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Sustainable Performance of Industrialised Building Systems in the Construction Phase

Noor Fatin Aida Noor Azhar[1], Nor Haslinda Abas[2]*, Nurul Hasanah Mohd Ta'at[3], Hilyati Sabtu[1], Sasitharan Nagapan[1]

[1] *HSS Renovation & Services, 43800 Dengkil, Selangor, MALAYSIA*
[2] *Faculty of Civil Engineering and Built Environment*
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA
[3] *Faculty of Architecture, Planning and Surveying*
Universiti Teknologi Mara, 40450 Shah Alam, Selangor, MALAYSIA

*Corresponding Author: nhaslin@uthm.edu.my
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Abstract

The Industrialised Building System (IBS) is a construction method where components are manufactured in controlled environments, either on-site or offsite, before being assembled into construction works. Over the past several decades, it has garnered growing interest as a method to promote sustainable building. This study identified sustainable indicators through literature reviews, extracting sixteen indicators for a sustainability evaluation. A survey was conducted among developers, designers, civil and structure (C&S) consultants, mechanical and electrical (M&E) consultants, manufacturers, and contractors in North Malaysia, focusing on Kedah state, to identify their perceptions on the sustainable indicator performance of IBS construction. The participants had experience in both IBS and conventional construction. The data collected from the questionnaires were analysed for the mean and Relative Importance Index (RII). The results revealed significant changes in IBS construction compared with conventional construction across all indicators. The top three indicators were reducing the amount of formwork, labour availability, and reducing site disruption. Next, the analysis of the within-group comparison using Intra-class Correlation (ICC) of the indicators revealed that contractors, developers and manufacturers possessed moderate similarity within the same group of organisations. This research gives an overview of the present perspectives of performance of sustainable indicators across key stakeholders in the Kedah construction sector. This is especially beneficial because IBS has grown in popularity and popularity owing to its ability to enhance the building environment, quality, and productivity.

1. Introduction

The construction industry immensely contributes to the improvement and development of a country's economic sector [1]. However, despite its contributions, it is not an environmentally friendly activity. It can bring several problems if its growth and development are not planned properly [1]. One of the major problems is the generation of construction waste. Construction waste is defined as any by-product generated and removed from workplaces or sites of building and civil engineering structure construction, renovation, and demolition [2]. The construction industry is a large user of non-renewable resources and a significant generator of waste, and building operations contribute to almost half of all CO2 emissions [1]. Despite the creation of various technologies to facilitate work and practice environmental sustainability, most construction projects in Malaysia still use the conventional construction method.

One strategy to solve this problem is through the adoption of prefabrication, or commonly termed Industrialised Building System (IBS) in Malaysia. IBS brings many benefits compared to conventional construction, such as increased labor and work quality, reduced costs, sufficient safety, waste reductions, and enhanced productivity. All of these benefits, among others, can be linked to sustainable dimensions, which are economic, environmental, and social [3]. The introduction of sustainability through the use of IBS may provide high-quality construction and improve the living environment for occupants [4]. However, not many research studies have been conducted in Malaysia that measure the impact of IBS on sustainability based on sustainability indicators. Yunus et al. [5] identified the critical sustainability factors for improved implementation of IBS. However, the study was conducted more than a decade ago.

This study suggests that identifying the current critical sustainable performance indicators is important as the results will represent the current perspective of the IBS industry. In addition, since the main stakeholders involved in various phases of construction are different, involving all IBS stakeholders in the study is deemed crucial. This is to better understand the extent of stakeholders' perceptions and concerns on IBS sustainable performance indicators for improved sustainable IBS implementation. Insufficiently addressing the stakeholders' concerns may lead to project failure [6]. Therefore, this study seeks to investigate the critical sustainable performance indicators of IBS construction from the perspectives of IBS construction stakeholders, using the identified indicators from Jiang et al. [3] study.

