Civil Engineering and Architecture 11(5A): 3200-3208, 2023 http://www.hrpub.org
DOI: 10.13189/cea.2023.110829

Validation of the Guidelines for Sustainable Construction of Industrialized Building System (IBS)

Riduan Yunus[1,2,*], Bambang Trigunarsyah[2], Abdul Rahim Abdul Hamid[3], Syamsul Herman Mohammad Afandi[4], Salman Riazi Mehdi Riazi[5]

[1]Geostructure and Rehabilitation Centre (GSRC), Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Malaysia
[2]School of Property, Construction and Project Management (PCPM), RMIT University, Australia
[3]School of Civil Engineering, Universiti Teknologi Malaysia (UTM), Malaysia
[4]Department of Economics, School of Business and Economics, Universiti Putra Malaysia, Malaysia
[5]School of Housing, Building and Planning, Universiti Sains Malaysia, Malaysia

Received December 30, 2022; Revised March 25, 2023; Accepted July 5, 2023

Cite This Paper in the Following Citation Styles

(a): *[1] Riduan Yunus, Bambang Trigunarsyah, Abdul Rahim Abdul Hamid, Syamsul Herman Mohammad Afandi, Salman Riazi Mehdi Riazi , "Validation of the Guidelines for Sustainable Construction of Industrialized Building System (IBS)," Civil Engineering and Architecture, Vol. 11, No. 5A, pp. 3200 - 3208, 2023. DOI: 10.13189/cea.2023.110829.*

(b): *Riduan Yunus, Bambang Trigunarsyah, Abdul Rahim Abdul Hamid, Syamsul Herman Mohammad Afandi, Salman Riazi Mehdi Riazi (2023). Validation of the Guidelines for Sustainable Construction of Industrialized Building System (IBS). Civil Engineering and Architecture, 11(5A), 3200 - 3208. DOI: 10.13189/cea.2023.110829.*

Abstract Validation of developed guidelines is vital to ensure their applicability and accuracy in responding to real scenarios within the local context. A case study was adopted in this research to assess the application of developed guidelines in a real scenario that improves sustainability for Industrialized Building System (IBS) projects. This process ensures the significance of the guidelines as a decision tool in promoting sustainability. Every process and procedure was validated to ensure the guidelines could be used in the actual projects. It is important to demonstrate on advantages and benefits of the guidelines to explicitly assist the design team in making the best decision. There are five criteria in selecting the appropriate case projects, namely 1) location, 2) information accessibility, 3) method of construction, 4) high-impact projects for the community and 5) IBS Score. Only non-residential buildings were selected in this study. This study's two data collection methods are semi-structured interviews and documents review. Eleven (11) respondents from the management team were selected to participate in the interviews. The results show that the respondents confirmed that the guidelines appropriately apply in the construction industry. Similar results were achieved, and sustainability was improved in the selected projects. All participants' comments and recommendations were synthesised to improve the project outputs. Accordingly, improved guidelines were developed that significantly improved the sustainable deliverables of IBS applications.

Keywords Decision Making, Prefabrication, Sustainability, Construction, Management

1. Introduction

Most developing countries depend on the construction industry to improve social well-being. Uncontrolled construction development causes not only environmental degradation but also social problems. Many unskilled construction workers cause remittance and unemployment to local workers. In addition, construction activities involve many natural resources such as aggregates, cement, steel and timber. The usage of fossil fuels also has a negative impact on the environment. Air and water pollution are some of the examples that can be caused by the construction industry. In the social context, on-site construction work has long been criticized for its poor performance in safety and health. Moreover, the method is identified as ineffective, affecting a construction project's productivity. In brief, conventional construction is defined

as construction activities that will be completed on-site, whereas raw materials will convert into building components. Pheng & Hou [1] highlighted that applying conventional methods is labour-intensive, capital-intensive and longer to complete. Skilled workers, with the assistance of unskilled labours, will execute tasks given at the construction site. The usage of advanced technology and equipment is low due to the low initial capital provided by the main contractors.

