FACTORS THAT ENHANCE SUSTAINABLE DELIVERABLES IN INDUSTRIALISED BUILDING SYSTEM (IBS) CONSTRUCTION

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ABSTRACT

The purpose of this paper is to identify the factors that could enhance the sustainable deliverables for Industrialised Building System (IBS) construction in Malaysia. With the Construction Research Institute of Malaysia (CREAM) collaboration, the authors are developing guidelines for decision-making in sustainable IBS construction. A holistic and integrated approach is required to evaluate critical factors in improving sustainable deliverable effectively. This paper presents significant sustainable factors in IBS construction by considering robust input from key stakeholders. Questionnaire was used as the main tool for data collection. As a result, a conceptual framework is being produced. The result showed that there are many statistically significant factors in improving sustainability in IBS construction. The correlation between factors was also investigated. As the outcome, an efficient guideline for stakeholders could incorporate sustainability issues and concepts into IBS applications. This paper developed a conceptual model to integrate sustainable considerations in a modern method construction which is IBS. The model expanded on the triple bottom line (TBL) of "economy", "environment" and "social"; and further added the "technical quality" and "implementation and enforcement" consideration to enhance sustainable deliverables in IBS construction. Should all these main four criteria of concerns be addressed, it is postulated that this would help support the wider adoption of IBS within the construction industry in the developing country such as Malaysia; and furthermore created a unified understanding between key stakeholders to achieve sustainability goals.

Keywords: *Sustainability, Industrialised Building System (IBS), prefabrication, factors, decision making*

1.0 INTRODUCTION

Industrialised Building System (IBS) is a construction system with a combination of components manufactured either on or off site then positioned and assembled into structures [CIDB 1]. Also known as prefabrication, offsite production (OSP) and modern methods of construction (MMC) in the other parts of the world, the objective of this innovation is to move some of the effort that conventionally executes on the site works into a controlled environment of a manufacturing facility [2]. The production in a controlled environment reduces the number of workers involved, construction time, cost and construction waste. On the other hand, it also increases quality of buildings, utilises more effective resources, and enhances occupational health and safety. In addition, several reports from developed countries such as *Rethinking Construction* [3], *Current Practice and Potential Uses of Prefabrication* [4] and *Construction 2020: A vision for Australia's Property and Construction Industry* [5] are looking at IBS as future directions for improving industry over the next decade. This construction system is a key to improve efficiency and cost effectiveness in the industry. These advantages and directions provide opportunities for IBS in contributing towards the agenda of sustainable building projects.

However, according to previous reports, the usage level of IBS in the Malaysia construction industry stands at 15 % in 2003 and only 10 % in 2006. This achievement is very low as compared to forecasting IBS project provided by Construction Industry Development Board (CIDB) which is 50 % in 2006 [1]. This situation is very disappointed and unexpected due to enormous benefits of IBS. Interestingly, this situation still happens even the Malaysian government is supporting this type of construction by endorsing the IBS Roadmap 2003-2010 and offers incentives for IBS adopters such as levy exemption and eligible for Accelerated Capital Allowances (ACA) for a period of three years [MIDA 6]. Possible reasons include limited understanding among stakeholders on the potential of IBS, specifically in improving sustainability for the long term. Most of the stakeholders have negative perceptions in IBS and are unable to foresee the benefits of this approach. Unsuccessful past experiences associated with this approach such as joint failure, water leaking and higher cost also contribute to the reluctance to adopt IBS practices. Therefore, feasibility for change is difficult. Moreover, decision making in the selection of this approach is not made consistently due to the lack of decision tools that embrace the concept of sustainability.

This paper engaged a quantitative approach to analyse primary data from the survey to explore the understanding of the potential of IBS in enhancing sustainability. This is required before a wider adoption taken place and accelerates the usage level. Specifically, an integrated assessment process and an effective collaboration between key stakeholders on the key attributes and evaluation of sustainability factors need to be strategized towards sustainable IBS delivery. Key stakeholder's involvement such as manufacturer, designer, contractor, authority and user is imperative to ensure the success of the construction project. They need to work together by providing consensus input for the decision making. Based on the previous intensive literature review, the authors expanded Triple Bottom Line (economic, social and environment) to another two important dimensions, which are technical quality and implementation and enforcement.

2.0 ECONOMICAL VALUE

As a developing country, Malaysia is moving towards a sustained growth rate that has been proposed in the Brundtland commission report. According to the report, a sustained growth rate in the developing countries should be about 5 to 6 %. This is required to provide an economic basis for an increased level of distributional equity without placing any restrictions. To support this vision, the Construction Industry Development Board Malaysia (CIDB) has identified the importance of increasing the level of knowledge within the construction community in the Malaysian Construction Industry Master Plan 2005-2015 [7]. This approach is mandatory to drive changes in the local construction market to pursue long term sustainability and to ensure sustainable capabilities to the stakeholders. In addition, the improvement will enhance the ability of local construction players to compete in the global market by emerging sustainable development principles. However, it is important to note that the progress of adopting sustainability in the Malaysian construction industry is still at the early stage and awareness on this issue should be improved immediately [8].

