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The Drivers and Challenges of Adopting the Malaysia Industrialised Building System for Sustainable Infrastructure Development

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Abstract

Malaysia's Industrialised Building System (IBS) has been increasingly adopted for sustainable development by the country's construction industry. However, although it has been used for commercial building projects, its application to sustainable infrastructure development has been limited to date. This study examines the drivers and challenges involved. A preliminary conceptual framework was initially developed based on a systematic literature review. Semi-structured interviews involving twenty participants were undertaken to gain insightful thoughts from the construction practitioners to discover the perception towards IBS application in the construction industry, the applicability of IBS particularly in infrastructure projects, the strategies of IBS delivery and the sustainable potential of its application. A two-round Delphi study was conducted with fifteen experienced and knowledgeable panellists to further identify, verify and prioritise factors developed from the literature review and interview findings. Then, the results were synthesised and triangulated to demonstrate a holistic insight. The results show the main drivers to be better productivity, quality, environmental, safety and health, constructability design and cost, policy and requirements, with the main challenges being project planning and cost-related issues, inexperience and industry capacity. The study's main contribution is in systematically determining the practical implications involved in applying the IBS to sustainable infrastructure developments in Malaysia and other similar developing countries.

Keywords:

Industrialised Building System, sustainable development, infrastructure, Malaysia.

1. Introduction

As with many around the world, the Malaysian construction industry's productivity and performance is quite poor relative to such other industries as manufacturing, pharmaceuticals, etc. (Chia et al., 2012). In seeking improvements, the Government of Malaysia (GoM) developed its 2006-2015

Construction Industry Master Plan (CIMP) to uphold sustainable construction in Malaysia (CIDB, 2015). The importance of an industrialised building system (IBS) is specifically emphasised for CIMP's greater success.

Malaysia's IBS is an innovative construction system comprising a specialised construction method that adopts prefabricated or precast components through off-site construction or modularisation. It is said to be a sound approach for minimising whole-life-cycle costs (Chen et al., 2010), increased quality and productivity (Boyd et al., 2013; Jaillon & Poon, 2008), enhanced environmental preservation (Bari et al., 2012; Lachimpadi et al., 2012; Yunus & Yang, 2014) and reduced construction waste (Tam et al., 2007).

Despite the potentials of the IBS in sustainable construction, the application of the IBS approach to infrastructure projects in Malaysia has received only limited attention and its drivers and challenges in practical applications in different kinds of construction projects have yet to be established with any rigour. Although the number of studies of IBS have been increasing, many discuss IBS implementation in general (Blismas & Wakefield, 2009) or just focus on multi-storey buildings (Arif et al., 2010; Boyd et al., 2013; Jaillon & Poon, 2008; Meiling et al., 2014; Pan et al., 2012; Pons & Wadel, 2011). Moreover, as long ago as 2003, however, a survey conducted by CIDB of Malaysia found the usage level of IBS in local construction industry standing at only 15% (IBS Survey, 2003), with the consequent rectification step taken with a government mandate stating that all government *infrastructure projects* from 2008 should be at least 70% IBS-based (IBS components usage not less than 70%). Despite this, there is limited research on the actual applications of IBS to infrastructure projects for sustainability in Malaysia. The respective drivers and challenges of IBS adoption to sustainable infrastructure projects in Malaysia have not been well-researched with rigour.

In response, this study systematically explores the drivers and challenges in applying the IBS to sustainable infrastructure developments in Malaysia. The findings will contribute to a wider application of IBS to sustainable infrastructure development in Malaysia and other developing countries.

2. Literature review

2.1 IBS and infrastructure projects

The application of the industrialisation concept has emerged in the construction innovation field, introducing a unitised building using off-site construction. For example, Soriano et al. (2014) proposed a modular house, with prefabricated and industrialised elements built by an assembly process. Lawson et al. (2012) suggested the modular approach that can be applicable to different building types if suitable materials are critically selected. Crowther (2005) designed a disassembly guide to use interchangeable building parts for modular designs, prefabricated sub-assemblies and mass-production systems. Initiated by the Ministry of Housing and Local Government in the 1960s, Malaysia's IBS is being increasingly adopted in construction development, especially for multi-storey residential and commercial buildings (Boyd et al., 2013; Jaillon & Poon, 2008; Lawson et al., 2012; Lee et al., 2014) but it has not yet been widely adopted for infrastructure projects (Eriksson et al., 2014).

Construction industrialisation by standardised products and processes is challenging for some infrastructure developments (Larsson et al., 2014). It is unusual to see IBS applications in infrastructure projects because only limited types of components and subsystems of infrastructures are suitable for standardisation and prefabrication. Accelerated bridge construction is one of the infrastructure projects that obviates the need for cast-in-place activities by the application of prefabricated components such as decks, piers, abutments, walls and girders (Hällmark et al., 2012). Using IBS for accelerated bridge construction can help minimise site works, reduce construction time and provide a safer work environment. For example, Michigan's old Parkview Avenue Bridge replacement project employed a fully prefabricated element system to achieve significant cost and time savings (Attanayake et al., 2014). Other examples of infrastructure components that can be standardised and prefabricated include tunnel linings, noise barriers, retaining walls, edge beams, bridge foundations and permanent concrete casting moulds (Larsson et al., 2014).

IBS application to infrastructure will contribute to achieving sustainability during the operation and maintenance stage of infrastructures. For example, design for disassembly (DfD) and industrialised, flexible and demountable (IFD) should be considered in project life cycle of sustainable infrastructure developments. Using IBS for DfD and IFD will allow sustainability to be maximised in the whole project life cycle (Jaillon & Poon, 2010).