Malaysia is a developing country and has been experiencing these problems for more than decades. The main issue is a shortage of construction labour. A government report shows that 69% of the 800,000 registered workers in the country are not local [2]. Most foreign workers come from other developing countries such as Bangladesh, Nepal, Indonesia, Vietnam and Pakistan. The statistics show that most foreign workers in the construction sector are unskilled and not ready to work in the industry. They need proper training to improve the work productivity and quality of work produced. Normally, there are only involved in activities that require labour-intensive and manual work. Most of the migrant worker in Malaysia is not reliable. There are not possess the required skill and knowledge demanded by the employer. This is due to a false claim that there are professionals when completing the job application form [3]. With a very low social status and lack of education, the massive availability of unskilled foreign workers is the main cause of most economic and social problems [4]. On the other hand, the use of an Industrialized Building System (IBS) has many benefits, including improved construction process efficiency, reduced waste and minimized negative impacts on the environment [5]

This study is the last stage of the whole study, reported in [6] and [7]. The critical factors for the sustainable construction of IBS are reported in the first publication [6]. Table 1 shows the eighteen (18) sustainability factors that were identified.

The factors were identified by a quantitative approach using a questionnaire survey. From the statistical analysis, the factors were categorized into five different groups, namely: 1) economic value; 2) ecological performance; 3) social equity and culture; 4) implementation and enforcement, and 5) technical quality.

Then, the factors were further investigated by adopting semi-structured interviews and applying the SWOT (strengths, weaknesses, opportunities, and threats) for the analysis. The technique is significant for structuring and systematically reporting the interview findings. The interview process allows researchers to investigate each factor and formulate appropriate strategies. The outcomes of the semi-structured interviews are reported in the second publication [7]. A table for each critical factor is developed to guide the decision-maker. The table provides designers with strengths, weaknesses, opportunities and threats before they can make a decision. The appropriate action plans are also provided in each table.

The study aims to validate the developed guidelines and check the decision-making process in improving sustainability for IBS applications. The case studies were identified as the best approach to demonstrate how the guidelines can improve sustainability for the designers. The application of guidelines in real projects is vital to evaluate the applicability and effectiveness of the developed guidelines. This validation is mandatory to ensure that the developed guidelines are appropriate for the local context. All selected cases were carefully examined to represent the real scenario in the IBS development. The results from the analysis show that the number of the selected cases for the study is sufficient. The three projects identified for case studies provide good results in validating and verifying the findings. The replication of the findings provides concrete evidence in showing that the guidelines can improve sustainability for IBS applications.

Table 1. Sustainability Factors for IBS [6]

No.	Sustainability Factors
1.	Construction time
2.	Production
3.	Waste generation
4.	Constructability
5.	Knowledge and skills
6.	Defect and damages
7.	Labour cost
8.	Waste disposal
9.	Procurement system
10.	Durability
11.	Working condition
12.	Standardisation
13.	Usage efficiency
14.	Labour availability
15.	Material consumption
16.	Legislation
17.	Project control guidelines
18.	Maintenance and operation costs

2. Projects' Criteria of the Selection of Project in the Case Study

The project's criteria will significantly impact the development of the guidelines. Proper project selection for case studies will ensure the achievement of the study objectives. IBS Score and characteristics of projects in promoting sustainability are the two (2) main criteria in selecting a case project. It is important to note that the

selection must focus on the research problems [8]. It is mandatory to ensure the selected projects can provide rich information in answering the formulated research questions. The selected case projects must be able to provide appropriate information and sufficient data to determine the best solution.

The selection of the project is determined based on the basic criteria that have been set for the study. In this study, only projects located in the Peninsular of Malaysia are accepted for consideration to be included in the case study. The approval for accessibility to project information should be granted by the project owner or relevant authorities The following criteria in selecting the suitable case projects are:

(i) The projects are in Peninsular Malaysia.
(ii) Information was accessible and reliable. Permission is requested from the relevant bodies or organizations.
(iii) The construction activities were focused on building construction. Infrastructure projects such as dams, communication towers, bridges and roads will not be selected to participate in the case studies.
(iv) High percentages of IBS Score.
(v) The IBS Score for the case project is more than 70% and greatly impacts the environment and the local community.

The concept of sustainability is still not widely applied and practised for construction projects in Malaysia [9]. Most construction stakeholders still think sustainability will increase the project's cost. The support from the government and increasing awareness among the construction stakeholders are changing the perception. Accordingly, more researchers conduct a study to improve construction project delivery, especially to improve sustainable deliverables [6, 10, 11]. Commonly, any projects with more than 70% of the IBS Score will be considered able to contribute to sustainable development. It is important to note that the score does not objectively represent the project for sustainability. At the project level, the doers, especially at middle management and lower levels, were struggling to integrate sustainability as there were no systematic procedures or guidelines to assist them.

