation capacity. Breaking this cycle requires comprehensive, coordinated interventions across education, industry, and policy domains.

RESEARCH METHODOLOGY

Research Design

This study employs a systematic literature review methodology to identify, analyze, and synthesize evidence on workforce competencies for IBS implementation in rural school reconstruction. The systematic review approach was selected for its rigor, transparency, and ability to comprehensively synthesize findings across multiple studies to generate evidence-based conclusions (Lim, Selvanathan, & Ilham, 2016).

Literature Search Strategy

A comprehensive literature search was conducted across multiple academic databases including SciSpace Paper Search, SciSpace Full Text Search, and Google Scholar. The search strategy employed combinations of keywords related to three core concepts: (1) Industrialised Building System (IBS, prefabrication, modular construction, off-site construction); (2) workforce competencies (skills, knowledge, training, education, capacity building); and (3) Malaysian construction context (Malaysia, Sarawak, rural construction, school reconstruction). The initial search yielded 201 potentially relevant research papers (Google Scholar, Academia, ScienceDirect, SciSpace). After deduplication and relevance screening, 55 unique papers were retained for detailed review. These papers were then reranked based on relevance to the specific research question regarding workforce competencies for IBS-based rural school reconstruction in Sarawak.

Inclusion and Exclusion Criteria

Papers were included if they met the following criteria:

- a) Focus on IBS, prefabrication, or industrialized construction methods

- b) Address workforce competencies, skills, knowledge, training, or human resource aspects
- c) Relevant to the Malaysian construction context or comparable developing country contexts
- d) Published in peer-reviewed journals, conference proceedings, or reputable academic sources
- e) Available in English or with English abstracts

Papers were excluded if they

- a) Focused solely on technical or engineering aspects without addressing workforce dimensions
- b) Addressed construction contexts fundamentally different from rural school reconstruction
- c) Lacked empirical evidence or theoretical grounding
- d) Not accessible for full-text review

Data Extraction and Analysis

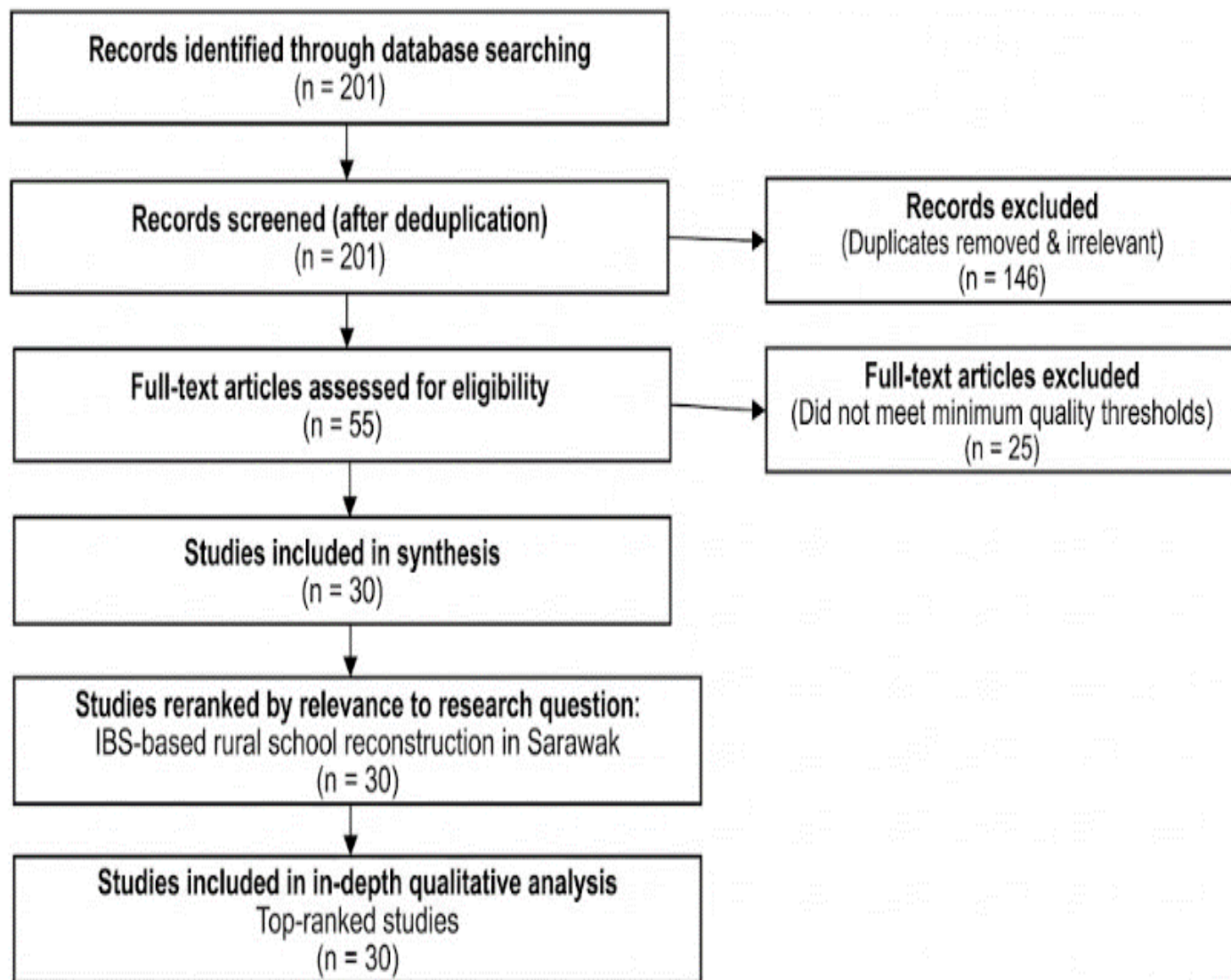
From the 55 papers in the combined dataset, the top 30 most relevant papers were selected for in-depth analysis based on relevance ranking. Data extraction focused on:

- a) Identified workforce competencies and skill requirements for IBS implementation
- b) Barriers and challenges to workforce competency development
- c) Training and education approaches for IBS workforce development
- d) Contextual factors affecting IBS implementation in rural or resource-constrained settings
- e) Strategic recommendations for enhancing workforce capabilities

A thematic synthesis approach was employed to analyze extracted data, identifying recurring themes, patterns, and relationships across studies.

Competencies were categorized into four domains (technical, managerial, digital, and context-specific) based on the nature and application of the competency. Barriers were similarly categorized into workforce-related, systemic, and contextual challenges.

Figure 1: PRISMA diagram for the research by Author



Quality Assessment

The quality and credibility of included studies were assessed based on publication venue (peer-reviewed journals and established conferences), methodological rigor (clearly described research design and data collection methods), relevance to the research question, and contribution to understanding workforce competencies for IBS implementation. The top 30 papers selected for detailed analysis all met minimum quality thresholds for inclusion in the synthesis.

Limitations

This review is subject to several limitations. First, the literature search was limited to English-language publications and specific databases, potentially excluding relevant studies published in other languages or venues. Second, the focus on Malaysian contexts may limit generalizability to other countries or regions, although findings may be transferable to similar developing country contexts.

Third, the rapidly evolving nature of IBS technology and practices means that some findings may reflect historical rather than current conditions. Finally, the review synthesizes existing literature rather than generating new primary data, and is therefore constrained by the scope and quality of available studies.

Current State of IBS Workforce Competencies in Sarawak

Knowledge and Awareness Levels

The current state of IBS knowledge among construction professionals in Sarawak reveals significant deficiencies that constrain implementation capacity. Alia et al. (Alia, Mahat, & Kipli, 2012) conducted a comprehensive survey of contractors in Sarawak and found that 78% reported insufficient knowledge of IBS systems, with only 22% indicating adequate understanding of IBS design principles, manufacturing processes, and construction techniques. This knowledge gap is particularly pronounced among small and medium-sized enterprises (SMEs), which constitute the majority of contractors in Sarawak's construction sector (Wan Muhammad, et al., 2016).