2.2 Drivers and challenges of IBS for sustainable infrastructure projects

Malaysia's IBS is regarded by many as a sound approach for minimising whole-life-cycle costs (Chen et al., 2010; Wuni & Shen, 2019) by promoting the efficient use of resources through the minimisation of manpower, construction processes and waste of materials (CIDB, 2003, 2015; Crowther, 2005; Jaillon & Poon, 2008; Olmati et al., 2015; Tam et al., 2007) to obtain up to 25% on-site labour cost savings (Kamali & Hewage, 2016) and reducing up to 50% of construction time through less downtime, less machines on-site, less transportation of workers and just-in-time material procurement practices (Smith & Quale, 2017). However, prefabrication does not necessarily save costs (Jaillon and Poon, 2008): cost and lead time are the most prominent factors for industrialisation in infrastructure projects (Eriksson et al., 2014; Larsson et al., 2014; Gan et al., 2018). There may be a high initial cost for a component mould design, uneconomical scenarios for small scale production, lack of low price local raw materials and an excess of cheap foreign labour (Lachimpadi et al., 2012; Tam et al., 2007). In addition, contractors involved in design-bid-build contracts tend to focus on short-term, instead of whole life cycle, project costs (Eriksson et al., 2014).

The IBS should also lead to better quality control and assurance (Boyd et al., 2013; Ibrahim et al., 2019; Jaillon & Poon, 2008) in allowing construction processes to be carried out in a controlled environment, which can minimise disruptions and uncertainties on-site such as 'wet-trades' and weather conditions (Gibb & Isack, 2003). It can also be supported by laser scanning, industrial cameras and BIM, as well as digital fabrication and automation techniques in component production (Qi et al., 2020). However, as a higher quality is expected from factory-produced building components, the lack of manufacturer or supplier skills, as well as insufficient R&D investment, can also impede success in practice (Boyd et al., 2013).

A further issue is that prefabrication applications are time-consuming in initial design development, requiring careful planning, as they are generally not amenable to design changes (Tam et al., 2007) and a lack of consideration in the planning and design stage of IBS applications can result in limited space for placing and storing the prefabricated components on site (Jaillon & Poon, 2008; Tam et al., 2007; Wuni and Shen, 2020).

Other challenges limiting the uptake of IBS that are typical of developing countries can be categorised into attitudinal, industry, process, financial, technical, aesthetic, knowledge and policy (Wuni & Shen, 2020). Key construction industry players have a major role but tend to be conservative and sceptical towards such construction innovations as IBS (Qi et al., 2020), with Dosumu & Aigbavboa (2018), for instance, finding that only a few project developers have embraced such innovations. Many consultants and contractors also have reservations because of the unknown risks and potential loss of profit involved due to the construction industry lacking sufficient awareness and knowledge (Wuni & Shen, 2020), and IBS not being commonly included in education and training at professional and trades level. With limited awareness, knowledge and experience in IBS, the construction industry faces technical and process management challenges of using IBS logistics (Jiang et al., 2018; Wuni & Shen, 2019), storage (Li et al., 2017) and supply chain arrangements of manufactured components (Luo et al., 2019). In addition, Luo et al. (2015) identify "poor cooperation between multi-interfaces", "inappropriate design codes and standards", "enormous difficulty in obtaining a sufficient return on high initial investment" and "lack of a quality monitoring mechanism for the production process" as the major risks involved in implementing the IBS.

Although some of the IBS drivers and challenges discussed above are generalised regardless of project characteristics, they are likely to depend on project type, design of physical structure, location of projects, budget limitations and procurement system, as well as project objectives. For instance, commercial building projects located in a new development area probably face less challenges of limited component storage space compared to the construction of railway transits in a traffic area. Similarly, an airport may require a better aesthetic appearance – involving specialised and exclusive architectural design – than a school design, and therefore become a greater challenge to apply the IBS. Therefore, the construction stakeholders' perspectives (Luo et al., 2019) need to be explored in assessing the applicability and practicality of IBS infrastructure development.

3. Research methods

Semi-structured interviews and a two-round Delphi survey are used. The former is employed to gain insightful thoughts from the construction practitioners to discover the perception towards IBS application in the construction industry, the applicability of IBS particularly in infrastructure projects, the strategies of IBS delivery and the sustainable potential of its application. This goes beyond answering "what" questions and addresses the reasons "why" (Saunders et al., 2009), and is therefore suited to the study's highly exploratory nature due to the limited *a priori* information available regarding the application of the IBS to sustainable infrastructure projects. This, together with a systematic literature review, also identified a total of 29 drivers (see Table 5 Round 1) and 23 challenges (see Table 6 Round 1) of IBS infrastructure projects relevant to the Malaysian construction industry. The Delphi study was then conducted to further identify, verify and prioritise the 29 drivers and 23 challenges found.

3.1 Interviews

Data collection

Due to the limited amount of sustainable IBS project work in Malaysia, only twenty individuals were available for the semi-structured interviews (Table 1). However, their lack of numbers is compensated by their representing diverse professional roles, organisation types and levels of experience. With an average of 13 years of relevant experience, all the interviewees have rich knowledge and experience in IBS implementation and/or infrastructure projects in Malaysia: working for contractors, consultants, government agencies, manufacturers and research institutions, their diverse professional background provides a good knowledge base of IBS applications.

Analysis

The interview data were analysed using QSR international's NVivo 11 software to establish appropriate themes and categorised set of nodes. During the coding process, the nodes were compared and modified until they became conceptually clear.

(Insert Table 1)

3.2 Delphi survey

The Delphi technique is a systematic procedure of structuring a group communication process between the researcher and a group of identified experts on a specified topic by assessing the feedback of individual contributions in relation to information and knowledge (Linstone & Turoff, 2002; Yousuf, 2007). The Delphi method is particularly useful when there is lack of empirical evidence and historical data (Ameyaw et al., 2016; Gupta & Clarke, 1996). It is a systematic procedure to gather expert opinion that is particularly appropriate for relatively new topics that require a holistic perspective. The process continues for a predetermined number of rounds or until a predetermined criterion has been met (Sourani & Sohail, 2015).