Yang et al. [9] stated that most of the economist measuring the status quo of the economy and the central measure of Gross Domestic Product (GDP) as the proxy for development. Environmentally friendly outcomes are always expected to involve huge financial burdens up front and costly. A new paradigm is required to ensure the harmonisation of the world development. The economic principle in sustainable construction requires equitable distribution of costs and benefits to all parties without neglecting ethics and local economies [10]. The economic value in IBS construction is the attributes that reduce a not only tangible cost but also intangible costs for the whole building lifecycle. Tangible cost is a quantifiable cost or expenses arising from identifiable source or asset such as purchasing construction materials, paying salaries or renting equipments and machineries.

On the other hand, intangible cost is difficult to quantify and do not have a firm value. Estimations of the value are based on experienced and assumption. It represents a variety of expenses such as losses in productivity, marketing strategy or workers morale and motivation. The economic consideration in sustainable deliverables is expanded including in terms of flexibility, adaptability and local or domestic situation. Individuals, nations, generations and long-term effect are all being considered in setting the economic value in IBS construction.

According to Aldridge et al. [11], efficiency and effectiveness are mandatory in measuring economic value in the IBS construction. Efficiency is the ability to execute construction projects with a minimum amount of quantity waste, expense, or unnecessary effort, which is financially measureable by using a track record of expenses, time sheets or any documents that can be used to make a comparison. Effectiveness is the ability to do right things, which will eliminate the financial losses. It is also measureable by setting right targets to achieve a profit in financial perspective such as greater certainty of cost and time estimating. The benefits of IBS are largely dependent on design and specification of the buildings. The combination of building methods being used on a project also plays an important role [12]. For example, a building probably consists of three different types of IBS structural classifications. Probably precast concrete for the column and beam, timber structure for roof trusses and steel formwork for the slab. Each type of IBS is given different benefits and advantages.

Blismas et al. [12] highlighted that the main advantages of IBS in the financial perspectives are the quality, speed of construction and cost savings. The constructed buildings are ready to be used in shorter time with a low cost. Maintenance and operations costs are reduced with the high quality characteristic in IBS. Moreover, their research states that cost for labour and materials are also reduced in IBS implementation. Waste reduction and controlled usage of materials contribute to the savings of the overall cost of the project. Another study conducted by Jaillon and Poon [13] found that IBS demonstrated the good benefits of cost saving by reducing 16 % labour requirement on-site and 15 % of construction time. Furthermore, the implementation of IBS will enable standardisation process and reduce construction time substantially, shorten lead times, improve quality control and reduce material when it is employed efficiently [14-15].

Economic efficiency plays a key role in ensuring optimal consumption and production, especially in a construction project. This major contribution of sustainability should be measured with the assessment tools to evaluate the potential of IBS construction in enhancing sustainability. Some assessment tools, such as BREEAM and LEED, do not include financial aspects in the evaluation framework [16]. The challenge for the construction industry is to deliver economic buildings that maintain or enhance the quality of life, while at the same time reducing the impact of the social, economic and environmental burdens from the community.

2.1 ECOLOGICAL PERFORMANCE

Construction industry is recognized as major users of natural resources, especially energy and building materials. The construction activities normally will cause a nuisance to an adjacent area such as dust, noise, traffic congestion and more importantly generating a huge amount of construction waste. Therefore, several studies have called for the need to mitigate the considerable ecological performance. Interestingly, most understanding of the stakeholders to embrace sustainability has initially focused on environment issues before it is expanded to economic, social and institutional sustainability [8].

Spangenberg [17] defined environmental dimension as the sum of all bio-geological processes and their elements. Any attributes that will increase the possibility in IBS construction to preserve natural resources and reduce negative impact to environment are mandatory to ensure environment sustainability. Improvements in IBS components quality ensure consistent standards of insulation and service installation which reduced an operational energy. Moreover, IBS has major benefits in environmental, namely material conservation, reduction in waste and air pollution. This is proven by several researchers such as Jaillon et al. [18], Baldwin et al. [19] and Tam et al. [20] in their papers. The IBS components are locally manufactured using local products in reusable moulds. This will significantly reduce transportation cost and traffic congestion. Moreover, the construction waste is minimized and most of the manufacturing waste is recycled.

2.2 TECHNICAL QUALITY

Technical quality is the factor that provides physically measurable attributes of procedures in IBS construction by meeting professional standards. Controlled production environment reduces defects and damages for IBS components as well as improves durability of the buildings. Adaptability and flexibility features in IBS allow the system to fit in different building functions and accommodate the future technical condition. For example, the modular systems applied in the IBS can be reconfigured for reuse or recycling [21]. Any planned changes would be easier to be adapted, of which, this is the unique characteristic of IBS [22].

Furthermore, technical quality is important in improving durability and constructability. It will reduce construction cost and also maintenance and operation cost. Technical quality impacts are needed to accommodate of structural and architectural requirement. Building loads, foundation requisite and aesthetic requirement are some of the values to be considered. An evaluation of IBS in term of technical quality helps to identify both the narrow and broad impacts of this system in improving sustainable deliverables. Consistency of quality in IBS is easier to achieve because of the controlled production.