The knowledge deficiency extends beyond basic awareness to encompass deeper understanding of IBS benefits, applications, and implementation requirements. Researchers found that while many Sarawak contractors had heard of IBS, few possessed detailed knowledge of different IBS system types, their respective advantages and limitations, appropriate applications for different project types, or the technical and managerial requirements for successful implementation (Mohd Bohari, Mahat, & Kipli, 2011)(Alia, Mahat, & Kipli, 2012). This superficial awareness without substantive understanding creates a significant barrier to adoption, as contractors lack the knowledge base necessary to make informed decisions about IBS utilization or to effectively plan and execute IBS projects (Abd Rahman & Omar, 2006).

The knowledge gap is particularly acute regarding IBS-specific aspects that differ from conventional construction, including precision requirements in component manufacturing and assembly, tolerance management and quality control procedures, coordination between design, manufacturing, and assembly phases, supply chain management for prefabricated components, and regulatory compliance specific to IBS projects (Ayeop Abdul Khalil, Abd Aziz, Hassim, & Jaafar, 2016). These knowledge deficiencies directly impact project performance, with studies documenting higher rates of errors, rework, and delays in IBS projects executed by contractors with limited IBS knowledge [(Nasir, Alisibramulisi, Abdullah, Jaafar, & Zulkifli, 2021)].

Technical Skills Assessment

At the technical skills level, Malaysia faces a critical shortage of trained IBS installers and technicians capable of executing the precision assembly work required for prefabricated construction (Buyung & Ghani, 2014). (Buyung & Ghani, 2014) documented that the shortage of skilled component installers represents one of the most severe constraints on IBS implementation, with demand for qualified installers far exceeding supply. This skills gap is particularly pronounced in Sarawak and other rural areas where access to specialized training is limited and experienced IBS practitioners are scarce (Hadi, Muhamad, & Othman, 2017).

The technical skills required for IBS construction differ substantially from conventional construction skills. IBS installers must possess capabilities in reading and interpreting detailed assembly drawings and specifications, operating specialized lifting and positioning equipment, executing precision alignment and connection of prefabricated components, implementing quality control procedures specific to prefabricated systems, and troubleshooting and resolving on-site assembly challenges (Mohammed, 2016), [17]. These skills require specialized training and hands-on experience that many construction workers in Sarawak have not had opportunity to develop (Khor, Tiang, Abdullatef, & Wai, 2021).

An appraisal of workforce performance in IBS projects in Perak, Malaysia, and found significant variations in technical competency levels, with workers who had received formal IBS training demonstrating substantially higher performance levels than those who had learned through informal on-the-job experience (Khor, Tiang, Abdullatef, & Wai, 2021). The study identified specific technical skill deficiencies including inadequate understanding of tolerance requirements and precision assembly techniques, limited proficiency in using specialized IBS installation equipment, insufficient knowledge of quality control and inspection procedures, and weak problem-solving capabilities when encountering assembly challenges (Khor, Tiang, Abdullatef, & Wai, 2021).

The technical skills gap is compounded by limited opportunities for skill development in rural areas. Hadi et al. (Hadi, Muhamad, & Othman, 2017) noted that Sarawak's geographical dispersion and limited training infrastructure create barriers to accessing IBS skills training, with most specialized training programs concentrated in urban centers in Peninsular Malaysia. This geographical constraint particularly affects rural contractors and workers who would be involved in rural school reconstruction projects (Hadi, Muhamad, & Othman, 2017).

Managerial and Organizational Capabilities

Beyond technical skills, successful IBS implementation requires sophisticated managerial and organizational capabilities that are often underdeveloped among construction firms in Sarawak. Jabar et al. identified project management competencies as critical for IBS construction, encompassing project planning and scheduling adapted to prefabrication workflows, coordination between design, manufacturing, and assembly phases, supply chain management for prefabricated components, stakeholder management and communication, and risk management specific to IBS projects (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019).

Construction project managers in Malaysia and found significant gaps in IBS-specific project management competencies. Many project managers lacked understanding of the unique planning and coordination requirements of IBS projects, including the need for early design finalization, precise scheduling of component manufacturing and delivery, and tight coordination between off-site and on-site activities (Izatul laili, Faridah, Abdul Rashid, & Nur Mardhiyah, 2014). These managerial deficiencies contribute to project delays, cost overruns, and quality issues in IBS implementations (Gin, Ilham, & Arputhan, 2021).

The organizational capability challenges are particularly acute among SME contractors in Sarawak. The researchers documented that SMEs often lack the organizational systems, processes, and resources necessary to effectively manage IBS projects, including inadequate project management information systems, limited capacity for supply chain coordination, weak quality management systems, and insufficient financial and human resources to invest in IBS capability development (Sing Wong & Kung Lau, 2015). These organizational limitations create barriers to IBS adoption even when individual technical skills are present (Wan Muhammad, et al., 2016).

Leadership and change management capabilities also emerge as critical but underdeveloped competencies. The transition from conventional to IBS construction requires organizational change, including new workflows, roles, and responsibilities. However, many construction firms lack leaders with the vision, commitment, and change management skills necessary to drive this transformation [(Gin, Ilham, & Arputhan, 2021)], (Lim, Selvanathan, & Ilham, 2016). This leadership gap is particularly evident in rural contexts where construction practices are deeply rooted in traditional methods and resistance to change is strong (Hadi, Muhamad, & Othman, 2017).

Critical Workforce Competencies for IBS-Based School Redevelopment

a) Technical Competencies

Technical competencies form the foundation of successful IBS implementation, encompassing the specialized knowledge and skills required to design, manufacture, transport, and assemble prefabricated building components. Based on the synthesis of literature, five critical technical competency clusters emerge as essential for IBS-based rural school reconstruction.

b) IBS System Knowledge and Design Competencies

Fundamental understanding of IBS systems, principles, and design requirements is essential for all professionals involved in IBS projects (Abas, Hanafi, & Aswad Ibrahim, 2013). This includes comprehensive knowledge of different IBS system types (precast concrete, steel framing, modular systems) and their respective characteristics, advantages, and limitations; design principles specific to prefabricated construction including modularity, Standardization, and design for Manufacturing and Assembly (DfMA); structural behavior and performance

characteristics of IBS systems; and integration of building services and finishes within prefabricated components (Alawag, et al., 2021), (Abdullah & Egbu, 2010).

For rural school projects specifically, design competencies must extend to adaptation of standardized IBS solutions to site-specific constraints, integration of educational facility requirements (classrooms, laboratories, administrative spaces) within IBS frameworks, and consideration of local climatic conditions, cultural preferences, and community needs in design decisions (Mohammad Shamsudin, 2021). Abas et al. (Abas, Hanafi, & Aswad Ibrahim, 2013) emphasized that architectural firms involved in IBS projects require enhanced competencies in modular coordination, dimensional standardization, and design optimization for prefabrication—competencies that differ from conventional architectural practice.

c) Manufacturing and Quality Control Competencies

Understanding of IBS component manufacturing processes and quality control procedures is critical for ensuring component quality and project success (Nasir, Alisibramulisi, Abdullah, Jaafar, & Zulkifli, 2021). Key competencies include knowledge of prefabrication manufacturing processes, equipment, and quality standards; understanding of material properties, specifications, and quality requirements for prefabricated components; proficiency in quality control and inspection procedures throughout the manufacturing process; and ability to identify and address manufacturing defects and non-conformances (Buyung & Ghani, 2014), (Mohammed, 2016).

Researchers documented that workmanship performance in IBS projects is directly linked to understanding of manufacturing quality requirements and procedures. Workers and supervisors who lack this understanding are more likely to produce or accept substandard components, leading to downstream assembly problems and performance issues (Nasir, Alisibramulisi, Abdullah, Jaafar, & Zulkifli, 2021). For rural school projects where component replacement is logistically challenging and costly, manufacturing quality control competencies are particularly critical (Hadi, Muhamad, & Othman, 2017).

d) Component Handling, Transportation, and Logistics Competencies

The transportation and handling of prefabricated components require specialized knowledge and skills, particularly for rural projects where transportation distances are long and site access may be challenging (Hadi, Muhamad, & Othman, 2017). Critical competencies include understanding of safe lifting, handling, and transportation procedures for prefabricated components; knowledge of equipment requirements and capabilities for component handling (cranes, trucks, lifting gear); ability to plan and coordinate component delivery schedules aligned with site readiness and assembly sequences; and problem-solving skills for addressing transportation and access challenges in rural contexts (A Mohsen, R Yunus, R Handan, Kasim, & Hussain, 2018).