A total of 25 potential panellists was targeted, including construction project owners, consultants, contractors, suppliers and academics working in research bodies. Five potential participants from each group were approached. Fifteen of the potential panellists expressed their interest and agreed to participate, of which two ceased their participation after the first round of the Delphi survey, leaving only 13 panellists at the completion of the Delphi study. As Table 2 shows, the panellists include three representatives of clients or developers, four representatives of consultants or designers, four representatives of contractors, two representatives of suppliers or manufacturers and two IBS researchers. They have diverse backgrounds and experience relating to IBS implementation, with between 5 and 35 years' construction industry experience. Nine had at least 10 years' experience in infrastructure construction. Although D5 had minimal industry experience in infrastructure construction, D5 had substantial experience in conducting IBS research in the Malaysian construction industry. The panel as a whole formed a wide knowledge base of IBS implementation in the Malaysian construction industry.

(Insert Table 2)

The Delphi survey data were analysed by means and ranks. Mean ratings of 4.0 or above are considered to be high and significant. The level of agreement and inter-quartile range (IQR), the difference between the 75th and 25th percentiles, are calculated to recognise the consensus level of each item, the latter being used to assess the dispersion of the ratings – the lower the IQR, the less dispersed the data points and, therefore, leading more towards a consensus. The level of agreement for each item is given by

$$Level\ of\ agreement\ (\%) = \frac{\Sigma\, panellists\ who\ rate\ 1\ and\ 2}{Total\ number\ of\ panellists} \times 100\%$$

whereby a score of "1" and "2" denotes the item is irrelevant or not important, and

$$Level\ of\ agreement\ (\%) = \frac{\Sigma\, panellists\ who\ rate\ 4\ and\ 5}{Total\ number\ of\ panellists} \times 100\%$$

means the item is relevant or important.

Firstly, items with an IQR equal to or less than 1.0 were considered to reflect a consensus. As IQR lacks sensitivity in distinguishing the degree of agreement, particularly for items with IQR=1.0 (Rayens & Hahn, 2000), the "1" and "2" scores with at least a 60% level of agreement were eliminated as they are considered not relevant. The "4" and "5" scores with at least 60% level of agreement were considered relevant and were retained for further analysis, and those with "3" scores and an IQR of more than 1.0 were included in the round 2 Delphi questionnaire because of there being significant variability in the distribution of responses.

4. Results and findings

4.1 Interview findings

Drivers

As shown in Table 3, the drivers of IBS can be categorised into the aspects of time, cost, quality, productivity, safety and health and policy and regulations.

(Insert Table 3)

The majority of the interviewees agreed that the IBS helped complete projects faster, as it allowed some construction activities to be carried out concurrently. As Interviewee 2 commented:

> *"…you can cast off-site while you are doing the work on the site. So, let's say at the time the piling [is] in progress, the casting activities are already finished."*

The sequence of construction activities involving the IBS is no longer linear. The production of structural elements could be undertaken parallel to other on-site construction activities, which would logically reduce project duration.

Many interviewees agreed that component production under a controlled environment would guarantee higher product quality. As pointed out by Interviewee 12:

> *"The durability is guaranteed because the products which [are] produced by the supplier have been through a process of quality control and quality assurance to ensure internal and external quality."*

Interviewees 2 and 3 commented that the higher quality of components would have extend their lifespan and require minimal maintenance.

In terms of productivity, most interviewees highlighted that conventional construction involved an abundance of cheap foreign labour. As local labour shortages and imported foreign labour has been a critical issue in Malaysia, the minimisation of on-site labour and employment of skilled workers for the IBS application would alleviate this problem.

The IBS eliminates some on-site activities, such as concreting and plastering (I1), as well as eliminating irrelevant construction materials from the use of formwork (I2) and scaffolding (I8). This also provides a cleaner site area with minimal material wastage, therefore keeps the working environment safer (I1, I2, I7, I12, I17 and I19). Moreover, pollution caused by spreading dust and vibration noise from concreting activities can also be avoided (I1 and I11).

In terms of technical aspects, the design requirements and project location demand the application of the IBS. As commented by Interviewee 18:

> *"Engineers prefer to do the simple and easy design, as long as the structure [is] safe. But for the architect, they have their own design, so we have to go for the alternative."*

This situation occurs when a special architectural design or special shape is required for a specific structure. The interviewees believed that a steel structure could be a better option for a very long-span concrete structure (I13, I16 and I18). For projects that are in an urban area, especially those that affect traffic conditions, the IBS would be the best option (I11). Instead of the traditional build-up, the erection and installation of pre-cast components makes the construction process faster while minimising traffic disruption (I7).

Challenges

The interviewees identified the challenges related to the IBS, although believing they could be resolved over time. These challenges can be grouped into three main categories of cost, technical issues and stakeholder awareness and competency (Table 4).

(Insert Table 4)

The majority of the interviewees regarded cost as the main concern in implementing the IBS. Even though some interviewees agreed that cost savings might be achieved, others stated that IBS is expensive (I4, I8, I11, I15 and I17), involving a huge expenditure on the initial investment from upfront payments by the contractor to the supplier (I1) and the buying or renting costs of a reusable formwork system (I4). This explains why some interviewees (I2, I3, I16 and I17) claimed that IBS was uneconomical for small-scale projects. Moreover, limited local materials and resources, such as steel products, contributed to the higher cost of IBS applications (I18). Some interviewees also point out that conventional practice would remain the preferred option because of the availability of cheap foreign labour (I15 and I19).

The interviewees also revealed that there were technical issues impeding the implementation of the IBS, particularly for infrastructure construction projects. Design is a major challenge; for example, a longer lead time is required for the design stage (I6). Every component has to be designed carefully to build up a complete whole unit structure. As the IBS components are prefabricated, this does not allow for prompt design changes after the components are produced. Some of the interviewees found this to be a disadvantage, especially if unexpected problems occur during the installation or construction phases.