The integration of the technical quality in sustainability evaluation assists authorities to assess the system conformity to their respective building regulations and standards. The designer also could evaluate the safety and structural requirement of the buildings in decision making in improving sustainable deliverables.

2.3 SOCIAL EQUITY AND CULTURE

Social equity and culture are the factors that offer long-term opportunities for workers and enhance the quality of life in the local community. It is vital in sustaining the well-being of the people and communities in which the IBS construction is to be operated. As suggested in CIB report, Agenda 21 on sustainable construction [23], approaches in the planning, design or construction of a built environment should focus on ‘people centred’ and ‘socially inclusive’ in ensuring the successful of sustainable development.

Health of occupants, local economy and working conditions are among the factors that could improve sustainable deliverables in IBS. These factors will impact the development of the country by contributing to wealth and job opportunities. Culture in different regions contained different perspectives and views. In Malaysia, construction industry has a negative and bad image whereas the local workforces are reluctant to work in this industry. Issues such as low wages, low emphasis on occupational safety and health and heavy physical works have created an image of dirty, difficult and dangerous (3D) industry [24].

IBS has a potential to eliminate these images and improving local communities by promoting systematic construction process and local resources usage. The integration of sustainability in IBS construction would create a healthy and safe working condition, distribute an equitable manner social costs and benefits of construction and also contribute to employment opportunity. These additional values will improve the image of the construction and sustainability development.

2.4 IMPLEMENTATION AND ENFORCEMENT

Implementation and enforcement are the factors that ensure any planning will be carried out accordingly. Any good planning will be meaningless without proper implementation and enforcement. In Malaysia, government illustrates full commitment to implement IBS in minimising construction time and reducing the number of unskilled foreign workers in the industry. The commitment is well documented in government policy such as Construction Industry Master Plan 2006-2015 and Roadmap for Industrialised Building System (IBS) in Malaysia 2011-2015. In addition, the government has put forward regulatory requirements and incentives in order to promote IBS [7].

Strongly emphasized in previous papers [17, 25-28], institutional objectives must be complement to other sustainable objectives (economic, environment and social) to ensure the successful of sustainable development. Participation and collaboration from the governance are the important elements to integrate sustainability in decision making. This scenario will provide a strong platform on the overall implementation of sustainable initiatives.

3.0 RESEARCH METHODOLOGY

The main objective of this research is to evaluate potential factors in improving sustainable deliverables in IBS. This paper aims to gain critical factors based on consensus among the key stakeholder in this type of construction. Recent literature on the sustainability factors for IBS construction in covering for developed countries and lack investigation on developing countries. According to Shafii et al. [29], it is important that the local and regional characteristics in the physical environment are taken into account when identifying the factors or measuring the level of sustainability. A systematic description of situational preconditions and restrictions based on local conditions would be an important instrument in the adaptation of building processes to the physical surroundings and societal environments. The problems of poverty and rural development or social equity are sometimes ignored in the sustainable considerations. In an attempt to reflect on the potential sustainability factors in Malaysia, a list of combined factors from previous study were included in the questionnaire for the respondents to identify the most appropriate factors.

The questionnaire was divided into five sections exploring potential factors in improving sustainable deliverables in IBS construction. Respondents' demography, background and level of experience were identified in part 1. Then, in part 2, the potential sustainable factors were listed to help respondents rate the level of significance for each factor. In the questionnaire, five-point Likert scale were used with "5" indicating "very significant" and "1" indicating "very insignificant". Part 3 investigated the correlation between major categories in IBS construction and sustainable developments. Additional spaces were provided for respondents to supply additional comments in part 4. The final section of the questionnaire invited respondents to participate for the future investigation in the research.

In this study, designer/consultant company, manufacturer company, user/facility management company, client/developer company, research or academic institution, and authority/government agency are selected as the key stakeholders. They are selected because of their contribution to this industry and interdependence between each others in improving project sustainability. The list of potential respondents was extracted from the official list of professionals (for example: from the Construction and Industry Development Board, Industrialised Building System Centre, Green Building Index Malaysia). Their background was reviewed as to elicit their potential in participating in the survey. The questionnaire was sent to 300 individuals and 115 responded which giving a response rate of 38 per cent. According to previous researchers, the response rate for construction industry is between 20 to 30 per cent and therefore it is acceptable [e.g 30, 31]. Figure 1 shows the percentages of respondents according to their organisation types.