Hadi et al. (Hadi, Muhamad, & Othman, 2017) identified logistics management as a particularly critical competency for IBS implementation in Sarawak, where rural project sites may be accessible only by river transport or unpaved roads, and where component delivery must be carefully coordinated with limited on-site storage capacity. These logistical challenges require competencies that extend beyond conventional construction logistics to encompass specialized knowledge of prefabricated component handling and rural transportation constraints (Hadi, Muhamad, & Othman, 2017).

e) Precision Assembly and Installation Competencies

The on-site assembly of prefabricated components demands high levels of precision and technical skill (Buyung & Ghani, 2014), (Khor, Tiang, Abdullatef, & Wai, 2021). Essential competencies include ability to read and interpret detailed assembly drawings, specifications, and tolerances; proficiency in using specialized installation equipment (cranes, alignment tools, connection systems); skills in precision positioning, alignment, and connection of prefabricated components; understanding of tolerance requirements and ability to achieve specified dimensional accuracy; and knowledge of temporary works and support systems required during assembly (Mohammed, 2016), (A. Mohsen, R. Yunus, R. Handan, Kasim, & Hussain, 2018).

The skilled component installers are the most critical human resource for IBS projects, yet represent the most severe shortage in Malaysia's construction workforce (Buyung & Ghani, 2014). The precision requirements of IBS assembly—often requiring tolerances of $\pm 5\text{mm}$ or less—demand skill levels substantially higher than conventional construction, necessitating specialized training and experience (Buyung & Ghani, 2014). For rural school projects, these precision assembly competencies must be combined with adaptability to work in resource-constrained environments with limited access to specialized equipment or technical support (Mohammad Shamsudin, 2021).

a) Quality Assurance and Defect Rectification Competencies

Ensuring quality throughout the IBS construction process requires systematic quality assurance competencies (Nasir, Alisibramulisi, Abdullah, Jaafar, & Zulkifli, 2021). Key capabilities include knowledge of quality standards, specifications, and acceptance criteria for IBS projects; ability to conduct inspections and tests at manufacturing, delivery, and assembly stages; skills in identifying defects, non-conformances, and performance issues; and competency in implementing corrective actions and defect rectification procedures (Khor, Tiang, Abdullatef, & Wai, 2021).

The researchers (Khor, Tiang, Abdullatef, & Wai, 2021) found that workforce performance in IBS projects is significantly enhanced when workers possess strong quality assurance competencies, enabling early detection and correction of issues before they escalate into major problems. For rural school projects where access to specialized technical support is limited, on-site quality assurance competencies are particularly important for ensuring that assembled structures meet required performance standards (Hadi, Muhamad, & Othman, 2017).

b) Managerial and Leadership Competencies

Managerial and leadership competencies are essential for coordinating the complex, multi-phase processes involved in IBS projects and for driving organizational adoption of industrialized construction methods (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019).

c) IBS Project Planning and Scheduling Competencies

IBS projects require fundamentally different planning and scheduling approaches compared to conventional construction, necessitating specialized project management competencies (Izatul laili, Faridah, Abdul Rashid, & Nur Mardhiyah, 2014). Critical capabilities include understanding of IBS project workflows and the interdependencies between design, manufacturing, and assembly phases; ability to develop integrated project schedules that coordinate off-site manufacturing with on-site assembly; skills in critical path analysis and schedule optimization for IBS projects; and competency in managing schedule risks and contingencies specific to prefabricated construction (Gin, Ilham, & Arputhan, 2021), (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019).

Researchers found that many construction project managers in Malaysia lack adequate competencies in IBS-specific project planning, leading to scheduling conflicts, delays, and inefficiencies (Izatul laili, Faridah, Abdul Rashid, & Nur Mardhiyah, 2014). For rural school projects, planning competencies must also address logistical constraints, seasonal accessibility issues, and coordination with school operational schedules (Mohammad Shamsudin, 2021).

d) Supply Chain and Procurement Management Competencies

The supply chain for IBS projects is more complex than conventional construction, requiring sophisticated procurement and coordination capabilities (Lou & Kamar, 2012). Essential competencies include understanding of IBS supply chain structures, including manufacturers, suppliers, and logistics providers; ability to evaluate and select appropriate IBS systems and suppliers for specific project requirements; skills in procurement planning, contract management, and supplier coordination; and competency in managing supply chain risks including component delivery delays and quality issues (Alawag, et al., 2021), (Abdullah & Egbu, 2010).

Lou & Kamar (Lou & Kamar, 2012) emphasized that effective supply chain management is critical for realizing the potential benefits of IBS, requiring competencies in supplier relationship management, just-in-time delivery coordination, and supply chain risk mitigation. For rural school projects in Sarawak, supply chain management competencies must address the specific challenges of long transportation distances, limited local supplier availability, and coordination across multiple remote project sites (Hadi, Muhamad, & Othman, 2017).

e) Stakeholder Management and Communication Competencies

IBS projects involve diverse stakeholders with different interests, knowledge levels, and expectations, requiring strong stakeholder management and communication competencies (Lim, Selvanathan, & Ilham, 2016). Key capabilities include ability to identify and engage relevant stakeholders including clients, end-users, regulatory authorities, and communities; skills in communicating IBS concepts, benefits, and requirements to stakeholders with varying levels of technical knowledge; competency in managing stakeholder expectations and addressing concerns about IBS adoption; and ability to facilitate collaboration and coordination among project team members and stakeholders (Gin, Ilham, & Arputhan, 2021).

For rural school reconstruction projects, stakeholder management competencies are particularly critical given the involvement of multiple government agencies, school communities, local leaders, and rural populations who may have limited familiarity with IBS (Mohammad Shamsudin, 2021). Effective communication and engagement can build support for IBS adoption and address potential resistance or misconceptions (Wan Ahmad, 2025b).

f) Risk Management and Problem-Solving Competencies

IBS projects present unique risks that require specialized risk management competencies (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019). Essential capabilities include ability to identify and assess risks specific to IBS projects including design changes, manufacturing defects, transportation delays, and assembly challenges; skills in developing risk mitigation strategies and contingency plans; competency in monitoring and responding to emerging risks throughout project execution; and problem-solving abilities to address unexpected challenges in resource-constrained rural contexts (Gin, Ilham, & Arputhan, 2021), (Lim, Selvanathan, & Ilham, 2016).

Jabar et al. identified risk management as a core competency in their IBS project management framework, emphasizing the need for proactive risk identification and mitigation throughout the project lifecycle (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019). For rural school projects, risk management competencies must address context-specific risks including accessibility constraints, limited local resources, and potential community resistance to unfamiliar construction methods (Wan Ahmad, 2026).

g) Leadership and Change Management Competencies

Successful IBS adoption requires leadership competencies to drive organizational and industry transformation (Gin, Ilham, & Arputhan, 2021), (Lim, Selvanathan, & Ilham, 2016). Critical capabilities include vision and commitment to IBS adoption and continuous improvement; ability to lead organizational change and overcome resistance to new construction methods; skills in building organizational capabilities and fostering a culture of innovation; and competency in strategic decision-making regarding IBS investment and implementation (Lou & Kamar, 2012). Leadership commitment is a critical success factor for IBS adoption, with organizational leaders playing a key role in championing IBS, allocating resources for capability development, and creating an organizational culture that supports innovation (Gin, Ilham, & Arputhan, 2021) (Lim, Selvanathan, & Ilham, 2016). For rural school reconstruction programs, leadership competencies are needed at multiple levels including government agencies, construction firms, and educational institutions to drive systemic change (Mohammad Shamsudin, 2021).

h) Digital and Technological Competencies

The integration of digital technologies with IBS represents a critical frontier for enhancing construction efficiency, quality, and coordination (Kamaruddin, Mohammad, & Mahbub, 2018).

i) Building Information Modeling (BIM) Competencies

BIM has emerged as an essential technology for IBS projects, enabling integrated design, manufacturing, and assembly coordination (Abdullah & Egbu, 2010). Critical competencies include proficiency in BIM software and tools for IBS design and coordination; understanding of BIM workflows and information exchange protocols; ability to use BIM for clash detection, constructability analysis, and assembly sequencing; and skills in leveraging BIM data for manufacturing automation and quality control (Alawag, et al., 2021).