The positive support from the government and professional bodies such as the Board of Engineers Malaysia (BEM), Malaysian Institute of Architects (PAM) and Board of Quantity Surveyors Malaysia (BQSM) to improve sustainable deliverables for construction projects are encouraging. For example, the introduction of Malaysia's Carbon Reduction and Environmental Sustainability Tool (MyCREST) assists industry players in reducing carbon emissions and environmental impact for a government project. The ability of the tool to integrate socio-economic which considering the built environment and urban development is lifting up the potential of the construction industry to improve sustainability in the construction industry. Moreover, the current government policy, such as Construction Industry Transformation Plan (CITP), also highlights the importance of sustainability. These positive scenarios could improve project deliverables and encourage research on this matter. Innovation in construction and using advanced technology, such as IBS applications, could deliver more sustainable construction compared to conventional methods in construction projects. The higher quality of the project can be achieved with precise and modern construction equipment [12].

In this study, the selected project types were the construction of a building and the structural elements from IBS components. The location of the projects was in three main states in Peninsular Malaysia, namely, Melaka, Penang and Johor. Evaluating the possibility of guidelines being used for different regions in Malaysia is important. It is important to note that there are some varieties in terms of culture and work environment for different areas. For example, the working and non-working days differ for Johor and Melaka. To ensure interesting comparisons between selected projects, the function of each building is different.

These characteristics are significant in ensuring the case study can provide meaningful investigation, as they are representations of the applicability and suitability of the guidelines for the IBS project. The three selected case study projects satisfy all the pre-determined requirements to ensure appropriate comparability and represent the common projects constructed in Malaysia. Table 2 shows the characteristics of the selected project for the case study.

Table 2. Characteristics of selected projects.

Project Criteria	Characteristics		
	CP-A	CP-B	CP-C
Location	Ayer Itam, Penang	Ayer Keroh, Melaka	Batu Pahat, Johor
Building Characteristics	Large area for hall and office building	Storage area and administrative building	Facilities and buildings for educational purposes
The function of the Project	Administration office, trial hall and rooms for solving legal problems or issues	Administration office with storage space	Administration office, education facilities for the local community

Table 3. Main interview questions for case studies

No.	Main Questions
1	In what ways can 'legislation' contribute to this project's sustainability?
2	In what ways can 'procurement system' contribute to this project's sustainability?
3	In what ways can 'standardisation' contribute to this project's sustainability?
4	In what ways can 'project control guidelines' contribute to this project's sustainability?
5	In what ways can 'production' contribute to this project's sustainability?
6	In what ways can 'knowledge and skills' contribute to this project's sustainability?
7	In what ways can 'material consumption' contribute to this project's sustainability?
8	In what ways can 'waste generation' contribute to this project's sustainability?
9	In what ways can 'labour availability' contribute to this project's sustainability?
10	In what ways can 'defects and damages' contribute to this project's sustainability?
11	In what ways can 'construction time' contribute to this project's sustainability?
12	In what ways can 'labour cost' contribute to this project's sustainability?
13	In what ways can 'constructability' contribute to this project's sustainability?
14	In what ways can 'working condition' contribute to this project's sustainability?
15	In what ways can 'durability' contribute to this project's sustainability?
16	In what ways can 'maintenance and operation cost' contribute to this project's sustainability?
17	In what ways can 'usage efficiency' contribute to this project's sustainability?
18	In what ways can 'waste disposal' contribute to this project's sustainability?

3. Materials and Method

This research used a case study for two primary purposes. First, the case study provided validation and verification of the questionnaire survey and semi-structured interviews. According to Simons [13], case studies provide an opportunity to explore the unique characteristics of a given case. Rather than focusing on generalities, the case is analyzed as an integrated system. Qualitative case study methodology allows researchers to explore intricate phenomena within a particular context in depth [14]. It was examined in depth whether the guidelines were applicable and appropriate, and if any issues were overlooked, they were addressed. A second purpose of the case study was to demonstrate how the guidelines developed in this research may be used by designers to make their projects more sustainable. In this study, three projects were selected based on their characteristics. This is vital to show all processes involved and how the guidelines can be implemented. The respondents were requested to critique and comment on the developed guidelines. Suggestions for improvement will also be included.