Design issues can also be problematic if the architectural design is too futuristic with a unique or elaborate pattern (I1, I2, I8, I12, I16 and I19), especially with the limited variety of standardised components available on the market (I12 and I19). This usually creates conflict between the engineer and the architect. As expressed by Interviewee 2:

> *"They* [*architects*] *prefer to produce something that looks fancy or futuristic. However, they actually don't bother about the construction method… The aesthetical value is more important for their design stand".*

However, there is a significant need for a mutual understanding between both parties to resolve such conflicts. Unfortunately, practitioners have no standard or specification for IBS to refer to (I8, I11 and I15).

The other technical difficulties relate to the delivery and transportation of prefabricated components. Massive structures require many delivery trips, and thus involves huge transportation costs (I2, I8, I11, I14 and I18). Additionally, for a project located in an urban area or close to a nearby traffic route, the delivery scheduling is critical, as there is limited space for temporary component storage (I18). Meanwhile, if the project is situated in a remote area, the cost of transportation becomes higher, and it may not be worthwhile to apply IBS (I17).

Due to the limited number of competent contractors, consultants and manufacturers with relevant experience and knowledge, the interviewees claimed that applying the IBS would be challenging (I3 and I15). As Interviewee 15 explained:

> *"…as long as you have the knowledge and understand how to apply the IBS, then it should be OK. When you don't have them, then you have a lot of limitations."*

4.2 Delphi survey findings

Drivers

The drivers rated by the panellists are presented in Table 5. In Round 1, approximately 60% of the items reached at least 60% agreement for being relevant. However, five of these items had an IQR of more than 1.0, which indicates the ratings scored by the panellists were highly varied. Therefore, only 15 of the 29 items were considered as having reached a consensus in this round, leaving 14 items for reassessment in Round 2.

The agreement between the panellists in the second and final round is improved, with the variation in rating score for each item being smaller – as represented by a decrease in the IQR. "Produce better construction quality" has total agreement in this round. Additionally, another nine items also reach a consensus. Two items ("Offer dismantling ability" and "Increase property value") do not achieve at least 60% agreement, while the scored ratings of the remaining items are highly variable.

(Insert Table 5)

Overall, the top five and bottom five IBS drivers are consistently rated. As Figure 1 shows, the highest rated are related to construction productivity. On the other hand, the factors "cost", "policy" and "others" are ranked substantially lower.

(Insert Fig 1)

Challenges

The results of the rating for the challenges are provided in Table 6. Only seven items reached a consensus in Round 1, with the remaining 11 that achieved 60% of agreement for being relevant having a high variation in ratings. The agreement for being relevant for five items was questionable. Therefore, a total of 16 items relating to challenges were included in the second round of the survey. This time, the majority of the items achieved a better agreement for being relevant, although only 11 items achieved at least 60% agreement. Based on the IQR values, nine items reached a consensus, with a total of 16 items recognised as the challenges of IBS infrastructure projects.

(Insert Table 6)

Most of the challenges were rated between 3.0 to 4.0, which suggests that the panellists might have had difficulty in deciding whether these challenges are relevant or not. With reference to Figure 2, “cost” was the most critical challenge for IBS applications, followed by “knowledge and experience” and “design factors”. Comparing the ratings between the drivers and challenges, the drivers are clearly and considerably more prominent than the challenges.

(Insert Fig 2)

5. Discussion

5.1 Drivers of IBS infrastructure projects

25 out of the total 29 drivers were identified as relevant to the Malaysian construction industry by construction practitioners and researchers from the Delphi study. Of these, *productivity*, *quality*, *environmental*, *safety and health*, *constructability*, *design* and *cost*, as well as *policy and requirements* are considered significant (mean ≥ 4.0) based on the Delphi analysis.

Productivity is the most important driver of IBS infrastructure projects. The IBS simplifies construction activities by breaking down the construction process into several separable locations. This allows site preparation work and component production to be done simultaneously, which is in line with the Construction Industry Transformation Programme 2016-2020 (CITP) target of more than doubling production in the Malaysian construction industry (CIDB, 2015). Moreover, in manufacturing environments, systemised parallel activities and operations lead to higher productivity (Kamali & Hewage, 2016). Component production commonly operates inside a production facility and is thus protected from potential interruptions caused by weather conditions (Durdyev & Ismail, 2016). A large proportion of the construction workforce is low-skilled labour (CIDB, 2015). Defects due to the poor workmanship of an unskilled workforce and underperforming labour may require extensive rework and result in low productivity (Durdyev & Ismail, 2016). Therefore, the employment of machinery for component production can reduce the dependency on labour in IBS applications, and thus also reducing human-made defects. In addition, construction supervision can be optimised by up to 19% by moving on-site work to the manufacturing plant (Abd Hamid et al., 2017). At the same time, the mechanisation and industrialisation in IBS applications means the Malaysian construction sector can reduce reliance on foreign labour (Abd Hamid et al., 2017).

IBS is preferred for *quality performance*. This is consistent with CITP, which encourages the adoption of modern methods of construction to obtain a higher quality score (CIDB, 2015). The manufacturing process assures the production of components fabricated according to design specifications. The accuracy of the instruments and machinery used in the factory promises better consistency of product quality. Boyd et al. (2013) found that establishment of robotic systems in the assembly line allows for close tolerances, predictability and consistency based on a grid design. In addition, quality is measured not only by physical appearance, but also by the extent of the structural strength of each component. Component testing in a factory allows the better control of safety factors and quality conformance. For example, temperature-controlled curing ensures that the quality of the pre-cast component is better than concrete cast in-situ (MIDF, 2014). Moreover, the factory also enables new and advanced materials and processes to be adopted and tested, which is not practical with on-site construction (Blismas & Wakefield, 2009).