Abdullah et al. (Abdullah & Egbu, 2010) emphasized that knowledge management through BIM and digital platforms is critical for improving IBS adoption and implementation. However, BIM competencies remain underdeveloped among many Malaysian construction professionals, particularly in rural areas where access to training and technology is limited (Azmi & Salleh, 2024). For rural school projects, BIM competencies can enable more effective coordination between design teams, manufacturers, and on-site assembly crews, reducing errors and improving efficiency (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019).

j) Digital Fabrication and Automation Competencies

Understanding of digital fabrication technologies and automation in IBS manufacturing is increasingly important (Kamaruddin, Mohammad, & Mahbub, 2018). Key competencies include knowledge of computer-aided manufacturing (CAM) and automated production systems; understanding of digital fabrication processes including robotic assembly and 3D printing applications; ability to interpret and work with digital manufacturing data and specifications; and awareness of Industry 4.0 technologies and their applications in IBS (Alawag, et al., 2021).

The economic implications of mechanization and automation in IBS, noting that digital fabrication technologies can significantly enhance productivity and quality. However, competencies in these emerging technologies are limited among Malaysian construction professionals, creating a barrier to adopting advanced IBS manufacturing approaches (Kamaruddin, Mohammad, & Mahbub, 2018).

k) Data-Driven Decision Making and Digital Project Management Competencies

Modern IBS projects increasingly rely on digital project management tools and data-driven decision-making (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019). Essential competencies include proficiency in digital project management platforms and collaboration tools; ability to collect, analyze, and interpret project data for performance monitoring and decision-making; skills in using digital tools for schedule tracking, resource management, and quality control and competency in leveraging data analytics for continuous improvement (Gin, Ilham, & Arputhan, 2021).

These digital competencies enable more effective coordination of the complex, multi-phase processes involved in IBS projects and support evidence-based decision-making throughout project execution (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019). For rural school projects, digital project management tools can help overcome geographical distances and coordination challenges, enabling real-time communication and information sharing among distributed project teams (Hadi, Muhamad, & Othman, 2017).

l) Context-Specific Competencies for Rural Sarawak

Beyond generic IBS competencies, successful rural school reconstruction in Sarawak requires context-specific capabilities that address the unique challenges of rural construction environments (Mohammad Shamsudin, 2021) (Wan Ahmad, 2025c).

m) Rural Logistics and Site Access Management Competencies

Rural project sites in Sarawak present unique logistical challenges requiring specialized competencies (Hadi, Muhamad, & Othman, 2017). Critical capabilities include understanding of rural transportation infrastructure and access constraints; ability to plan component delivery considering river transport, unpaved roads, and

seasonal accessibility; skills in coordinating with local transportation providers and logistics networks; and problem-solving abilities to address unexpected access challenges (Mohammad Shamsudin, 2021).

Logistics management is one of the most critical challenges for IBS implementation in rural Sarawak, requiring competencies that extend beyond conventional construction logistics to address the specific constraints of remote locations. These competencies are essential for ensuring timely component delivery and avoiding costly delays in rural school projects (Hadi, Muhamad, & Othman, 2017).

n) Local Material and Resource Integration Competencies

Successful rural school reconstruction requires ability to integrate IBS components with locally available materials and resources (Mohammad Shamsudin, 2021). Key competencies include knowledge of local building materials, construction practices, and resource availability; ability to design hybrid solutions that combine prefabricated components with local materials; skills in adapting IBS systems to local conditions and constraints; and competency in leveraging local labor and resources to complement prefabricated components (Sing Wong & Kung Lau, 2015).

This integration capability is particularly important for achieving cost-effectiveness, building local acceptance, and ensuring long-term sustainability of school facilities (Mohammad Shamsudin, 2021). The successful IBS implementation in Sarawak often requires adaptation to local contexts rather than rigid application of standardized systems (Sing Wong & Kung Lau, 2015).

o) Community Engagement and Cultural Sensitivity Competencies

Rural school projects involve close interaction with local communities, requiring strong community engagement competencies (Wan Ahmad, 2025c). Essential capabilities include understanding of local cultural norms, values, and communication practices; ability to engage effectively with rural communities, traditional leaders, and local stakeholders; skills in explaining IBS concepts and benefits in culturally appropriate ways; and competency in incorporating community input and preferences into project planning and execution (Abd Rahman & Omar, 2006). These competencies are critical for building community support, addressing concerns about unfamiliar construction methods, and ensuring that reconstructed schools meet community needs and expectations (Mohammad Shamsudin, 2021). Effective community engagement can also facilitate local labor participation and knowledge transfer, building long-term local capacity (Wan Ahmad, 2025c) (Hadi, Muhamad, & Othman, 2017).

p) Adaptive Problem-Solving and Resourcefulness Competencies

Rural construction environments require high levels of adaptability and resourcefulness (Mohammad Shamsudin, 2021) (Hadi, Muhamad, & Othman, 2017). Critical competencies include ability to improvise solutions with limited resources and equipment; skills in troubleshooting and resolving problems with minimal external support; competency in adapting plans and procedures to unexpected site conditions; and resilience and flexibility in working in challenging rural environments (Sing Wong & Kung Lau, 2015). These adaptive competencies are essential given the resource constraints, limited technical support, and unpredictable challenges characteristic of rural construction projects in Sarawak (Hadi, Muhamad, & Othman, 2017). Workers and managers who possess strong adaptive problem-solving skills are better equipped to successfully execute IBS projects in these challenging contexts (Mohammad Shamsudin, 2021).

IMPLEMENTATION BARRIERS AND CHALLENGES

Workforce-Related Barriers

a) Knowledge and Awareness Deficiencies

Insufficient knowledge and awareness of IBS among construction professionals represents a fundamental barrier to implementation (Abd Rahman & Omar, 2006), (Ayeop Abdul Khalil, Abd Aziz, Hassim, & Jaafar, 2016). As documented in Section 4.1, 78% of contractors in Sarawak report inadequate IBS knowledge. This knowledge

gap manifests in multiple ways including limited understanding of IBS benefits, applications, and implementation requirements; misconceptions about IBS costs, quality, and suitability for different project types; lack of awareness of available IBS systems, suppliers, and support services; and insufficient knowledge of regulatory requirements and approval processes for IBS projects (Abd Rahman & Omar, 2006), (Md. Ali, Abas, Mohd Affandi, & Abas, 2018).

The researcher identified lack of knowledge as one of the primary barriers to IBS implementation in Malaysia, many contractors avoid IBS projects due to unfamiliarity and perceived risks (Abd Rahman & Omar, 2006). This knowledge barrier is particularly pronounced in rural areas where exposure to IBS projects is limited and information dissemination is constrained (Hadi, Muhamad, & Othman, 2017).

b) Skills Shortages and Training Gaps

Critical shortages of skilled IBS installers and technicians represent one of the most severe workforce barriers (Buyung & Ghani, 2014), (A. Mohsen, R. Yunus, R. Handan, Kasim, & Hussain, 2018). (Buyung & Ghani, 2014) documented that Malaysia faces a substantial deficit of trained component installers, with existing training programs producing insufficient numbers to meet industry demand. This skills shortage is compounded by limited availability of IBS-focused training programs, particularly in rural areas; inadequate practical training components in existing educational programs; limited opportunities for hands-on experience with IBS projects; and high turnover of trained workers to other sectors or regions (Azmi & Salleh, 2024), (Mohammed, 2016).