Case study questions were executed by considering input from the questionnaire survey and semi-structured interviews. The questions were open-ended in nature. Table 3 provides the main questions for the interview sessions. Sub-questions will be provided to further understand the answers provided by the respondents.

4. Data Collection

The major objective of the case study is to confirm the applicability of the proposed guidelines. It is important to ensure that the process and procedure are suitable and can assist the designer in making effective decision-making. The guidelines will be improved by getting feedback from the key stakeholders. Interviews and archival documents are the main methods used to collect the research data in this study. The duration for data collection was two months. The case studies can only be executed after the developed guidelines were ready. As mentioned in Section 1, the developed guidelines were presented in the second publication [7]. These documents were prepared and checked carefully to ensure the finding could be analyzed systematically.

Semi-structured interviews can provide insights into the application of the guidelines. The interviews were conducted to retrieve first-hand information from the key stakeholders in the construction projects. Their validation of the potential and suitability of the guidelines to improve sustainability were recorded. The selected professionals, including Consultant Engineers, Architects, Construction Managers, Project Managers, and Local Authority Officers, are the decision-makers for a construction project.

Even in the same project, the participation from different organisations and positions allowed the researcher to synthesise the findings. A validation and verification process also can be done by providing the respondents with the developed guidelines. The expert views contribute to the understanding of the insight into the activities and operations in the construction project that can be improved. All respondents explained their roles in this study, and they supported the research objectives. They clearly highlighted that the guidelines could improve project deliveries.

For every participant invited for the interview session, the participant will provide any documents and records for their ongoing project. The project's documents, such as technical specifications, construction drawings, IBS score

reports, environmental impact assessment reports, progress reports, and awards or achievements from the selected project, were important to collect significant information. The information will be synthesized. A cross-check will be made and verified based on the received reports and documents.

5. Findings and Discussion

This section presents the findings and discussion from all case projects. The case studies confirmed that the sustainability improvement in IBS deliverables could be improved by applying the proposed guidelines. A systematic and structured assessment tool in the guidelines is improving sustainability in the early stage. The guidelines are simple and easy for designers to integrate sustainability. The next section will further explain the findings for each case project.

5.1. Project CP-A

For this project, three respondents that directly involved in the project were interviewed. The respondents were selected from different organizations (contractors, consultants). All three respondents stated that the guidelines could assist them in improving sustainability for the IBS project. The guidelines could help them to integrate sustainability initiatives at the early stage of construction works clearly and systematically. The 18 identified factors were also confirmed as critical.

The assessment and evaluation of the guidelines were made by the participants. In general, they confirmed that the proposed guidelines are helping them to integrate sustainability strategies in the design stage. They also highlighted that there were no tools for assessment or support in making decisions during the design stage that prioritized sustainability. Respondent 1A stated that he is experiencing most of the threats and weaknesses provided in the guidelines on his project. He also highlighted that the organization never reviewed the potential of sustainability for its project, which normally focuses on the economic factor solely. Normally, everyone in the project will join a "circle of blame" whereby any parties will not take responsibility, especially when the responsibility is not clearly stated in the contract document (Figure 1).