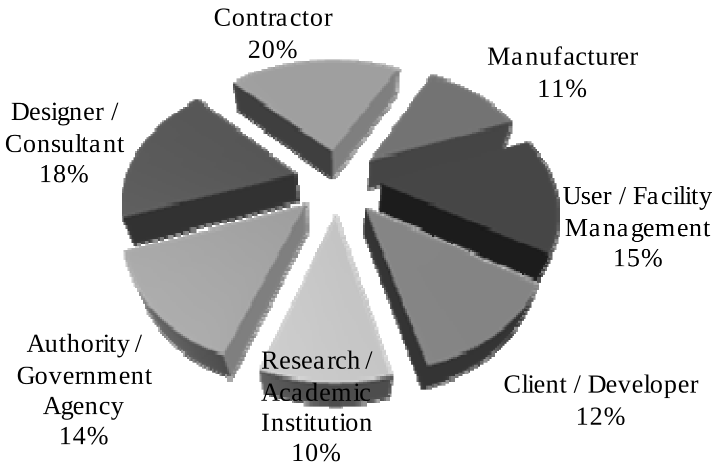

Figure 1: Distribution of respondent by organisation type

To capture the consensus among the stakeholders in deciding critical sustainable factors for IBS, quantitative analysis was used to investigate the cluster of relationship and level of significance. Various tests were conducted to identify appropriate factors which represents unified view from all stakeholders; this include Mean Test, t-Test, Analysis of variance, and Mann-Whitney test. All the analysis was performed with the assistance of Predictive Analytics Software (PASW) Statistics 18.0 which previously used to be known as Statistical Packages for Social Science (SPSS) Statistics.

4.0 THE QUANTITATIVE ANALYSIS

The data from received questionnaires were sorted in Microsoft Excel before imported in PASW 18.0. Mean analysis was conducted to identify the relative significant of critical sustainable factors based on the survey data. It must be noted that the ratings in the scale indicate only the level of significance of the factor, rather than how much more significant each rating is than the other. Therefore, non parametric procedures must be adopted to produce meaningful results [32]. Based on the mean value, the ranking results for each criteria category (e.g., economical value), and for all criteria are presented in Table 1. The total of investigated factors is 62, however only 37 factors were selected by the respondents as “significant” and “very significant”. The cut-off value for the mean analysis is 4.00 as this value represents “significant” in the Likert scale.

According to Table 1, a total of 37 factors, consisting of 6 economical value criteria, 9 ecological performance criteria, 7 social equity and culture criteria, 6 technical quality criteria, 9 implementation and enforcement criteria, were recorded to have significant level. However, to identify the critical factors, t test was conducted to eliminate factors that have t-value lower than 1.6598. As a result, only 26 factors can be accepted as critical sustainable factors in IBS construction.

Table 1: Ranking of the 37 sustainable factors for IBS construction

Sustainable Factors	Mean	Std. Deviation	Mean ranking	*t*-value
Economical value				
Construction time	4.64	.665	1	11.186*
Production	4.52	.742	2	8.268*
Labour cost	4.39	.780	7	6.066*
Material costs	4.14	.981	18	2.067*
Maintenance and operation costs	4.13	.755	20	2.562*
Life cycle costs	4.08	.829	26	1.660*
Ecological performance				
Waste generation	4.50	.792	3	7.323*
Waste disposal	4.38	.838	8	5.462*

Material consumption	4.28	.785	15	4.514*
Recyclable / renewable contents	4.12	.974	21	1.898*
Site disruption	4.10	.868	24	1.799*
Reusable / recyclable elements	4.08	1.010	29	1.364
Ecology preservation	4.04	.976	34	1.026
Embodied energy	4.01	.987	35	0.665
Water consumption	4.01	1.031	37	0.607
Social equity and culture				
Knowledge and skills	4.45	.797	5	6.753*
Working conditions	4.33	.734	11	5.557*
Labour availability	4.30	.900	14	4.222*
Workers' health and safety	4.14	.926	17	2.190*
Site attributes	4.10	.868	23	1.799*
Community disturbance	4.04	.940	33	1.066
Traffic congestion	4.01	.940	36	0.638
Sustainable Factors	Mean	Std. Deviation	Mean ranking	*t*-value
Technical Quality				
Constructability	4.45	.728	4	7.393*
Defects and damages	4.41	.687	6	7.161*
Durability	4.36	.797	10	5.471*
Usage efficiency	4.30	.728	13	5.223*
Adaptability and flexibility	4.10	.917	22	1.703*
Loading capacity	4.08	.909	30	1.512
Implementation and enforcement				
Procurement system	4.37	.722	9	6.028*
Standardisation	4.33	.769	12	5.304*
Legislation	4.19	.915	16	2.844*
Project control guidelines	4.14	.895	19	2.275*
Policy and strategy match	4.09	.851	25	1.730*
Design standard and project function	4.08	.918	27	1.502
Transportation and lifting	4.08	1.036	28	1.328
Governance	4.07	.904	31	1.421
Integrated environmental and economic program	4.05	.943	32	1.162
*Critical sustainable factors with t-value > 1.6598				
"Mean" score: 1 = very insignificant and 5 = very significant				

General consensus on the rankings of the critical sustainable factors for IBS construction among different stakeholders is very important in developing efficient guidelines for decision making. Kruskal-Wallis one way ANOVA was conducted for measuring the agreement and investigated either there was a significant difference in rating the significant level of sustainability factors. Table 2 shows, out of 26 factors, only 9 factors have slight differences agreement across the key stakeholders. An agreement of other potential sustainability factors demonstrated that the future developed guidelines have the potential to significantly improve sustainable deliverables in IBS construction. However, it requires further investigation on which factors are significantly different from each other across the group types and the level of disagreement before those 9 factors will be eliminated.