Researchers emphasized that enhancing skilled worker requirements is essential for improving IBS implementation, yet training infrastructure and programs remain inadequate to address the scale of the skills gap (Mohammed, 2016) (A. Mohsen, R. Yunus, R. Handan, Kasim, & Hussain, 2018). For rural school projects, the skills shortage is particularly acute as trained workers are concentrated in urban areas and may be reluctant to work on remote rural projects (Hadi, Muhamad, & Othman, 2017).

c) Resistance to Change and Risk Aversion

Psychological and behavioural barriers including resistance to change and risk aversion impede IBS adoption (Md. Razak & H. Awang, 2014). Many construction professionals are comfortable with conventional construction methods and reluctant to adopt unfamiliar IBS approaches, particularly when they perceive risks including uncertainty about IBS project outcomes and performance; concerns about initial investment costs and learning curves; fear of making mistakes due to limited IBS experience; and preference for familiar conventional methods despite their limitations (Md. Ali, Abas, Mohd Affandi, & Abas, 2018), (Md. Razak & H. Awang, 2014).

The contractors' perceptions of IBS implementation are significantly influenced by risk concerns and resistance to change (Md. Razak & H. Awang, 2014). Overcoming these behavioral barriers requires not only technical training but also change management interventions that address psychological factors and build confidence in IBS approaches (Gin, Ilham, & Arputhan, 2021), (Lim, Selvanathan, & Ilham, 2016).

Systemic and Structural Challenges

a) Inadequate Training Infrastructure and Educational Programs

The training and education infrastructure for IBS workforce development remains inadequate in Malaysia (Azmi & Salleh, 2024). Key structural challenges include limited number of institutions offering IBS-focused training programs; insufficient practical training facilities and equipment for hands-on IBS skills development; weak linkages between educational institutions and industry, resulting in programs that do not align with actual industry needs; and limited availability of qualified instructors with practical IBS experience (Azmi & Salleh, 2024), [15].

TVET curriculum practices in Malaysia contributed significant gaps in IBS-related technical education, noting that many programs lack practical components and industry engagement. This educational infrastructure gap constrains the pipeline of IBS-competent professionals entering the workforce (Azmi & Salleh, 2024).

b) Limited Industry-Academia Collaboration

Weak collaboration between industry and academia limits the effectiveness of workforce development efforts (Abdullah & Egbu, 2010). Challenges include limited industry involvement in curriculum development and program design; insufficient opportunities for students and trainees to gain practical experience through internships or industry projects; weak knowledge transfer mechanisms between research institutions and industry practitioners; and limited joint research and development initiatives addressing IBS implementation challenges (Alawag, et al., 2021), (Lou & Kamar, 2012).

Abdullah et al. emphasized that knowledge management and effective knowledge transfer between academia and industry are critical for improving IBS adoption. However, existing collaboration mechanisms remain underdeveloped, limiting the translation of research findings into practical workforce development initiatives (Abdullah & Egbu, 2010).

c) Insufficient Government Support and Policy Implementation

While the Malaysian government has established policies supporting IBS adoption, implementation and enforcement remain inconsistent [4], [6]. Challenges include limited enforcement of IBS requirements in government projects; insufficient financial incentives for contractors to invest in IBS training and capability development; inadequate support services for SME contractors seeking to adopt IBS; and weak coordination among government agencies responsible for construction industry development (Md.Ali, Abas, Mohd Affandi, & Abas, 2018).

Rahman et al. [6] and Ali et al. (Md. Ali, Abas, Mohd Affandi, & Abas, 2018) documented that despite policy support, practical implementation barriers persist due to insufficient government follow-through on incentive programs, limited technical assistance for contractors, and inconsistent enforcement of IBS requirements. For rural school projects specifically, government support mechanisms need to be tailored to address the unique challenges of rural construction contexts (Mohammad Shamsudin, 2021).

Contextual Challenges in Rural Sarawak

a) Geographical Dispersion and Accessibility Constraints

Sarawak's vast geography and dispersed rural population create unique challenges for workforce development and project implementation (Mohammad Shamsudin, 2021), (Hadi, Muhamad, & Othman, 2017). Key issues include limited accessibility of rural project sites, particularly during monsoon seasons; long distances between project sites and training facilities, manufacturing plants, and urban centers, high transportation costs for moving workers, equipment, and components to remote locations; and difficulty in providing on-site technical support and supervision in isolated areas (Wan Ahmad, Workforce Skill Challenges in IBS Project Implementation in Rural Area Sabah & Sarawak: A Systematic Analysis, 2026) (Hadi, Muhamad, & Othman, 2017).

Hadi et al. (Hadi, Muhamad, & Othman, 2017) identified geographical factors as critical challenges for IBS implementation in Sarawak, noting that logistics and accessibility constraints significantly increase project complexity and costs. These geographical challenges require specialized competencies in rural logistics management and adaptive problem-solving (Mohammad Shamsudin, 2021).

b) Limited Local Contractor Capacity

The construction sector in Sarawak is dominated by SME contractors with limited financial resources, technical capabilities, and organizational capacity (Wan Muhammad, et al., 2016), (Sing Wong & Kung Lau, 2015). Challenges include limited financial capacity to invest in IBS training, equipment, and capability development; small organizational size limiting ability to undertake large-scale IBS projects; limited exposure to IBS projects

and best practices; and weak organizational systems and processes for managing complex IBS projects (Wan Muhammad, et al., 2016).

SME contractors in Sarawak face particular challenges in adopting IBS due to resource constraints and limited organizational capabilities (Sing Wong & Kung Lau, 2015). Addressing these capacity limitations requires targeted support programs designed specifically for SME contexts (Wan Muhammad, et al., 2016), (Hadi, Muhamad, & Othman, 2017).

c) Cultural and Social Factors

Cultural and social factors in rural Sarawak communities can influence IBS adoption and implementation (Mohammad Shamsudin, 2021). Considerations include community preferences for traditional building designs and materials; concerns about unfamiliar construction methods and their long-term performance; limited trust in external contractors and unfamiliar technologies; and importance of community participation and local labor employment in rural development projects (Abd Rahman & Omar, 2006).

These cultural factors require careful navigation through community engagement, culturally sensitive communication, and integration of local preferences and practices into IBS project planning and execution [1]. Failure to address cultural considerations can lead to community resistance and project delays (Abd Rahman & Omar, 2006).

d) Infrastructure and Resource Limitations

Rural areas in Sarawak face infrastructure and resource limitations that complicate IBS implementation (Hadi, Muhamad, & Othman, 2017). Challenges include limited availability of electricity, water, and other utilities at remote project sites; inadequate road infrastructure for transporting large prefabricated components; limited availability of local skilled labor and technical expertise; and constrained access to construction equipment, tools, and materials (Mohammad Shamsudin, 2021), (Sing Wong & Kung Lau, 2015).

These infrastructure limitations require careful project planning, resource mobilization, and often hybrid construction approaches that combine IBS components with locally available resources and capabilities (Sing Wong & Kung Lau, 2015), (Hadi, Muhamad, & Othman, 2017).

Strategic Framework for Workforce Development

Multi-Level Training and Education Strategy

a) Formal Education Integration

Integrating IBS content into formal construction education programs is essential for building long-term workforce capacity (Azmi & Salleh, 2024). Strategic actions include incorporating IBS principles, systems, and practices into construction management, civil engineering, and architecture curricula at universities and polytechnics; developing specialized IBS courses and degree programs at technical and vocational institutions; establishing practical training facilities with IBS equipment and components for hands-on learning; and engaging industry practitioners as guest lecturers and mentors to provide real-world perspectives (Alawag, et al., 2021), (Abdullah & Egbu, 2010).

Azmi & Salleh (Azmi & Salleh, 2024) emphasized the need for TVET curriculum reform to better address IBS competency requirements, including stronger practical components and industry alignment. For Sarawak specifically, establishing IBS training facilities at local technical institutions would improve accessibility for rural contractors and workers (Hadi, Muhamad, & Othman, 2017).

b) Industry-Based Training Programs

Complementing formal education, industry-based training programs provide practical skills development for current construction professionals (Mohammed, 2016), (A. Mohsen, R. Yunus, R. Handan, Kasim, & Hussain,

2018). Key initiatives include establishing IBS training centers offering short courses and certification programs for contractors, supervisors, and workers; developing apprenticeship programs that combine classroom instruction with on-the-job training on actual IBS projects; creating mobile training units that can deliver IBS training in rural areas with limited access to fixed training facilities; and implementing train-the-trainer programs to build a cadre of qualified IBS instructors (Buyung & Ghani, 2014).