Reducing the negative impact to *the environment* is a major concern for the Malaysian construction industry. With an increasing demand for major infrastructure projects, such as rail transit systems, highways and commercial buildings, a large amount of construction waste is being produced. Ecological awareness is critical to ensure that the progress of infrastructure development does not increase the atmospheric burden (Boyle et al., 2010). Minimisation of waste generation is raised by several interviewees, in line with growing academic interest relating to the IBS regarding environmental concerns (Dong & Ng, 2015; Jaillon et al., 2009; Lachimpadi et al., 2012; Yunus & Yang, 2014). The IBS removes such labour-intensive activities as steel bending, formwork fabrication and in-situ concreting. No formwork is used, meaning that no timber or plywood is wasted. IBS eliminates the need for such temporary structures as scaffolding, packaging waste and temporary support for materials handling and hoarding. It contributes to reducing waste at the construction site (Bari et al., 2012).

Most infrastructure projects are located in urban areas or within high traffic areas, and therefore the impact of *health and safety* from such project sites not only relates to construction workers, but also to the neighbourhood community. The IBS provides neater and safer working environments with minimal dormant material and machinery. Moreover, transferring in-situ casting to a more systemised manufacturing process offers better control of hazardous environments. Construction works are considered dirty, difficult and dangerous (Salleh et al., 2014). This pressure reveals the IBS to be an appropriate solution to lift the standard of the local construction industry.

Constructability is an important consideration in project implementation. For infrastructure projects, constructability is defined as the optimum use of construction knowledge and experience throughout the project life cycle to achieve the overall project objectives. At the planning stage, IBS applications provide an easier assessment of cost-driver analyses, as the potential for unexpected consequences is considered low. In terms of design, the IBS increases customisation options for special and complex design requirements, including the utilisation of additives or the substitution of another kind of material. For example, the utilisation of steel structures might be a better option instead of bulky and long spans of concrete structures. During component assembly, the IBS also lessens such installation issues as difficult elevated or restricted work areas due to adjacent structures or those that are over water. The IBS manages to incorporate new design aesthetics of a variety of shapes, finishes and high quality (Azman et al., 2012).

Cost factors are regarded as the driving force for IBS applications in the long run. While the initial costs of implementing IBS are likely to be high, IBS has potential to lower life-cycle costs in the long run. Life-cycle costs not only comprise the initial construction costs, but also include costs due to the design, operation, inspection, maintenance, repair and damage consequences in the structure's lifetime (Frangopol & Liu, 2007). As the IBS is perceived as delivering a good quality component, this may lessen post-construction costs in the long term. As IBS construction is less likely to be affected by such uncontrolled risks as poor workmanship and bad weather conditions, IBS offers cost certainty and allows for comprehensive budget planning. The shorter construction period of IBS allows a quicker return on investment by clients, which, in turn, helps other stakeholders obtain early payment from clients.

Malaysian government *policy* mandated implementing the IBS for government building construction projects in 2005, and this has risen from a target of at least 50% to 70% since 2008 (Hamid et al., 2011). The IBS has not only been used for government projects but has also been adopted for private projects. This factor has greatly driven the progression of IBS applications in the Malaysian construction industry. In recognition of the industry's response, a levy exemption was granted to IBS adopters to promote further IBS adoption. However, this policy is only valid for building construction projects; infrastructure projects such as bridges, tunnels, dams, viaducts and drains are excluded. Adoption of the IBS needs to be client driven. Project developers need to take the initiative to establish their own IBS requirements, and designers and builders need to promote a greater uptake of IBS applications. Consequently, the CITP recommends that the Public Work Department, a key client for most government-linked projects in Malaysia, should establish a requirement for the IBS's incorporation into Pre-Approved Plans to support policy implementation (CIDB, 2015).

5.2 Challenges to IBS infrastructure projects

Of the 23 challenges retrieved from the interviews and the literature, 16 reached consensus as being relevant. Only four were considered significant (mean ≥ 4.0), namely: "a high capital investment", "uneconomic for small-scale projects", "lack of experience" and "highly restrictive construction tolerances". Two of these are cost-related, which is consistent with the panellists' ratings as the most prevalent challenges. Clients and consultants were mostly concerned with the lack of experience, while the contractors and manufacturers found that the IBS was uneconomic for small-scale projects. All of the challenges rated by the participants can be categorised as *project planning* and *cost-related* issues, *inexperience* and *industry capacity*.

Cost-related factors are the biggest challenge. A high capital investment is needed to establish a component production facility, with an IBS manufacturer normally required to advance up to 75% of the capital to manufacture the components (Hamid et al., 2017) – the initial start-up including the cost of purchasing machines, the prefabrication yard, raw materials, moulds, foreign technology transfer and wages of skilled workers (Kamar et al., 2010; Rahman, 2014). As a result, the IBS is not usually economical for small-scale projects, as the production cost per unit is higher if the component order is for small quantities (Pan et al., 2011). An increase in costs is also attributed to the intensive expenditure on component transportation and delivery, especially for infrastructure design that involves oversized components or complex features. Furthermore, it is more challenging if the location of the project is remote from the manufacturing facility. Small contractors usually prefer to use conventional construction techniques for smaller projects. Moreover, conventional practice is often preferable because of the abundance of cheap foreign labour in Malaysia. Malaysian contractors do not pay for skills, relying instead on low cost-resources to generate profits (MIDF, 2014).

Project planning is greatly affected, as the IBS should ideally be taken into consideration at the initiation of a project. This requires the involvement of all stakeholders to ensure that all decision-making in the process of designing, constructing and managing the project execution incorporates IBS considerations, as it is unlikely to be effective and efficient with inappropriate procurement practices. For example, the contractor can face cash flow issues because of the need to deposit a large amount of money upfront to the supplier (regardless of any payment delay by the client). CITP recommends the separation of IBS procurement from the main contract to remove the contractor's financial liquidity burden (CIDB, 2015). Selection of suppliers or product manufacturers can be delayed until the tender stage of the construction supply chain (Kamar et al., 2010), which means that difficulties outside the designers' perspectives are not considered early enough. Conflicting interests between the architect and engineer in the architectural and structural design make it challenging to implement IBS. Moreover, infrastructure with complex and aesthetic features would be a challenge for the designers to apply IBS. Geometrical designs may need to be rationalised (Smith, 2011). Moreover, accuracy of the design configuration is very important as it affects workability in the assembly process. Once the production process begins, further design changes are not expected as even a small change can affect the whole construction phase: an interruption in the manufacturing process due to design adjustment can have a severe impact on production planning, where the concurrent production of components from other construction projects is also scheduled (Kamar et al., 2010).