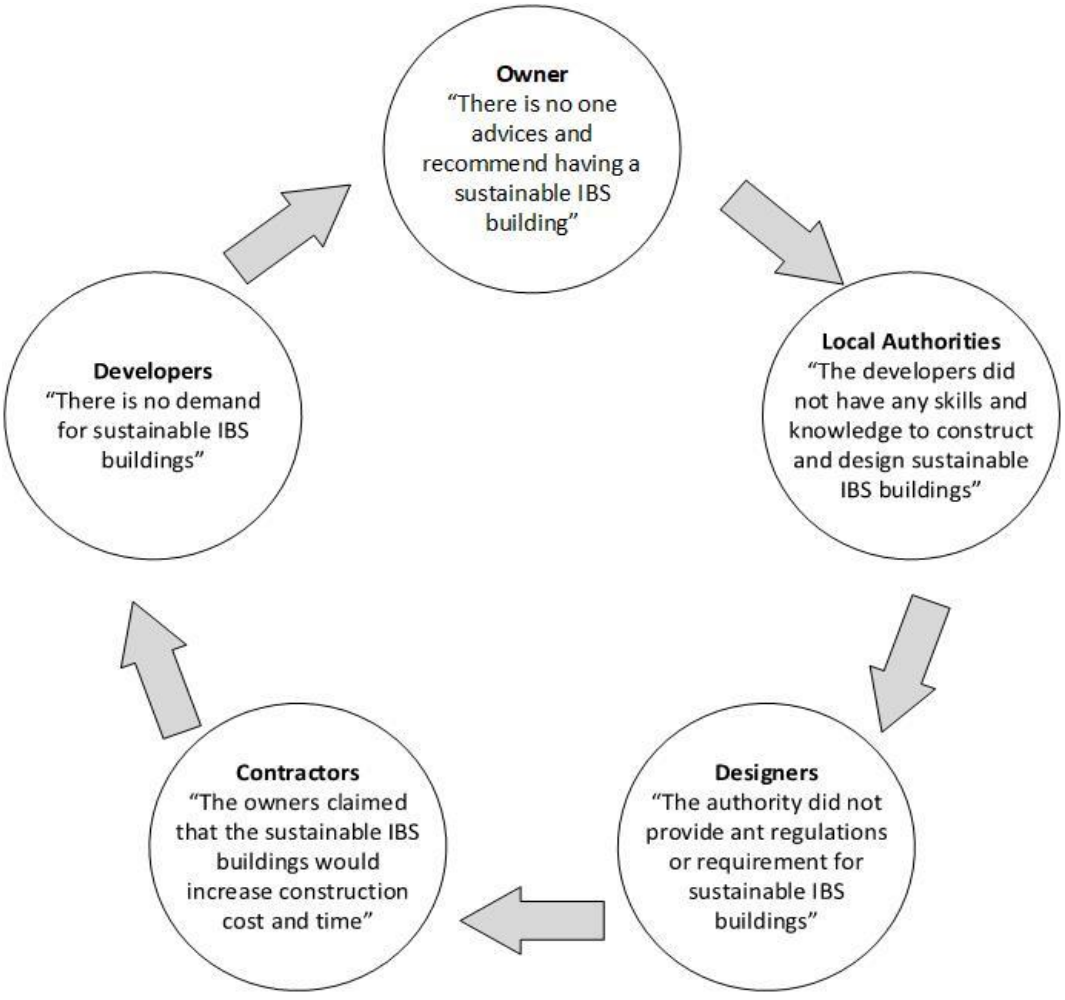

Figure 1. Circle of Blame

In construction projects, participants often criticised the other party for not implementing their sustainably and for lacking sustainable initiatives [10, 15, 16]. No clear guidelines or documents assist the construction stakeholders in integrating sustainability initiatives into their projects. Abidin [9] argued that the construction players resist integrating sustainability into their construction projects if there is no regulation or by-law enforcement. In addition, respondent 3A claimed that the cooperation and responsibility among the key stakeholders were still low even though the architect highlighted the significance of sustainability in the project during the kick-off meeting.

Participation and actions are required from all stakeholders in delivering sustainable construction. Priority should be given in the design stage. Good planning and scheduling with the integration of sustainability can create consensus. These efforts can avoid miscommunication and misleading in the construction project. The sustainable objectives should be explicitly shared among participants in the earlier stage so that every player can monitor the progress of the ongoing project. Over time, progress meetings and reports should take place to identify any problems or issues that hinder the progress of a project. Respondent 3A suggests that a sustainability committee should be formed in the early stage of construction. A sustainability manager should be appointed as a coordinator to achieve sustainability objectives. However, in some projects, the suggestion might not be suitable due to a low understanding and knowledge of sustainability.

The project uses the design-and-build approach. The appointed main contractor includes an in-house designer and manufacturer in their team. The construction activities overlap with the design stage. However, the local authority must approve and endorse the preliminary drawings before starting the construction activities. This project is a good example of using the developed guidelines, whether suitable for a different procurement type or not.

Respondent 1A highlighted that the guidelines could assist the top management in monitoring the sustainability initiatives and efforts implemented in the project. The impact of construction activities on the economy, environment and society also can be highlighted. The respondent also suggested a recommendation in the interim report, highlighting the unsustainable practices and opportunities to improve sustainability for future activities or the next project. The organization's response to integrate sustainability also can be highlighted. In addition, incentives and appreciation that given by the top management based on their performance to promote sustainability. This will motivate the employees to pursue sustainability in the ongoing project actively.