Mohammed (Mohammed, 2016) and (A. Mohsen, R. Yunus, R. Handan, Kasim, & Hussain, 2018) advocated for enhanced skilled worker training programs specifically targeting IBS component installers and technicians. For rural school reconstruction, mobile training programs could address geographical barriers by bringing training directly to rural contractors and communities (Hadi, Muhamad, & Othman, 2017).

c) Continuous Professional Development

Ongoing professional development ensures that construction professionals maintain and enhance their IBS competencies (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019). Strategic approaches include mandatory continuing education requirements for professional registration and licensing; industry conferences, workshops, and seminars on IBS innovations and best practices; online learning platforms providing accessible IBS training resources; and professional certification programs recognizing IBS expertise and competency levels (Gin, Ilham, & Arputhan, 2021).

The project management competencies for IBS require continuous updating as technologies and practices evolve. Professional development programs should address both technical and managerial competency domains (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019).

Industry-Academician-Government Partnerships

a) Collaborative Research and Development

Joint research initiatives can address knowledge gaps and develop context-specific solutions for IBS implementation in rural school reconstruction (Abdullah & Egbu, 2010), (Lou & Kamar, 2012). Priority areas include research on IBS system adaptations for rural school applications; development of cost-effective IBS solutions suitable for SME contractors; investigation of hybrid construction approaches combining IBS with local materials and practices; and evaluation of IBS project performance and lessons learned from rural school reconstruction projects (Alawag, et al., 2021).

Researchers emphasized the importance of knowledge management and research collaboration for advancing IBS implementation. Establishing research partnerships between universities, government agencies, and construction firms can generate practical knowledge to inform workforce development and project implementation (Abdullah & Egbu, 2010) (Lou & Kamar, 2012).

b) Industry Engagement in Education

Strengthening industry involvement in educational programs enhances relevance and practical applicability (Azmi & Salleh, 2024). Mechanisms include industry advisory boards guiding curriculum development and program design; internship and cooperative education programs providing students with practical IBS project experience; industry-sponsored capstone projects addressing real IBS implementation challenges; and industry provision of equipment, materials, and expertise for educational programs (Alawag, et al., 2021).

These engagement mechanisms ensure that educational programs align with actual industry needs and provide graduates with job-ready competencies (Azmi & Salleh, 2024), (Abdullah & Egbu, 2010).

c) Government Facilitation and Coordination

Government agencies play a critical coordinating role in workforce development initiatives [4], [6]. Key functions include establishing national IBS competency standards and certification frameworks; coordinating training program development and delivery across multiple institutions and regions; providing financial support

for training infrastructure development and program delivery; and facilitating knowledge sharing and best practice dissemination across the construction industry (Gin, Ilham, & Arputhan, 2021), (Md. Ali, Abas, Mohd Affandi, & Abas, 2018).

For rural school reconstruction specifically, government coordination is essential for aligning workforce development initiatives with project implementation timelines and ensuring adequate trained workforce availability (Mohammad Shamsudin, 2021).

Targeted Interventions for Rural Contexts

a) Rural-Specific Training Programs

Workforce development programs must be adapted to rural contexts and constraints (Hadi, Muhamad, & Othman, 2017). Design principles include delivering training in rural locations to improve accessibility for local contractors and workers; incorporating rural-specific content addressing logistics, site access, and resource constraints; using practical, hands-on training methods suited to adult learners with limited formal education; and providing training in local languages and culturally appropriate formats (Mohammad Shamsudin, 2021).

Hadi et al. emphasized that training programs for rural contractors must address the specific challenges of IBS implementation in rural Sarawak contexts. Mobile training units and community-based training delivery models can improve accessibility (Hadi, Muhamad, & Othman, 2017).

b) SME Capacity Building Programs

Targeted support for SME contractors is essential given their dominance in rural construction (Sing Wong & Kung Lau, 2015). Interventions include subsidized or free IBS training programs for SME contractors and workers; technical assistance programs providing on-site support during initial IBS project implementation; financial incentives for SME investment in IBS equipment and capability development; and facilitation of SME consortia to enable collaboration on larger IBS projects (Mohammed, 2016).

The specific challenges faced by SME contractors in Sarawak and emphasized the need for tailored support programs (Sing Wong & Kung Lau, 2015)] and (Hadi, Muhamad, & Othman, 2017). Government-sponsored SME capacity building initiatives can accelerate IBS adoption among this critical contractor segment (Wan Muhammad, et al., 2016)].

c) Community-Based Workforce Development

Engaging rural communities in workforce development builds local capacity and ensures project sustainability (Mohammad Shamsudin, 2021). Approaches include training programs for local workers to participate in IBS project implementation; community awareness programs explaining IBS benefits and addressing concerns; employment of local labor in IBS projects to build experience and skills; and knowledge transfer initiatives ensuring that local communities can maintain and manage IBS school facilities [6].

Community-based workforce development not only builds technical capacity but also fosters local ownership and acceptance of IBS approaches (Wan Ahmad, 2025c) (Mohammad Shamsudin, 2021). This is particularly important for rural school projects where community engagement is critical for project success (Wan Ahmad, Bridging the Divide: An Analysis of Community-Led Approaches in Sabah & Sarawak, Malaysia Rural Infrastructure Development, 2025c).

Technology-Enabled Learning and Knowledge Sharing

a) Digital Learning Platforms

Technology-enabled learning can overcome geographical barriers and improve training accessibility (Azmi & Salleh, 2024). Initiatives include development of online IBS training courses and resources accessible from rural areas; mobile learning applications providing just-in-time training content; virtual reality (VR) and augmented

reality (AR) training simulations for IBS assembly procedures; and online communities of practice facilitating knowledge sharing among IBS practitioners (Abdullah & Egbu, 2010).

Digital learning platforms can significantly expand the reach of training programs, particularly benefiting rural contractors and workers with limited access to physical training facilities (Azmi & Salleh, 2024), (Hadi, Muhamad, & Othman, 2017).

b) Knowledge Management Systems

Systematic knowledge capture and dissemination supports continuous learning and improvement. Key components include documentation and dissemination of IBS project case studies and lessons learned; development of IBS best practice guidelines and technical resources; establishment of knowledge repositories accessible to construction professionals; and facilitation of peer learning and knowledge exchange networks (Alawag, et al., 2021). Abdullah & Egbu emphasized that effective knowledge management is critical for improving IBS adoption and implementation. Systematic knowledge sharing mechanisms can accelerate learning and reduce repeated mistakes (Abdullah & Egbu, 2010).

Policy and Regulatory Interventions

a) Competency Standards and Certification

Establishing formal IBS competency standards and certification programs ensures workforce quality (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019). Policy actions include development of national competency standards for IBS roles (designers, project managers, installers, supervisors); implementation of certification programs recognizing IBS competency achievement; integration of IBS competency requirements into professional licensing and registration; and enforcement of competency requirements for IBS project personnel (Gin, Ilham, & Arputhan, 2021).

Formal competency standards provide clear targets for training programs and enable quality assurance in workforce development (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019).

b) Incentive Programs

Financial and non-financial incentives can motivate investment in workforce development (Rashidi & Ibrahim, 2017), (Md. Ali, Abas, Mohd Affandi, & Abas, 2018). Mechanisms include tax incentives or subsidies for contractor investment in IBS training; preferential treatment in government project procurement for contractors with certified IBS competencies; grants or low-interest loans for training infrastructure development; and recognition programs celebrating IBS excellence and innovation (Abd Rahman & Omar, 2006).