Inexperience and lack of successful involvement makes stakeholders hesitate to make changes. The tendency to self-enhance also makes decision-makers reluctant to acknowledge the need for change (Audia & Brion, 2007). Moreover, experiencing failure at the first attempt may set them back for the next attempt. While the effort to promote IBS applications began in the last decade, there is still pessimism and scepticism around this method. Bad impressions have been caused by underperformance, such as low quality of buildings, leakage, abandoned projects and monotonic architectural appearances (Kamar et al., 2010). Additionally, some stakeholders, especially contractors, are too comfortable with traditional methods, causing them to be reluctant to become involved with this new venture. IBS application guidelines that are currently available are only applicable for certain types of systems. In practice, applying the IBS to infrastructure projects does not work in isolation; instead, it is a hybrid system. Lack of comprehensive codes and standards for such application leads to pessimism regarding the practicality and workability of the IBS applications as a whole. Undoubtedly, however, most stakeholders have knowledge and awareness of the IBS's drivers, and the project initiator, clients and consultants have the ability to break the "chicken-egg dilemma" by first changing their attitude towards IBS applications. Optimisation of resource allocation for sustainable infrastructure should ideally be driven by the planners and designers of the projects (Norris, 2012).

The local industry does not have sufficient *capacity* for implementing the IBS. Even though there are 237 IBS companies in the Malaysian construction industry, they are just able to fulfil 60% of the demand, with most only able to produce certain housing construction components (CIDB, 2017). The lack of appropriate technology and special equipment needed to provide an advanced production facility is impeding the industry in dealing with the complexity of design features.

6. Conclusions

To conclude, this empirical study found a series of drivers for implementing sustainable IBS infrastructure projects: productivity, quality, environment, constructability, design, cost, policy and regulation. The intuitive nature of these factors encourages their use by stakeholders to identify and develop prospective opportunities to improve and refine their role in promoting use of the IBS for sustainable construction. In addition to the many drivers of the IBS, this study also provides insights into the hitherto unresearched industry practitioner's perceptions of the challenges to expanding sustainable IBS applications. These challenges are due to discrepancies during project planning, cost-related issues and site constraints, as well as an immature industry capacity.

In terms of the number of significant factors, the drivers outnumber the challenges involved. This indicates a positive attitude to sustainable IBS infrastructure projects in Malaysia. By featuring the underlying drivers and challenges, strategies to upgrade the uptake of the IBS for sustainable projects can be better formulated and articulated. However, it also important to note that the real advantages of the IBS for sustainable work can only be realised through a comprehensive understanding of the attributes underpinning the IBS's process flow itself, while also discovering solutions to the challenges to continuously motivate sectors of the industry towards sustainability.

A limitation is that, although this study identified drivers and challenges of sustainable IBS infrastructure development, the context of such projects mentioned during the interviews is not conclusive. Further exploration of IBS applications to specific types of sustainable built infrastructure also needs to be undertaken in future research. Different types of infrastructure projects may have unique characteristics in addition to their specific functions. More research is also needed to determine how the drivers and challenges of using prefabrication in sustainable infrastructure differ from IBS/prefabrication/modular construction for sustainable buildings.

This research contributes to the neglected research area of IBS applications in infrastructure projects for the sustainable development of the construction industry. The findings are not only useful for Malaysia's construction industry to solving the current problems associated with IBS for sustainable infrastructure projects and expanding its adoption but are also applicable to other similar developing countries with an expanding construction sector and infrastructure developments, the extent of which needs to be examined in future research.

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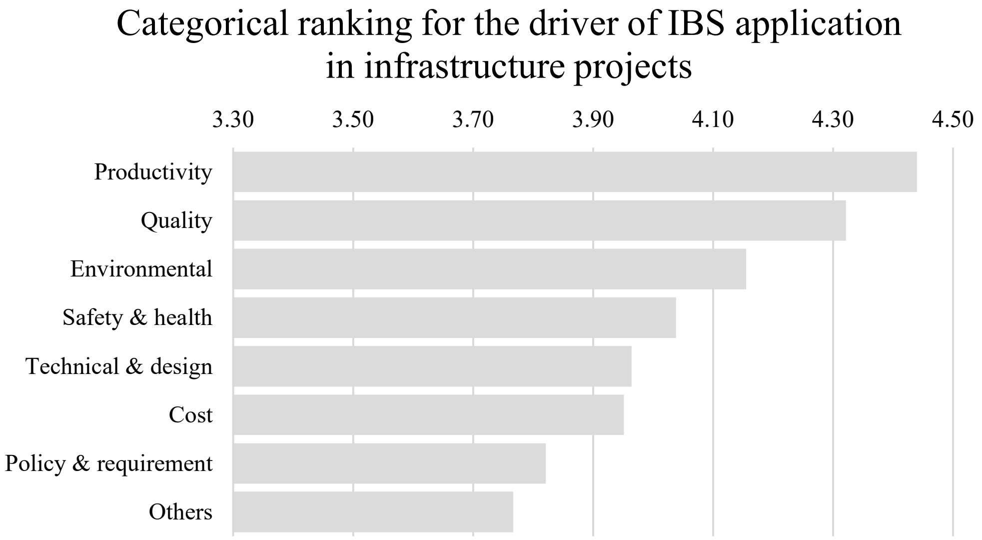