5.2. Project CP-B

Precast concrete was used as the main structural component for the constructed building in the project. The components include spun piles, precast columns, precast slabs, and precast walls. The IBS score reported for the project is 70%. Four respondents were interviewed for this project. They represent different organizations and have more than 10 years of construction experience. Respondent 1B represents the client as the Superintending Officer (SO). His responsibilities included supervising activities on site and monitoring the construction process. He is responsible for ensuring the project can complete on the scheduled time. He pointed out a communication problem during the IBS components production. It is mainly because of the fragmentation and unclear requirement by the local authority. In this project, there is a conflict between the structural and electrical engineers regarding the local authority's requirements. There were some discrepancies in the construction drawing. The situation caused miscommunication among nominated sub-contractors and construction delays. It is recommended to appoint a coordinator to minimize fragmentation risk. An experienced coordinator can foresee problems at the early stage and predict any risk that could occur in the construction project. The usage of advanced technology such as Building Information Building (BIM) will be able to reduce any errors. Previous research also highlighted the advantage of BIM, which can integrate design, performance simulation and verification, and manufacturing-related information [17]. It is important to note that good planning and proper handling are mandatory.

Respondent 2B clearly stated that creativity and uniqueness in design are limited due to modular coordination and standardization. It is important to ensure the stability of load distribution, especially for the stability of structural components. Creativity in design is important to reduce construction waste and, at the same time, will improve the aesthetic value. Symmetry buildings can create a pleasant environment and spacious area for the building's user. Moreover, effective management of construction waste will reduce the total cost of the project [18]. Luther and Bauer [19] highlighted that using precast concrete makes smaller structural component sizes possible. The case study project also shows that more floor space can be gained for the precast project. The small size of the precast component will reduce the dead load that needs to be supported by structural components.

The location and distance of the project from the prefabrication plant will affect the selection of the construction method for a project. The frequencies and distance for the transportation will increase the project's total cost. It is vital to reduce the excessive usage of fossil fuels and traffic congestion. Therefore, effective planning and scheduling are mandatory to properly manufacture, handle, deliver and install a construction project by eliminating unnecessary waste. Respondents in this project stated that the Just-in-Time (JIT) method would be able to ensure the optimization of the processes involved. Double-handling and unnecessary deliveries of IBS components can be eliminated by applying JIT. Polat et. al [20] pointed

out that the inventory cost can be reduced by applying JIT in small batches of IBS components. A small storage area is available for this project which requires applying the JIT concept. A good scheduling technic ensures that only required components will be sent to the construction site.

In conclusion, all respondents confirmed that the guidelines would improve the sustainability of their project. The proposed guidelines assist key stakeholders in the IBS application in making better decisions. Simple and systematic guidelines assist the stakeholders in determining potential strategies for their project in promoting sustainability.

5.3. Project CP-C

The IBS Score for project CP-C was 72.79%. This project aims to provide a facility for about 1200 students. The project uses pre-stress cables to support the structural loads. The cables are integrated into the precast elements, including beams, columns, walls, and slab construction. An open tender is used for a procurement system. The tender will be evaluated to select the best contractors and suppliers for this project.

The interviews were conducted with four respondents from this project. The focus of the session was to validate and verify the guidelines. During the interview sessions, all information in the guidelines was discussed and explained on how it could improve sustainability in the IBS application. As the project manager, Respondent 1C (project manager) highlighted the importance of managing construction waste efficiently. Most of the project participants in his project neglected the importance of waste separation and recycling and only focused on completing the project on time. With the developed guidelines, top management is aware of the importance of sustainability. It supports the project team in identifying criteria that should be considered to improve sustainability in IBS.

From the designer's perspectives, Respondents 3C (architect) and 4C (structural designer) agreed that the guidelines incorporate the potential of sustainability for a construction project in the early stage. This is important to ensure the life cycle cost of the building can be considered, including the operation and maintenance costs. The guidelines were simple, with a clear and systematic process. The guidelines should focus on the designer’s involvement and other stakeholders’ requirements in promoting sustainability.