Incentive programs can help overcome the initial investment barriers that discourage contractors, particularly SMEs, from developing IBS capabilities (Wan Muhammad, et al., 2016), (Md. Ali, Abas, Mohd Affandi, & Abas, 2018).

c) Regulatory Requirements

Regulatory mandates can drive workforce development by creating demand for IBS competencies (Rashidi & Ibrahim, 2017). Policy options include mandatory IBS utilization requirements for government-funded school reconstruction projects; minimum competency requirements for contractors bidding on IBS projects; quality assurance requirements ensuring adequate supervision and inspection by qualified personnel; and reporting requirements tracking workforce development progress and outcomes (Abd Rahman & Omar, 2006).

For rural school reconstruction specifically, government mandates requiring IBS utilization combined with workforce development support can create a virtuous cycle of capability building and project implementation (Mohammad Shamsudin, 2021), (Rashidi & Ibrahim, 2017).

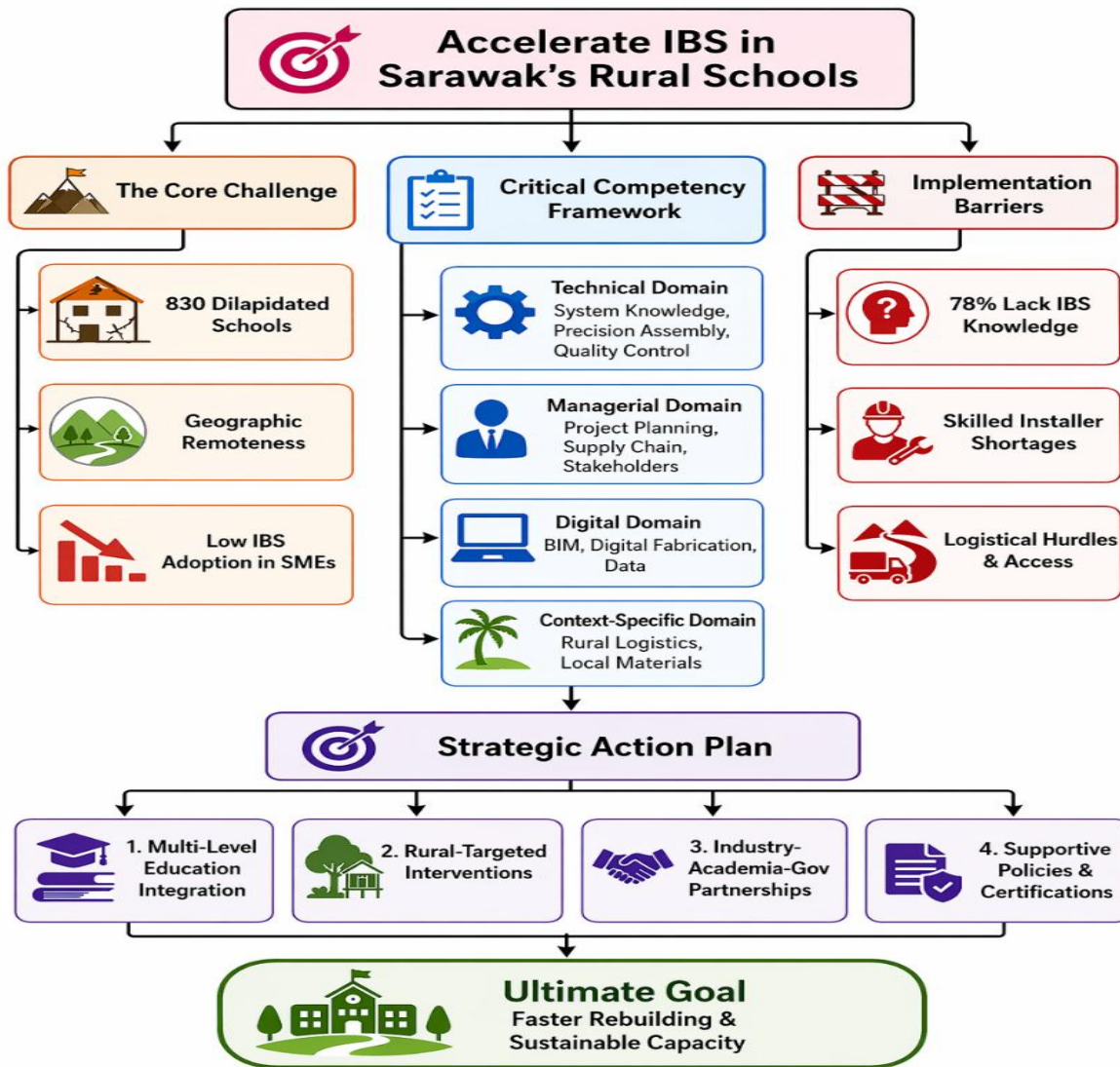


Figure 2: A multi-level strategy for strengthening IBS capacity and improving rural school infrastructure delivery in Sarawak by Author

DISCUSSION AND IMPLICATIONS

Synthesis of Key Findings

This systematic review has identified critical workforce competencies required for successful IBS-based rural school reconstruction in Sarawak, encompassing four interconnected domains: technical competencies (IBS system knowledge, manufacturing and quality control, component handling and logistics, precision assembly, and quality assurance); managerial competencies (project planning and scheduling, supply chain management, stakeholder engagement, risk management, and leadership); digital competencies (BIM proficiency, digital fabrication knowledge, and data-driven decision-making); and context-specific competencies (rural logistics management, local resource integration, community engagement, and adaptive problem-solving) (Mohammad Shamsudin, 2021), (Hadi, Muhamad, & Othman, 2017), (Buyung & Ghani, 2014), (A. Mohsen, R. Yunus, R. Handan, Kasim, & Hussain, 2018), (Khor, Tiang, Abdullatef, & Wai, 2021), (Abdullah & Egbu, 2010), (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019).

The current state assessment reveals substantial competency gaps across all domains, with 78% of Sarawak contractors reporting insufficient IBS knowledge (Mohd Bohari, Mahat, & Kipli, 2011), critical shortages of skilled installers (Buyung & Ghani, 2014), underdeveloped managerial capabilities [3], (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019), and limited digital competencies (Azmi & Salleh, 2024), (Abdullah &

Egbu, 2010). These gaps are compounded by systemic barriers including inadequate training infrastructure (Azmi & Salleh, 2024), weak industry-academia collaboration (Abdullah & Egbu, 2010) and contextual challenges specific to rural Sarawak including geographical dispersion, SME contractor dominance, and infrastructure limitations (Wan Muhammad, et al., 2016), , (Hadi, Muhamad, & Othman, 2017).

The strategic framework proposed addresses these challenges through multi-level interventions encompassing formal education integration, industry-based training, continuous professional development, industry-academia-government partnerships, rural-specific programs, technology-enabled learning, and supportive policy and regulatory measures (Abd Rahman & Omar, 2006), (Azmi & Salleh, 2024), (Alawag, et al., 2021), (Gin, Ilham, & Arputhan, 2021), (Mohammed, 2016), (A. Mohsen, R. Yunus, R. Handan, Kasim, & Hussain, 2018), (Abdullah & Egbu, 2010), (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019). Successful implementation of this framework requires coordinated action across multiple stakeholders and sustained commitment over time.

Theoretical Contributions

This study contributes to construction management theory in several ways. First, it extends competency-based frameworks for construction workforce development by identifying competencies specific to the intersection of industrialized construction, rural contexts, and educational infrastructure—a domain not previously addressed in the literature. While existing frameworks such as Jabar et al. (Jabar, Abdul-Aziz, Suresh, Renukappa, & Enshassi, 2019) have identified general IBS competencies, this study demonstrates that rural school reconstruction requires additional context-specific competencies that are critical for project success (Mohammad Shamsudin, 2021), (Hadi, Muhamad, & Othman, 2017). Second, the study contributes to understanding of technology adoption and diffusion in construction by highlighting the central role of workforce competencies as both enablers and barriers to IBS implementation. The findings support and extend diffusion of innovation theory by demonstrating that successful adoption of construction innovations requires not only technological readiness but also comprehensive human capital development across multiple competency domains (Abd Rahman & Omar, 2006), (Gin, Ilham, & Arputhan, 2021), (Md. Ali, Abas, Mohd Affandi, & Abas, 2018).