Fig. 1. Drivers of IBS infrastructure projects by category

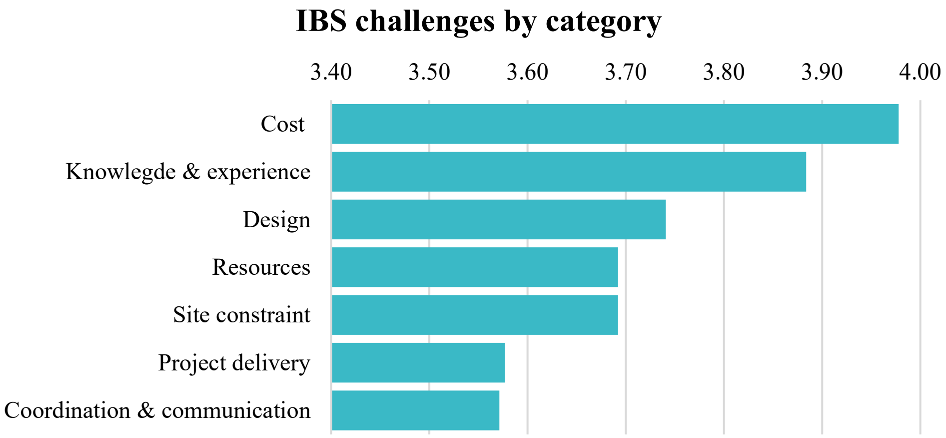

Fig. 2. Challenges of IBS infrastructure projects by category

Table 1. Profile of the interviewees

Interviewee (I)	Interviewee Position	Stakeholder Type	Years of IBS Experience
I1	Director	Manufacturer/ Contractor	5~10
I2	IBS Specialist/ Consultant	Manufacturer/ Consultant	11~20
I3	Consulting Engineer/ IBS Trainer/ Competent Project Manager	CM Consulting/ Government Agency/ Academic Institution	>30
I4	Lead Planning Engineer	Contractor	5~10
I5	Principal Consultant	Contractor	<5
I6	Resident Architect	Consultant	11~20
I7	Resident Architect	Consultant	11~20
I8	Senior Design Engineer	Manufacturer	5~10
I9	Senior IBS Engineer	Manufacturer	11~20
I10	Head of Innovation and Development/ Researcher	Manufacturer	11~20
I11	Director	Architecture Consultant	11~20
I12	Project Engineer	Consultant	5~10
I13	Professor/ Senior Director	Research/ Academic Institution	5~10
I14	Senior Manager	Authority/ Government Agency	11~20
I15	IBS Specialist	Consultant	5~10
I16	Senior Manager	Developer	5~10
I17	Director	Manufacturer/ Consultant	21~30
I18	Construction Manager	Consultant	5~10
I19	Director/ Researcher	Research Institution	21~30
I20	Director/ IBS Consultant/ Trainer	Consultant	11~20

Table 2. Profile of the Delphi panellists

D1	Facility Manager	Client/developer	10
D2	Quantity Surveyor	Contractor	14
D3	Senior Engineer	Consultant/designer	18
D4	Director	Consultant/designer	35
D5	Researcher	Research/academic institution	1
D6	Project Manager	Client/developer	14
D7	Senior Engineer	Consultant/designer	7
D8	Project Manager	Contractor	8
D9	Engineer	Consultant/designer	5
D10	Project Manager	Contractor	3
D11	Researcher	Research/academic institution	10
D12	Construction Manager	Contractor	15
D13	General Manager	Manufacturer/supplier	20
D14	Design Manager	Client/developer	5
D15	Director	Manufacturer/supplier	35

Table 3. Summary of the IBS drivers mentioned by the interviewees

Key aspect	Drivers
Time	Speedy (I2, I3, I11), faster (I2, I13, I20), save time (I4), time reduced (I6), shorten time (I7, I12, I16), expedite (I16, I19)
Cost	Save cost (I4, I7, I18), reduce cost (I6, I8), cost effective (I11)
Quality	Quality controlled (I1, I13), more durable (I2), high quality (I3, I20), precision (I6), guaranteed quality (I12), better quality (I16, I18)
Productivity	Reduce the number of workers (I2), reduce human involvement (I11), reduce power (I12), use of skilled workers (I16), dependent on machinery (I18), simplify tasks (I15)
Safety & Health	Neat and tidy (I1), cleaner site (I2, I13, I19), less wastage lying on the site area (I4), assure/improve safety (I1, I7), improve site cleanliness (I12), less wastage (I4, I13, I17), minimise traffic disruption (I7)
Policy & Regulations	Fulfil government authority requirements (I11), meet clients' requirements (I4)

Note. "I" represents the interviewee number.

Table 4. Summary of the challenges to IBS applications mentioned by the interviewees

Key aspects	Challenges mentioned by the interviewees
Cost	High cost (I4, I8, I11, I15, I17) High capital investment (I1, I3, I4, I5, I11) Uneconomical for small scale work (I2, I3, I16, I17) Limited local resources (I18) Availability of cheap labour (I15, I19)
Technical	Longer lead time (I6) Inflexible design changes (I2, I14, I18) Inappropriate for architectural design aesthetics (I1, I2, I8, I12, I16, I19) Limited variety of standardised components (I12, I19) Lack of a standard/specification for implementing the IBS (I8, I11, I15) Delivery or transportation difficulties (I2, I8, I11, I14, I17, I18) Limited on-site storage space (I2, I18)
Stakeholders' Awareness and Competency	Limited competent contractors (I3, I15) Limited competent consultants (I15) Limited competent manufacturers (I15) Conflicts between stakeholders (I1, I2, I8) Resistant to change (I1)