According to Pallant [33], Mann-Whitney test is able to test differences between two independent groups on a continuous measure by comparing two groups in each measurement. The score on the continuous variable is converted to ranks in order to evaluate whether the ranks differ significantly. Table 3 shows the major different views of the respondents on the relative significant level of sustainable factors for IBS. The differences could be noticed among pairs G.1/G.2 (designer/consultant and contractor), G.1/G.3 (designer/consultant and manufacturer), G.1/G.4

(designer/consultant and user), G.2/G.3 (contractor and manufacturer), G.2/G.4 (contractor and user), G.3/G.7 (manufacturer and authority/government agency), G.4/G.7 (user and authority/government agency), G.2/G.5 (contractor and client), G.2/G.7 (contractor and authority/government agency), G.3/G.6 (manufacturer and research/academic institution), G.4/G.6 (user and research/academic institution), G.1/G.5 (designer/consultant and client), G.2/G.6 (contractor and research/academic institution), G.3/G.5 (manufacturer and client) and G.5/G.7 (client and authority/government agency).

It is notable that the maximum numbers of differences in agreement is only six out of nine in the three compared organisations; G.1/G.3 (designer/consultant and manufacturer), G.1/G.4 (designer/consultant and user) and G.3/G.7 (manufacturer and authority/government agency). It seems interesting to find that, although designer/consultant is supposed to design according to user requirement, these two organisations have different perspective in deciding what factors should be selected as the critical factors in improving IBS sustainability. It could be assumed that the level of knowledge among designer/consultant may not be parallel with user understanding in improving sustainability. Designer/consultant also have different perception from manufacturer which highlighted the importance to integrate the collaboration between those two stakeholders in improving effectiveness of this construction system. It is also presumed that manufacturer has a conflict of interest with authority/government agencies. In Malaysia, authority/government agencies are forced to increase adoption of this construction system in replacing conventional system. Manufacturer and other players are given incentives to promote IBS construction. The understanding of IBS in enhancing sustainability is expected from this research by providing an integrated decision making guidelines.

Although there are differences in determining critical sustainability factors in IBS construction among the stakeholders, it is notable that the differences occur not more than 50% from the total frequencies of differences. As generally known, different stakeholders have a different focus. For example, contractors are very concerned on costs and profits compared to designer which normally is concerned on aesthetic value and ability of the elements to support structural loads. By integrating these elements as the critical factors, both stakeholders could improve sustainability in IBS construction. It is normal to accept that dissimilar focuses among stakeholders do exist [31]. However, these selected critical factors will be validated by the industries in the next stage of this research by semi-structured interviews. As the nature of this method, it will able to allow participants to have an overall point of view but be sufficiently flexible to explore issues or factors as they arose during the interview session [34]. As a result, these selected critical factors were integrated in the preliminary conceptual model and divided in three major phases in the construction process; pre-construction, construction and post-construction as show in Figure 2.

5.0 FACTORS ENHANCING SUSTAINABLE DELIVERABLES IN PRECONSTRUCTION STAGE

Preconstruction stage is the phases where the client’s needs were identified then the appropriate design solutions were proposed by consultants. Proper planning is required to ensure projects running smoothly and achieve targeted goals. In improving sustainability, the selected critical factors in IBS were sorted in a logical sequence to help stakeholders understand the process of improvement easier. Communication and co-ordination between the project’s participants is very important to ensure the achievement of sustainable goals. As stated by many researchers, the integration of sustainability in the construction projects failed because lack of consideration and inadequate information at the early stage [16, 35]. In this research, ten critical sustainable factors were identified in the preconstruction stage; legislation, project control guidelines, procurement system, standardisation, policy and strategy match, material cost, production, knowledge and skills, material consumption and waste generation.

In this stage, most of the factors involved are categorised as implementation and enforcement. It clearly shows that, for developing countries such as Malaysia, an effort from the authorities are very important to be a starting point to integrate sustainability. Legislation is the exercise of the power and function of making rules that are agreed which have the force of authority by virtue of their promulgation by an official organisation of state.

The simplification and accuracy to deliver information in IBS provide a clear direction for construction process involved. The control and monitoring process could be easily conducted with an explicit responsibility for every stakeholder involved from an early stage of construction. It is important to note that standardisation will enable mass production and reproduction, which certainly reduced construction cost. In addition, IBS is able to match sustainable policy and strategy designed in order to improve efficiency of the construction works.

For economic value, there are two factors identified in the pre-construction stage, namely material cost and production. The first factor, material cost, includes all the cost involves before the materials transform into IBS components. The cost includes production, deliveries, and storages of the materials. The second factor, production, is related to the ability in reducing cost by repetition, mass production and improves quality of the products. From the social equity and culture perspectives, ‘knowledge and skills’ is vital to ensure the success of IBS implementation. Participants of the IBS projects must have sufficient knowledge and exposure to sustainability technologies in conducting construction works.