2. Sustainable Performance Indicators of the Industrialised Building Systems

Table 1 and Table 2 present the indicators of the sustainable performance of IBS throughout the construction period. The indicator system consists of sixteen indicators: five are related to the economic dimension and include labour reduction, weather disruption, site disruption, construction waste, pollution generation, energy and water consumption, and formwork consumption; six are related to the environmental dimension and include constructability, health and safety risk, construction quality, attractive options, and labour availability; and five are related to the social dimension. The indicator system of sustainability is based on the work of Kamali & Hewage [7], who established the most widely used indicator system for measuring building sustainability.

Table 1 *Summary of the sustainable indicators of IBS based on the literature review*

Dimension	Indicator	[10]	[1]	[11]	[3]	[5]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	Total Cited
Economic	Cost saving	/	/	/	/			/		/		/	/	8
	Construction time	/	/	/	/	/	/	/	/	/	/	/	/	12
	Labour reduction	/	/	/	/	/	/	/	/	/	/	/	/	12
	Executing cost	/	/	/	/	/	/	/	/	/	/	/	/	12
	Weather disruption	/		/	/	/		/			/	/		7
Environmental	Site disruption	/		/	/	/	/	/	/		/		/	9
	Construction waste	/	/	/	/	/	/	/	/	/	/	/	/	12
	Pollution generation	/		/	/	/	/	/	/					7
	Energy consumption	/	/	/	/	/	/	/	/	/	/	/	/	12
	Water consumption	/		/	/	/		/			/		/	7
	Formwork consumption	/	/	/	/	/	/	/		/	/	/	/	11
Social	Construct-ability	/	/	/	/	/	/	/	/	/	/	/	/	12
	Health & safety risk	/	/	/	/	/	/	/	/		/	/	/	11
	Construction quality	/		/	/	/	/	/	/	/	/	/	/	11
	Aesthetic options	/		/	/	/	/	/		/	/	/		9
	Labour availability	/	/	/	/			/	/	/	/	/	/	10

Table 2 *Description of sustainable indicator of IBS [3]*

Indicator	Description
Cost saving	The reduction of costs including labour, materials, and machinery equipment fees.
Construction time	The duration of time it takes for a project to be completed, from planning to completion.
Labour reduction	The number of workers on the site.
Executing cost	Execution and operation costs of construction activities on site are more demand.
Weather disruption	The entire time of weather-related schedule delays.
Site disruption	Construction activities are influenced by the availability of labour, materials, machinery, and equipment, as well as the surrounding environment.
Construction waste	The amount of waste generated on-site during construction.
Pollution generation	On-site pollution levels (e.g., noise, dust, etc.)
Energy consumption	The amount of diesel and electricity used during the construction phase.
Water consumption	The amount of water consumed in the construction.
Formwork consumption	The amount of formwork that was used on the work.
Constructability	The level of construction difficulty.
Health and safety	The risks of safety and health issues (e.g., injury, fatality, etc.).
Construction quality	The building's quality and lifespan (e.g., fewer de-bonding tiles and water leakage).
Aesthetic option	Visual appearance of internal and external of the building.
Labour availability	The amount of labour that will be required.

2.1 Economic

Five indicators for the economic dimension were found. It is important to consider more economic factors, such as cost savings, building time, execution expenses, and weather disruption. For instance, cost analysis was a crucial factor in the decisions that most stakeholders' customers [8], [9]. For the cost-saving indicator, the IBS technique has saved money by considering labour savings, a shorter construction period, lower execution costs, and weather-related delays. Cost analyses in their entirety have all been classified as economic dimensions.

2.2 Environmental

The environmental dimension has enabled the identification of six sustainability indicators. Significant environmental dimension attributes are associated with energy waste. Because the IBS components are manufactured at the factory before being installed on the construction site, less construction waste is used. Therefore, the majority of the work was completed in factories. Because IBS simplifies the manufacturing process, energy usage is decreased. The IBS approach reduces the amount of construction waste, the number of pollutants produced, the amount of water used, and the amount of formwork used on the construction site. These characteristics serve as the environmental component of IBS implementation.