Respondent 2C (assistant project manager) stated that the greatest benefit of sustainability in applying IBS is minimizing the on-site activities. This scenario will transfer the dynamic and uncertain process to a controlled environment (factory). However, skilled labour in fabricating and managing the IBS components is still required in either on-site or factory locations. Therefore, the availability of skilled labour is crucial. He pointed out the importance of training programs for certified local workers to manufacture, transport, and install IBS components. The IBS benefits from the social sustainability dimension by improving the project's safety performance, decreasing the complex and aerial works, and eliminating the high dependency on labour [21]. The solution also improves benefits in terms of social and community development. Cooperation from technical institutions such as polytechnic and technical institution is crucial. In addition, he also highlighted that the location of the IBS production plant must be strategic and accessible to minimise transportation costs.

In terms of building quality, Respondent 3C (architect) agreed that the IBS building could be produced as a more durable and high-quality building. He added that the IBS application could provide a systematic and controlled environment for the production process. The perfect curing process, use of factory-engineered concrete and load testing assurances are some of the benefits of IBS construction. On the contrary, the conventional method requires a long waiting period for concrete to harden and low-quality buildings. The controlled environment will overcome problems such as inconsistent temperature and the rainy season. It is high time to transform the local construction industry to adopt new technology and advanced method to meet higher demand in the construction industry nowadays [22].

5.4. Summary of Findings

All three selected projects confirmed that guidelines could assist decision-makers in improving sustainability for IBS projects. Table 3 shows the summary of the cross-case analysis for the study. Stakeholders agreed that the guidelines could improve sustainable deliverables of IBS in four dimensions, namely 1) economy, 2) environment, 3) social and 4) institutional. The application of guidelines for non-residential projects demonstrates its suitability to be applied for government and public projects.

A structured guideline for each significant factor helps the decision-maker identify strengths, weaknesses, opportunities and threats through SWOT analysis. The guidelines also provide action plans for determining strategies to improve sustainable deliverables. This simple approach can be easily understood and encourages stakeholders to prioritize sustainability in making a decision. The guidelines will help decision makers such as consultant engineers or local authorities to put into consideration of sustainability in their projects.

Table 3. Summary of cross-case analysis.

Key Findings	CP-A	CP-B	CP-C
Minimize miscommunication and misunderstanding on the sustainable deliverables for stakeholders	Effective planning and scheduling. Early integration to create consensus between involved parties.	Appointing an experienced coordinator can reduce discrepancies.	Training programs for local workers. Certified by relevant bodies.
Commitment and cooperation for all stakeholders in integrating sustainability initiatives at the early stage.	The sustainable objectives should be explicitly shared among participants in the earlier stage.	Application of advanced technology (e.g. BIM) and lean management technique (e.g. Just-in-Time) will able to integrate sustainability at the early stage.	Top management is aware of the importance of sustainability and provides support to the project team at the early stage.
Provide a structured and simple assessment tool.	No tools for assessment or support for sustainability.	Assisting the coordinator to foresee problems at the early stage and predict any risk that could occur in the construction project.	Simple and complete with a clear process that assists designers to focus on the crucial issues in making the best decision.

6. Conclusions

It is vital to validate developed guidelines to ensure their applicability and suitability in the local context. A case study is an approach that offers an in-depth investigation that allows researchers to identify any overlooked issues. For this study, a case study provides a meaningful characteristic of actual scenarios, which increases the reliability of the study. The findings show that the developed guidelines are applicable and appropriate with minimal modification and improvements. The process and procedure for using the guidelines are clearly identified with support and guidance from the participants from the industry. The designers will be able to utilize the potential of IBS to improve sustainability. Identifying the strengths, weaknesses, opportunities, and threats for each critical criterion for IBS application in promoting sustainable deliverables is important. Action plans can provide strategies and assist designers in making better decisions to embrace sustainability for construction projects in the early stage. The cross-case analysis shows that it is vital to ensure no miscommunication and misunderstanding among the project team in improving sustainable deliverables for the project. Proper planning, scheduling and early integration of sustainability will assist contractors in achieving sustainability goals. A consensus between involved parties will allow all stakeholders to consider sustainable considerations. Future research could consider encapsulating the decision-making guidelines into computerized tools to more systematically analyze and process different constraints and scenarios at the project level.

Acknowledgements

This research was supported by the Ministry of Higher Education (MOHE) through Fundamental Research Grant Scheme (FRGS/1/2021/SS02/UTHM/02/2).

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