Ding [16] highlighted that little concern has been given to the importance in considering ecological performance during the early stage of the construction. In responding to this gap, two factors have been identified for this stage. The factors are material consumption and waste generation. In general, any reduction in on-site works leads to waste reduction because of the controlled environment. IBS also promotes innovation to the more efficient material management or design solution by incorporating sustainability [36].

5.1 FACTORS ENHANCING SUSTAINABLE DELIVERABLES IN CONSTRUCTION STAGE

The construction stage of the IBS project commences after the planning and design have been agreed and then appointed contractor will be responsible for all construction planning and implementation. Compared with many other industries, the construction industry is depending on labours to execute its activities. With supervision from professionals, labourers help to conduct the actual works on construction site based on the design provided. In this research, labour availability and labours cost have been identified as the critical factors in improving sustainability in IBS construction. IBS implementation will affect the labour consumption [37]. The usage of labour will reduce the number of labours needed, limit labours numbers on-site and improving the skill levels of labours. At the same time, IBS implementation will create middle-income workers instead of low-income workers.

There are two technical quality criteria identified in construction process stage, namely 1) defects and damages and 2) constructability. IBS components are delivered to the construction site to be assembled into structure to function as expected in design. Defect and damages will reduce structural performance of the IBS elements and accordingly increase the maintenance and operation cost. Simplification in IBS design assists the contractor to organise activities involved in the appropriate sequence of work efficiently. They are able to ensure continuity of work by managing labour, plant and equipment at an optimum rate. As the result, the construction time is reduced by minimising the duration of production, installation and construction. Lead time advantages in IBS construction will provide ample spaces at construction site and the IBS components can be used immediately as a platform after the installation.

Site attributes, working condition and workers health and safety are the additional three ‘social equity and culture’ dimension in improving sustainability for IBS implementation. IBS implementation will reduce area usage and staging space on site by adopting ‘Just in Time (JIT)’ concept. The operation does not affect the right-of-way and property boundaries and also encourage infrastructure development. The image of construction could be improved since IBS operations provide neat working condition, less risk and easier installation. In term of safety and health, IBS reduces risk of injuries, damages, death and chronic health risks for field workers in dangerous situations during construction or production of IBS components. The footprint of construction work also could be reduced by minimum disturbance to site area such as lesser noise, traffic congestions and air pollution.

Integration of design and construction processes at the early stage will enable multiple synergies in the construction stage [38]. The construction team will enhance sustainability by targeting at the same goal individually. Any potential unsustainable activities such as

Table 2: Kruskal-Wallis Statistic for 26 critical sustainable IBS factors

Sustainable IBS Factor	Designer / Consultant	Contractor	Manufacturer	User	Client	Research / Academic Institution	Authority / Government Agency	Kruskal-Wallis statistics	*p*-value
Construction time	48.48	55.37	66.04	71.26	54.86	59.50	55.38	8.906	.179[a]
Production	43.07	65.78	63.23	60.76	56.64	63.32	56.75	8.544	.201[a]
Labour cost	40.12	59.28	77.42	70.06	55.50	59.32	52.31	16.631	.011[b]
Material costs	42.00	67.41	76.54	69.00	56.04	58.55	40.06	19.833	.003[b]
Maintenance and operation costs	51.14	62.54	65.35	67.68	54.79	51.14	51.75	5.380	.496[a]
Life cycle costs	42.21	64.11	69.31	68.91	55.07	58.55	51.34	10.812	.094[a]
Waste generation	54.64	52.76	58.00	71.88	61.86	54.36	45.71	8.327	.215[a]
Waste disposal	54.95	47.96	59.15	66.15	54.11	55.00	66.29	5.655	.463[a]
Material consumption	43.40	55.98	79.42	71.26	59.36	44.18	48.64	18.429	.005[b]
Recyclable / renewable contents	53.52	54.52	72.58	73.62	54.00	54.59	36.54	15.240	.018[b]
Site disruption	47.24	62.46	56.96	65.85	62.14	66.77	48.56	6.820	.338[a]
Knowledge and skills	64.02	49.20	44.04	62.21	57.61	76.36	57.34	10.772	.096[a]
Working conditions	47.29	61.76	77.50	61.97	59.79	50.86	49.94	10.592	.102[a]
Labour availability	50.86	55.11	66.65	66.85	57.57	49.86	61.06	4.875	.560[a]
Workers' health and safety	54.76	52.85	63.62	73.53	54.43	48.50	58.25	6.743	.345[a]
Site attributes	52.33	61.22	54.15	76.74	59.07	47.68	50.19	9.494	.148[a]
Constructability	40.74	71.98	75.35	63.35	55.25	49.77	48.84	20.032	.003[b]
Defects and damages	53.52	59.09	74.65	71.26	54.39	57.82	37.97	15.425	.017[b]
Durability	44.67	60.46	73.81	63.21	50.04	71.77	51.09	12.464	.052[a]
Usage efficiency	49.19	60.28	66.96	70.62	62.71	52.23	45.44	9.498	.147[a]
Adaptability and flexibility	41.45	68.39	66.58	68.53	48.11	57.55	55.59	12.923	.044[b]
Procurement system	53.81	50.17	57.96	73.62	60.25	54.91	50.32	7.791	.254[a]
Standardisation	53.17	49.76	54.12	73.56	54.54	65.14	60.94	8.033	.236[a]
Legislation	57.14	39.65	62.92	68.94	68.14	50.73	59.07	13.200	.040[b]
Project control guidelines	53.40	50.02	57.00	76.32	58.25	56.36	49.64	9.125	.167[a]
Policy and strategy match	48.14	42.20	65.77	72.65	71.25	64.77	47.11	18.803	.005[b]

df for Kruskal-Wallis test = 6

[a]*p*-value > .05 = there are no differences between the mean ranks of the sustainable factors for IBS between respondent's organisation.