2.3 Social

Five indicators for the sustainability of IBS were found in the social dimension: risks to health and safety, constructability, values, construction quality, and labour availability. These factors directly impact people who live nearby, such as labour availability. IBS's workforce is selected from the local community, and as more people are needed to work in these factories and on their construction, the standard of living will rise. Besides that, this IBS effort has increased construction quality and preference for aesthetics while lowering the risk to the workers involved. From Table 1, the most cited indicators from literatures are reduce construction time, labour reduction, low executing cost, less construction waste, reduce energy consumption, and increase constructability.

3. Methods

3.1 Questionnaire Development

The sustainable performance indicator factors were obtained through a comprehensive literature review of published journals, conference proceedings, and internet articles from 2006 to 2021. The researcher designed the questionnaire by incorporating three factors of sustainable indicators, i.e., economic, social, and environmental, as postulated by Jhiang et al. [3].

The questionnaire consists of 2 sections, as follows:

- Section A – Background of respondents; and
- Section B – Questions on the sustainable performance indicator factors of IBS construction. In this section, respondents were requested to rate the level of agreement on the sustainable performance factors compared to conventional construction, based on 5-point Likert Scale. The scale ranged from "1-Strongly disagree" (means the respondent agreed that conventional construction has a better performance than IBS) to "5-Strongly agree" (means the respondent agreed that IBS has a better performance than conventional construction).

Before distributing the actual questionnaire survey to respondents, an expert review and pilot study were conducted to ensure the content validity and reliability of the questionnaire. For content validity, an expert review was carried out with two academicians and one experienced stakeholder in the IBS construction industry. The criteria for the expert review participants were that they should possess more than 10 years of experience in the field of construction management and engineering. The questionnaire was revised based on the importance of the collated attributes before being distributed to the selected stakeholders.

For the pilot study, the reliability test of the questionnaire involved the Cronbach's alpha test based on the questionnaire answered by 10 selected stakeholders who have experience in IBS projects. The primary purpose of the expert review and pilot process was to ensure the data collected from the questionnaire were valid and reliable. The minimum score of the Cronbach's Alpha test was 0.70, indicating that the questionnaire is considered reliable [19]. From the result analysis, the Cronbach's Alpha test result was 0.874, further indicating its reliability.

3.2 Data Collection

The questionnaire was distributed to developers, designers, M&E consultants, C&S consultants, manufacturers, and contractors in Kedah's state, targeting those with experience in both IBS and conventional construction. Out of 120 questionnaires distributed, 37 responses were received, resulting in a 30.83% response rate. The limited number of responses received was due to the limited period of time to conduct the study.

3.3 Measures for Data Analysis

The data were tested for mean score analysis and Relative Importance Index (RII) using the Statistical Package for Social Sciences (SPSS) tool. Mean score analysis was utilized to compute the mean scores of the significant factors of sustainable indicators of IBS. The RII was used to determine the factor that yields the weight of importance in the perception of the respondent. Next, the analysis of within-group similarities/differences was done using Intraclass Correlation (ICC).

4. Results and Discussion

A total of 37 returned questionnaire forms were received from respondents. The background of respondents is shown in Table 3.

Table 3 *Background of respondents*

Description	Number of Respondents
Respondents' organization	
• Contractor	14
• Client	3
• Engineering consultant	12
• Architect	5
• IBS manufacturer	3
Working experience (in years)	
• More than 10 years	11
• 5 – 10 years	17
• Less than 5 years	9
Involvement in IBS method	
• Precast concrete	27
• Formwork system	24
• Prefabricated timber framing system	9
• Prefabricated steel framing system	17
• Blockwork	14
• Innovative	11

4.1 Analysis of Sustainable Performance Indicators of IBS

Table 4 shows the summary of respondents' answers analysis based on the mean value and RII. The indicators are categorized in three dimensions, which are economic, environmental and social.