Third, the study contributes to rural development and infrastructure literature by examining the specific challenges and requirements of implementing modern construction technologies in rural contexts. The identification of context-specific competencies for rural construction extends existing knowledge beyond urban-centric perspectives that dominate construction management research (Mohammad Shamsudin, 2021), (Hadi, Muhamad, & Othman, 2017).

Practical Implications

The findings have significant practical implications for multiple stakeholder groups involved in rural school reconstruction and IBS implementation.

Government Agencies

The competency framework and strategic recommendations provide evidence-based guidance for designing workforce development programs, allocating training resources, and establishing policy interventions to support IBS-based school reconstruction. Government agencies should prioritize establishment of IBS training facilities in Sarawak, development of SME-focused capacity building programs, and implementation of incentive mechanisms that encourage contractor investment in workforce development (Rashidi & Ibrahim, 2017), (Abd Rahman & Omar, 2006)], (Wan Muhammad, et al., 2016), (Hadi, Muhamad, & Othman, 2017), (Mohammed, 2016), (A. Mohsen, R. Yunus, R. Handan, Kasim, & Hussain, 2018).

Educational Institutions

Universities, polytechnics, and TVET institutions should integrate IBS content into construction-related programs, establish practical training facilities, and strengthen industry partnerships to ensure graduates possess job-ready IBS competencies. Particular attention should be given to developing programs accessible to rural

contractors and workers through mobile training delivery and flexible scheduling (Azmi & Salleh, 2024), (Alawag, et al., 2021), (Abdullah & Egbu, 2010).

Construction Firms

Contractors, particularly SMEs in Sarawak, should invest in workforce training and capability development to position themselves for IBS project opportunities. This includes sending personnel for formal IBS training, seeking opportunities to gain practical experience on IBS projects, and developing organizational systems and processes to support IBS implementation. Firms should view workforce development as a strategic investment rather than a cost (Wan Muhammad, et al., 2016), (Buyung & Ghani, 2014), (Khor, Tiang, Abdullatef, & Wai, 2021), (Md. Razak & H. Awang, 2014).

Industry Associations

Construction industry associations should facilitate knowledge sharing, coordinate training initiatives, advocate for supportive policies, and establish competency standards and certification programs. Industry associations can play a valuable coordinating role in workforce development efforts (Gin, Ilham, & Arputhan, 2021), (Abdullah & Egbu, 2010).

Addressing the Implementation Gap

The persistent gap between IBS policy support and actual implementation rates (Abd Rahman & Omar, 2006), (Md. Ali, Abas, Mohd Affandi, & Abas, 2018) can be substantially narrowed through systematic workforce development. The evidence suggests that competency deficiencies are a primary constraint on IBS adoption, particularly among SME contractors in rural areas (Mohd Bohari, Mahat, & Kipli, 2011), (Wan Muhammad, et al., 2016), (Hadi, Muhamad, & Othman, 2017), (Buyung & Ghani, 2014). By addressing these competency gaps through the strategic framework proposed in this study, Malaysia can accelerate IBS implementation and achieve rural school reconstruction objectives more effectively.

However, workforce development alone is insufficient. Successful IBS implementation requires simultaneous attention to other barriers including high initial costs, limited IBS manufacturer capacity, regulatory and approval process challenges, and supply chain constraints (Abd Rahman & Omar, 2006), (Md. Ali, Abas, Mohd Affandi, & Abas, 2018). Workforce development should be pursued as part of a comprehensive strategy addressing multiple dimensions of IBS implementation challenges.

Sustainability and Long-Term Capacity Building

A critical consideration for rural school reconstruction is long-term sustainability and local capacity building (Mohammad Shamsudin, 2021). Rather than relying solely on external contractors and workers, workforce development strategies should emphasize building local capacity within rural communities. This includes training local workers to participate in IBS project implementation, transferring knowledge and skills to local contractors, and ensuring that communities can maintain and manage IBS school facilities over their lifecycle (Wan Ahmad, Bridging the Divide: An Analysis of Community-Led Approaches in Sabah & Sarawak, Malaysia Rural Infrastructure Development, 2025c), (Abd Rahman & Omar, 2006).

This capacity-building approach not only supports immediate school reconstruction objectives but also contributes to broader rural development goals by enhancing local construction capabilities, creating employment opportunities, and building human capital in rural areas (Mohammad Shamsudin, 2021). The context-specific competencies identified in Section 5.4, particularly community engagement and local resource integration, are essential for achieving these sustainability objectives (Mohammad Shamsudin, 2021), (Hadi, Muhamad, & Othman, 2017).

Limitations and Future Research Directions

This study has several limitations that suggest directions for future research. First, the review is based on existing literature and does not include primary empirical data from active rural school reconstruction projects. Future

research should conduct field studies in ongoing IBS-based school reconstruction projects to validate the competency framework and identify additional competencies that may not be captured in existing literature.

Second, the study focuses specifically on the Sarawak context, which may limit generalizability to other regions or countries. However, the findings may be transferable to similar rural construction contexts in other developing countries. Comparative studies examining IBS workforce competencies across different geographical and cultural contexts would enhance understanding of universal versus context-specific competency requirements.

Third, the study identifies competencies and proposes a strategic framework but does not evaluate the effectiveness of specific training interventions or workforce development programs. Future research should assess the impact of different training approaches on competency development and project outcomes, providing evidence on which interventions are most effective.

Fourth, the rapidly evolving nature of construction technology means that competency requirements will continue to change. Future research should monitor emerging technologies such as advanced digital fabrication, robotics, and artificial intelligence in construction, and examine their implications for workforce competency requirements.

Finally, the study focuses on workforce competencies but does not deeply examine organizational and systemic factors that influence competency development and utilization. Future research should investigate organizational learning processes, knowledge management systems, and institutional factors that enable or constrain workforce competency development in construction firms and the broader industry.

CONCLUSION

The reconstruction of dilapidated rural schools in Sarawak represents a critical infrastructure challenge that demands innovative construction approaches and a highly competent workforce. This systematic review has identified four critical competency domains essential for successful IBS-based rural school reconstruction: technical competencies encompassing IBS system knowledge, manufacturing and quality control, component handling and logistics, precision assembly, and quality assurance; managerial competencies including project planning, supply chain management, stakeholder engagement, risk management, and leadership; digital competencies involving BIM, digital fabrication, and data-driven decision-making; and context-specific competencies addressing rural logistics, local resource integration, community engagement, and adaptive problem-solving.

The current state assessment reveals substantial competency gaps across all domains, with 78% of Sarawak contractors reporting insufficient IBS knowledge, critical shortages of skilled installers, underdeveloped managerial capabilities, and limited digital competencies. These gaps are compounded by systemic barriers including inadequate training infrastructure, weak industry-academia collaboration, and contextual challenges specific to rural Sarawak including geographical dispersion, SME contractor dominance, and infrastructure limitations.

Addressing these workforce competency gaps requires a comprehensive, multi-level strategic framework encompassing formal education integration, industry-based training programs, continuous professional development, industry-academia-government partnerships, rural-specific interventions, technology-enabled learning, and supportive policy and regulatory measures. Successful implementation of this framework demands coordinated action across government agencies, educational institutions, construction firms, and industry associations, with sustained commitment over time.

The findings have significant implications for policy and practice. Government agencies should prioritize establishment of IBS training facilities in Sarawak, development of SME-focused capacity building programs, and implementation of incentive mechanisms that encourage contractor investment in workforce development. Educational institutions should integrate IBS content into construction programs, establish practical training facilities, and strengthen industry partnerships. Construction firms should invest strategically in workforce

training and capability development. Industry associations should facilitate knowledge sharing, coordinate training initiatives, and establish competency standards and certification programs.

Ultimately, accelerating IBS-based rural school reconstruction in Sarawak depends on building a competent, confident, and capable workforce equipped with the technical, managerial, digital, and context-specific competencies required to successfully implement industrialized construction in challenging rural environments. By systematically addressing workforce competency gaps through the strategic framework proposed in this study, Malaysia can achieve its educational infrastructure development objectives while building sustainable local construction capacity that will benefit rural communities for generations to come.

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