[b]*p*-value < .05 = there are differences between the mean ranks of the sustainable factors for IBS between respondent's organisation.

Table 3: Probability values in Mann-Whitney test on critical sustainable factors

	Group	Defects and damages	Material costs	Labour cost	Constructability	Adaptability and flexibility	Recyclable / renewable contents	Material consumption	Legislation	Policy and strategy match
1	G1/G2	.524	.009*	.030*	.001*	.005*	.852	.114	.053	.315
2	G1/G3	.046*	.003*	.001*	.002*	.027*	.103	.002*	.555	.062
3	G1/G4	.068	.007*	.002*	.026*	.021*	.061	.009*	.201	.009*
4	G1/G5	.925	.153	.094	.156	.530	.971	.132	.261	.018*
5	G1/G6	.688	.108	.094	.305	.113	.850	.884	.570	.091
6	G1/G7	.132	.713	.342	.487	.149	.176	.567	.870	.969
7	G2/G3	.094	.353	.052	.648	.853	.070	.009*	.032*	.041*
8	G2/G4	.155	.913	.218	.307	.843	.035*	.067	.006*	.007*
9	G2/G5	.617	.249	.695	.065	.053	.947	.717	.012*	.015*
10	G2/G6	.898	.381	1.000	.018*	.244	.921	.241	.240	.061
11	G2/G7	.024*	.010*	.468	.016	.169	.065	.404	.058	.363
12	G3/G4	.702	.363	.376	.212	.763	.917	.348	.498	.439
13	G3/G5	.067	.053	.028*	.056	.127	.118	.050	.575	.554
14	G3/G6	.120	.079	.101	.017*	.397	.070	.004*	.255	.918
15	G3/G7	.003*	.007*	.037*	.020*	.313	.004*	.007*	.708	.054
16	G4/G5	.103	.194	.126	.439	.099	.073	.232	.926	.873
17	G4/G6	.192	.280	.326	.217	.292	.039*	.020*	.078	.399
18	G4/G7	.003*	.012*	.116	.177	.220	.002*	.038	.348	.010*
19	G5/G6	.756	.832	.757	.663	.377	.953	.218	.106	.504
20	G5/G7	.126	.128	.716	.539	.480	.167	.348	.411	.018*
21	G6/G7	.077	.083	.552	.828	.847	.062	.728	.533	.077
Frequency		4	6	5	7	3	4	6	3	7

*the probability value is significant at 0.05 level (2-tailed)

G.1-designer /consultant; G.2-contractor; G.3-manufacturer; G.4-user; G.5-client; G.6-research/academic institution; G.7-authority/government agency