Table 4 *Summary of respondents' answers by using mean value and RII of sustainable indicators*

Dimension	Sustainable Indicators	Mean value	RII	RII Ranking
Economic	Save construction costs	4.11	0.82632	9
	Shorter construction time	4.41	0.87568	4
	Reduce labour	4.27	0.81622	12
	Reduce the overall cost execution	4.03	0.81081	13
	Not affected weather disturbances	4.05	0.83243	8
Environmental	Reduce site disruption	4.19	0.87568	3
	Less construction waste	4.27	0.84865	7
	Reduce the generation of pollutants.	4.22	0.84865	6
	Reduce energy consumption	4.00	0.79459	15
	Reduce the usage of water consumption	4.14	0.81622	11
	Reduce the amount of formwork	4.43	0.88649	1
Social	Provide buildable construction	4.03	0.80000	14
	Low health and safety risks	3.97	0.78378	16
	High construction quality	4.24	0.84865	5
	High aesthetic options	4.14	0.82162	10
	Labour availability	4.32	0.87568	2

The results show almost all indicators that change significantly for IBS construction compared with conventional construction; except one (1) indicator indicated moderate change, i.e., health and safety risks. The respondents perceived that the IBS has better performance compared to traditional construction in the following indicators: reduce the amount of formwork, shorter construction time, labour availability, less construction waste and reduce labour. Meanwhile, the RII results show that the top five ranking of sustainable performance indicators are reducing the amount of formwork, labour availability and reducing site disruption, shorter construction, and high construction quality.

According to Amin et al. [9], IBS promotes sustainability from a controlled environment and minimization of waste generation. The prefabricated method enables manufacturing building components in a controlled environment and then assembling it on-site, which could produce better building quality and faster project completion [19]. In addition, the use of prefabricated components reduces or eliminates the conventional timber formworks. The concurrent process of IBS saves time over the whole construction process. The reduction in construction time results from components that are concurrently built in the factory with site preparation before the installation of the component starts. This differs from traditional construction, where more time is required to construct the building on-site. This is supported by Kadir et al. [21], whose study found that IBS reduced project duration and labour numbers.

Adopting IBS in a construction process will decrease material wastage, compared with the conventional method [10]. Tam et al. [2] identified the advantages of using prefabrication or IBS can enhance the quality of prefabricated products based on the shortening construction time, reducing construction costs, and improving environmental performance and aesthetics [16]. Quality-control and highly aesthetic end-products can be achieved through the processes of controlled prefabrication. Simplified installation maintains and ensures the quality of work.

IBS is perceived as moderately impacting safety and health despite the significant advantages in this aspect noted from several scholars [10], [22], [23]. According to Gibb [24], "offsite fabrication will reduce, or completely remove, the need for on-site work at height, which is an operation that is particularly hazardous. Furthermore, offsite fabrication tends towards a more thought-through approach to construction management, in that deliveries and installation need to be planned in advance in order for them to work at all". Therefore, by using offsite techniques, safety performance is enhanced due to the reduction in on-site hours, site labour, and the elimination of certain hazards [23]. However, IBS may be perceived as less sustainable in terms of health and safety through the use of heavy machinery and crane during precast installation at the site.

Next, the Intraclass Correlation (ICC) was used to analyse within-group similarities/differences, comparing the dimensions of indicators within the stakeholders' groups based on their perceptions of the sustainable performance indicators of IBS. Table 5 shows the results of the analysis. However, the results of ICC value for manufacturer, developer and architect groups are excluded for discussion due to the small number of respondents from each group.

The study adopted Koo & Li [25] range of ICC interpretation to assess the level of agreement within the stakeholder groups. From Table 5, the contractor group has moderate similarity across the respondents in each group. Meanwhile, the value of ICC for consultant indicates poor similarity among the respondents within the group. The divergent ICC values among stakeholders could reflect their unique roles and perspectives within the IBS sustainable performance framework.