Table 5. Rating results for the drivers of IBS infrastructure projects

Item		**IQR**	**Level of Agreement (%)**		**Reached Consensus ?**
			Not Agree	**Agree**	
ROUND 1					
1	Speed up on-site construction activities	1.0	0%	100%	YES
2	Reduce dependency on labour	1.0	0%	100%	YES
3	Simplify construction activities	1.0	0%	100%	YES
4	Reduce waste	1.0	0%	100%	YES
5	Allow simultaneous site preparation and construction work (component or panel production)	1.0	0%	100%	YES
6	Optimise consumption of materials	1.0	0%	93%	YES
7	Improve the quality control system	1.0	0%	93%	YES
8	Minimise weather-related delays	1.0	0%	80%	YES
9	Reduce energy consumption	1.0	0%	80%	YES
10	Reduce emissions	1.0	0%	80%	YES
11	Improve constructability	1.0	0%	80%	YES
12	Produce better construction quality	2.0	7%	73%	NO
13	Minimise nuisance (e.g., noise, dust and traffic disturbance) to the site's neighbourhood	2.0	7%	73%	NO
14	Improve recyclability of components (or panels)	2.0	13%	67%	NO
15	Reduce life-cycle costs	2.0	0%	60%	NO
16	Qualify for financial incentives	1.0	7%	73%	YES
17	Improve competitive capacity	1.0	0%	67%	YES
18	Government policy	0.0	13%	80%	YES
19	Reduce space required for materials inventory	1.0	20%	67%	YES
20	Client's requirements	1.0	7%	53%	NO
21	Offer dismantling ability	2.0	7%	47%	NO
22	Provide a safer working environment	2.0	27%	67%	NO
23	Increase speed of return of investment	1.0	20%	53%	NO
24	Reduce material transportation trips	1.0	20%	53%	NO
25	Ensure project cost certainty	1.0	20%	53%	NO
26	Increase customisation options for special and complex design requirements	1.0	20%	33%	NO
27	Offer flexibility	3.0	40%	40%	NO
28	Reduce construction costs	2.0	33%	40%	NO
29	Increase property values	2.0	27%	27%	NO
ROUND 2					
1	Produce better construction quality	1.0	0%	100%	YES
2	Minimise nuisance (e.g., noise, dust and traffic disturbance) to the site's neighbourhood	0.5	0%	92%	YES
3	Improve recyclability of components (or panels)	0.5	0%	77%	YES
4	Reduce life-cycle costs	0.0	0%	85%	YES
5	Client's requirements	0.5	0%	77%	YES
6	Offer dismantling ability	1.0	15%	54%	NO
7	Provide a safer working environment	1.0	8%	77%	YES
8	Increase speed of return of investment	1.0	8%	92%	YES
9	Reduce material transportation trips	1.5	8%	62%	NO
10	Ensure project cost certainty	1.0	8%	69%	YES
11	Increase customisation options for special and complex design requirements	0.0	8%	85%	YES
12	Offer flexibility	1.5	23%	62%	NO

Item		**IQR**	**Level of Agreement (%)**		**Reached Consensus ?**
			Not Agree	**Agree**	
13	Reduce construction costs	1.0	16%	69%	YES
14	Increase property values	1.0	8%	38%	NO

Table 6. Rating results for the challenges of IBS infrastructure projects

Items		**IQR**	**Level of Agreement (%)**		**Reached Consensus?**
			Not Agree	**Agree**	
	ROUND 1				
1	Uneconomic for small-scale projects	1.0	13%	87%	YES
2	Lack of experience	1.0	7%	80%	YES
3	High capital investment	1.0	7%	80%	YES
4	Highly restrictive construction tolerances	2.0	13%	73%	NO
5	Lack of structural and architectural design integration	2.0	20%	73%	NO
6	Negative perception and scepticism	2.0	7%	67%	NO
7	Insufficient knowledge	2.0	20%	73%	NO
8	Inflexible design changes	1.0	13%	67%	YES
9	Lack of flexibility	2.0	13%	67%	NO
10	Lack of codes and standard of application	1.0	20%	80%	YES
11	Poor cooperation between stakeholders	2.0	20%	73%	NO
12	Poor communication between stakeholders	2.0	20%	73%	NO
13	Inappropriate procurement practices	3.0	27%	73%	NO
14	Abundance of cheap labour	1.0	13%	60%	YES
15	Limited variety of standard components (or panels)	2.0	20%	67%	NO
16	Poor integration of the supply chain	1.0	13%	60%	YES
17	Longer lead times for definite project planning and design phases	2.0	27%	53%	NO
18	Restrictive for aesthetic and complex design	2.0	27%	60%	NO
19	Insufficient on-site space for temporary component inventory	2.0	27%	53%	NO
20	Lack of opportunities for standardisation and repetition in design	2.0	33%	60%	NO
21	Remote project site	3.0	40%	47%	NO
22	Lack of special equipment or technology	2.0	33%	27%	NO
23	Poor quality products of components (or panels)	2.0	53%	20%	NO
	ROUND 2				
1	Highly restrictive construction tolerances	0.5	-	85%	YES
2	Lack of structural and architectural design integration	1.0	-	69%	YES
3	Negative perception and scepticism	1.0	-	62%	YES
4	Insufficient knowledge	2.0	-	69%	NO
5	Lack of flexibility	2.0	-	54%	NO
6	Poor cooperation between stakeholders	1.0	-	62%	YES
7	Poor communication between stakeholders	1.0	-	54%	NO
8	Inappropriate procurement practices	1.0	-	62%	YES
9	Limited variability of standard components (or panels)	1.5	-	69%	NO
10	Longer lead times for definite project planning and design phases	1.0	-	69%	YES
11	Restrictive for aesthetic and complex design	1.0	-	62%	YES
12	Insufficient on-site space for temporary component inventory	2.0	-	54%	NO
13	Lack of opportunities for standardisation and repetition in design	2.0	-	54%	NO
14	Remote project site	1.0	-	62%	YES

Items		IQR	Level of Agreement (%)		Reached Consensus?
			Not Agree	Agree	
15	Lack of special equipment or technology	1.0	-	62%	YES
16	Poor quality products of components (or panels)	1.5	-	46%	NO