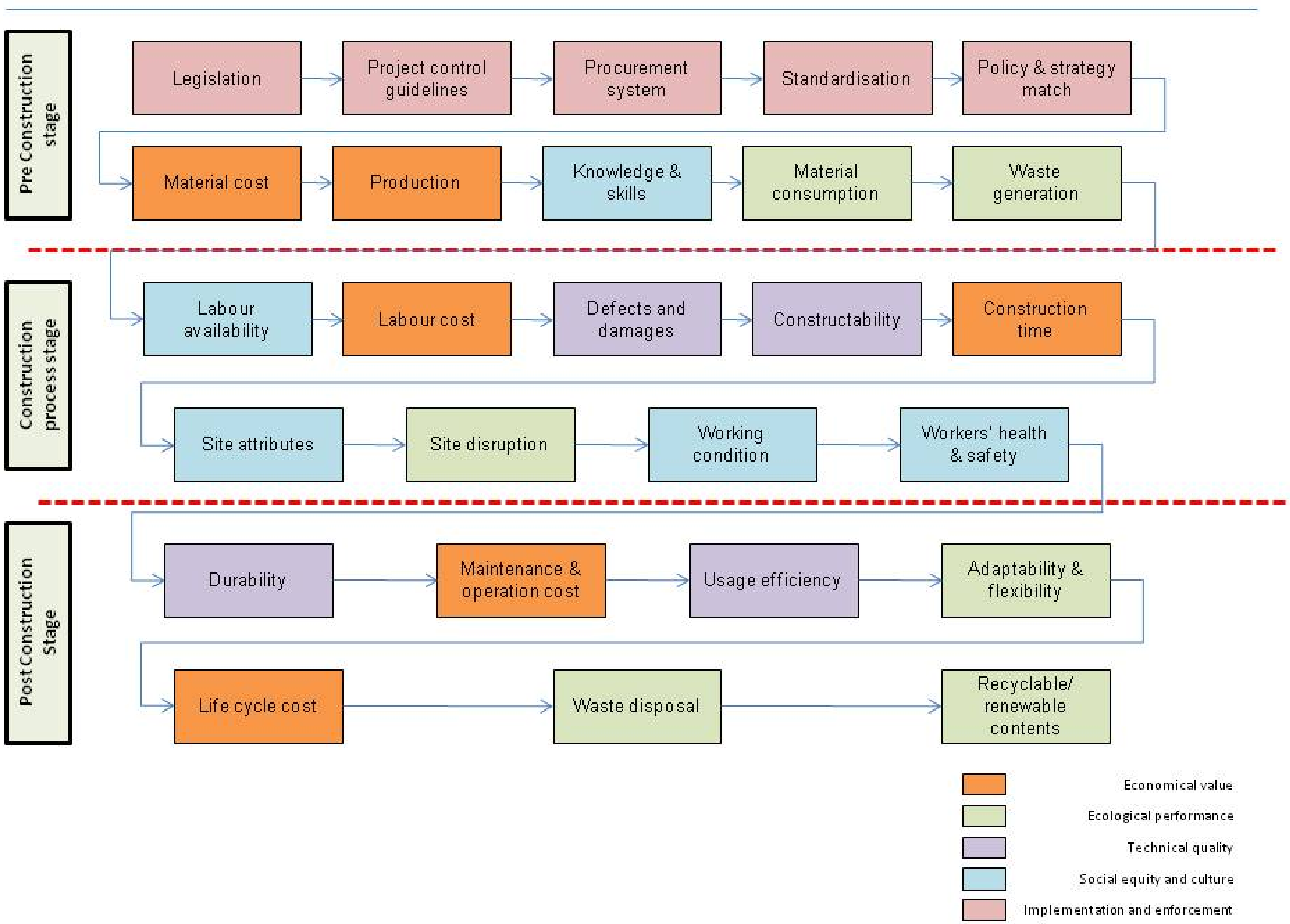

Figure 2: Conceptual model for developing guidelines for decision making in improving sustainable deliverables for IBS construction

resource wastages will be eliminated. People who work on the construction site and surrounding area are the main focus during this stage in improving sustainability.

5.2 FACTORS ENHANCING SUSTAINABLE DELIVERABLES IN POST CONSTRUCTION STAGE

The post construction stage started when the construction work finished. After the final completion, the IBS projects will be handed over to clients to be occupied and function as expected. However, several factors need to be considered to improve sustainability and minimise negative impacts to environment. Most of the previous research, often neglected this stage in improving sustainability deliverables. In this study, seven (7) critical factors have been identified. The factors are: 1) durability, 2) maintenance and operation cost, 3) usage efficiency, 4) adaptability and flexibility, 5) life cycle cost, 6) waste disposal and 7) recyclable/renewable contents.

For technical quality dimension, two (2) critical factors have been identified. The ability of IBS to construct highly durable buildings which have a long usable life, and cost effective improves sustainability deliverables for this type of construction method. Longer spans, slimmer size of column or slab are the examples of IBS characteristics in improving usage efficiency. The capacity of usage is maximized and allows quicker occupancy for assembled components.

From economical perspectives, maintenance and operation cost and life-cycle cost are able to provide sustainability benefits for the long-term in IBS implementation. Proper documentation and as-built drawing provide sufficient information for warranty, specifications and building details. Operation cost can be reduced when the maintenance follow the schedule. High durability and long service life for IBS help in reducing maintenance and operation cost. Lifecycle costing provide the evaluation for economic implications of the overall lifetime cost [39]. The use of such an approach for IBS will ensure the output at the end of the design corresponds to optimal and rational plan for maintenance and operation.

The ecological performance does not only depend on the material itself and the rest of components that perform the function with it, but also on the way they are put in place, for example, the operation and maintenance requirements, on the system longevity and location of the IBS buildings. In this study, three (3) critical factors have been identified; 1) adaptability and flexibility, 2) waste disposal and 3) recyclable/renewable contents. IBS implementation allows adaptability and flexibility for changes in accommodating future trends or modification, which not only reduces cost but also preserve environment. As identified by previous researchers, IBS have a huge potential in reducing waste arising during design and construction phases [18, 40-41]. The wastes from IBS implementation are too little because of controlled environment during production. In addition, the production of IBS components can use recyclable or renewable contents such as fly ash, silica fume and blast-furnace slag.

6.0 CONCLUSION

The construction industry is under emergency to response to sustainable awareness around the globe. IBS is seen as the perfect system to improve productivity and effectiveness in construction industry and at the same time ensures the success of sustainable development. This paper presents the factors that enhance sustainable deliverables in IBS construction. The statistical significant factors are well distributed among three main phases in IBS construction namely; pre-construction, construction and post construction stage. By expanding triple bottom line (TBL) with institutional dimensions in enhancing sustainability for IBS implementation. The importance of integration among stakeholders as well as developing guidelines is enormous, given its significant potentials to continually improve the overall sustainability of IBS construction.

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