Table 5 *Results of the ICC*

Stakeholder group	ICC dimension
Contractor	0.511
Engineering consultant	0.453

In the construction industry, contractors hold a vital role as they are directly responsible for bringing projects to life. This hands-on approach often leads to contractors being heavily involved in the practical aspects of sustainability efforts. Their duties not only involve putting sustainable practices into action but also ensuring that these practices are carried out effectively on site. In addition, contractors play a vital role in connecting the imaginative plans of architects with the tangible process of building. This crucial link highlights the importance of a thorough understanding of sustainability in IBS construction. By having a firm grasp on sustainable principles, contractors are able to ensure that the environmentally conscious features outlined in the design are effectively incorporated during construction. This not only promotes a more sustainable end result, but also cultivates a consistent internal perspective on sustainable measures, ultimately contributing to a stronger ICC value. Moreover, working directly with materials, workforce, and construction techniques, they are well-versed in the practical difficulties and advantages of using sustainable practices. This hands-on experience not only allows them to realize the benefits of sustainable methods, such as material and time savings, but also helps align their perspectives with other contractors within the group. This collaborative understanding can lead to a more cohesive perception among contractors regarding the importance of sustainability.

Meanwhile, consultants are frequently called upon to provide specialized knowledge and expertise on a wide range of subjects and projects. Their responsibilities frequently include evaluating multiple aspects of a project, providing technical advice, ensuring compliance, and, on occasion, challenging the status quo in order to achieve the best results. Given their broad and all-encompassing role, it is not surprising that their perspectives may differ more than those of other stakeholder groups.

5. Conclusion

This study provides an overview of the current perceptions of sustainable indicators performance among various stakeholders in Kedah construction industry. This is particularly useful as IBS has become increasingly popular and widely promoted due to its potential to improve the construction environment, quality, and productivity. This study identified sixteen sustainable indicators of the IBS through a comprehensive literature review and a questionnaire survey from stakeholder perceptions. The results revealed significant changes in IBS construction compared with conventional construction across all indicators. The top three indicators were reducing the amount of formwork, labour availability, and reducing site disruption. One indicator, health and safety risks, indicated moderate change.

In summary, the results highlight the important benefits of IBS construction over conventional construction techniques in several areas, including formwork reduction, time optimization, labour availability, and waste reduction. IBS's methodology, which makes use of prefabrication and controlled environments, naturally promotes waste reduction, sustainability, and improved construction quality. This view is supported by previous literature, where many researchers have emphasized the advantages of IBS, such as reduced labour costs, shorter project timelines, and appreciable gains in environmental performance.

On the other hand, it is critical to discuss the opposing viewpoint regarding the health and safety hazards connected to IBS. There is still a perception that offsite fabrication has a moderate impact on health and safety, despite its inherent advantages, which include fewer on-site hazards and a more planned approach to construction management. This view is primarily shaped by the requirement to use cranes and large equipment when installing precast components on-site.

The perspectives of different stakeholders regarding the sustainable performance indicators of IBS are further solidified by the ICC analysis. However, it's imperative to interpret the results cautiously. More research is required for a more thorough understanding because only a small number of respondents from specific stakeholder groups–such as manufacturers, developers, and architects–were surveyed.

The limitations of this study include its coverage of respondents only in Kedah state, unequal numbers of respondents from each organization, and a limited number of respondents involved in the study. Further research is recommended to extend the study to other states in Malaysia. The reliability and validity of the study would also be improved by ensuring that there were an equal number of respondents for each group and by increasing the overall number of respondents.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Noor Fatin Aida Noor Azhar and Nor Haslinda Abas;* ***data collection:*** *Noor Fatin Aida oor Azhar, Hilyati Sabtu and Nurul Hasanah Mohd Ta'at;* ***analysis and interpretation of results:*** *Noor Fatin Aida Noor Azhar, Nor Haslinda Abas, Sasitharan Nagapan;* ***draft manuscript preparation:*** *Nor Haslinda Abas and Nurul Hasanah Mohd Ta'at. All authors reviewed the results and approved the final version of the manuscript.*

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