# Four-pronged decision support framework for implementing industrialized construction projects

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## Abstract

**Purpose** – Industrialized construction is promoted to address some of the ills associated with the processes and products of the traditional construction approach. With several successful projects, industrialized construction is progressively becoming a preferred alternative construction approach and spurred interest of contractors, developers, and housing authorities in IC. Increasingly, these stakeholders are keen to ascertain the compatibility and feasibility of using IC in their projects. This paper aims to develop a knowledge-based decision support framework for implementing industrialized construction projects (ICPs) that can facilitate better and informed decision-making when deciding to implement ICPs.

**Design/methodology/approach** – A comprehensive literature review was implemented to recruit 40 decision support factors (DSFs) and grouped into project requirements, location and site attributes, labour considerations, and organizational factors. A 3-member expert panel validated the relevance of 35 DSFs, which became candidates for a structured questionnaire survey of experts in eighteen countries. Statistical techniques are used to evaluate and prioritize the DSFs, leading to the development of a conceptual framework.

**Findings** – Statistical analysis revealed thirty-three significant DSFs. The top five most significant factors that could influence the decision to implement IC in a project include stringent requirement for project quality control, suitability of design for IC, organizational readiness and competences in ICPs, client receptivity to IC, and need to minimize field construction time. A framework of project requirements, location and site attributes, labour considerations, and organizational factors was proposed as decision support.

**Practical implications** – The proposed framework may help to inform decision-making regarding the implementation of IC in a project. It has wider applicability because it includes technical, managerial, and operational aspects of and the required competences for IC which are shared between project types and territories. The prioritized DSFs could be used as a guide when implementing IC, especially in countries where bespoke decision support system can be developed.

**Originality/value** – The paper delineated the most important DSFs that are shared IC project types and territories and can be used to investigate the compatibility of using IC in a proposed project. This research constitutes the first exclusive attempt at delineating, quantifying, and ranking the sets of decision-making factors, drawing on international dataset and contributes to the empirical checklist of DSFs for ICPs.

**Keyword**: four-pronged; decision-making; decision support factors; decision support framework; industrialized construction; IC

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## 1. Introduction

Industrialized construction is an alternative construction method that leverages more innovative processes and technologies in the building construction, civil engineering, and infrastructure projects. Industrialized construction projects (ICPs) are designed to ensure that much of the construction project is manufactured offsite as modules and then transported to the construction site in sections for assembly and installation (Goodier et al., 2019; Wuni and Shen, 2020a). The typical schedule of works in ICPs include feasibility, design development, offsite production of modules, casting of each module carcass, offsite module fit-out, transportation of modules to site, and installation (Wuni et al., 2019).

Where circumstances merit and favourable conditions exist, IC in construction projects constitute an approach to build faster, deliver better quality and control defects, reduce construction programme, achieve lifecycle cost-effectiveness, reduce the need to work from a higher altitude and provide workers with a safer working environment, offer bespoke solutions – wood, steel, concrete or hybrid options with high-quality finishes, and constitutes a sustainable approach to reduce construction waste, noise and dust (Blismas et al., 2006; Jaillon and Poon, 2008; Kamali and Hewage, 2017).

Given the numerous benefits and several exemplar projects in many economies, the global construction community is widely promoting the adoption of IC in projects (Wuni and Shen, 2020a). This has spurred the interest of contractors, developers, and housing authorities, who are keen to ascertain the possibility of implementing the solutions in their projects (Hwang et al., 2018). Increasingly, construction owners and engineers are faced with a decision problem at the initial stages of a construction project design regarding whether to use industrialized or traditional design and method of construction (Wuni and Shen, 2019a). However, several factors and conditions must converge to make IC compatible, feasible, and economical for a given project. The challenge usually lies in identifying the conditions and factors that render IC compatible and the best value-for-money option for a proposed project and has been recognized by researchers.

For instance, Murtaza et al. (1993) developed a computerized knowledge-based decision support system that supports the assessment of decision-making factors such as plant location, labour characteristics, environmental and organizational factors, project characteristics, and project risks when deciding to use IC in a petrochemical or power plant. Although of merit, this constitutes an outdated decision-making model and relied on experts from North America only. Hwang et al. (2018) developed a computerized knowledge-based decision support system that supports the compatibility assessment of decision-making factors when deciding to use IC for building and construction projects in Singapore. Although recent and useful, it relied on expert knowledge in Singapore and considered fewer factors. Daget and Zhang (2019) employed the analytical hierarchy process to develop a multicriteria decision-making support model for evaluating the suitability of implementing IC in housing projects in Ethiopia. Although this research assessed 30 decision-making factors, it relied on experts from Ethiopia; a developing country with limited experience and expertise in industrialized construction.

Wuni and Shen (2019a) and Abdul Nabi and El-Adaway (2020) employed literature research to establish some decision-making factors for ICPs, but they neither verified their practical relevance nor quantified their impacts. Furthermore, prevailing decision-making frameworks for ICPs do not necessarily reflect the diverse and multiple interconnected and associated factors. As such, there is a pressing need to identify and quantify a comprehensive list of decision-making factors that reflect recent changes in the decision-making processes of ICPs. It is also essential to develop comprehensive decision-making models or frameworks that incorporate and accommodate the most important and shared decision-making factors that could influence the decision to use IC in a project. This paper seeks to develop a comprehensive knowledge-based decision support framework that accommodates a holistic and complex set of factors and conditions that could influence the decision to implement IC in building, civil engineering and infrastructure projects. It focuses on providing a decision-making methodological framework that could be used in deciding whether to use IC in construction projects. The research seeks to achieve this through identifying, prioritizing and grouping those decision-making factors that help construction owners and consulting engineers involved in conceptual project design in their industrialized decisions and proposes a four-pronged framework for decision-making support.

As a result, this paper seeks to develop a knowledge-based decision support framework that draws on the most important shared factors to inform the decision to implement IC in projects. The paper draws on an international survey of industrialized construction experts in developing the framework since a knowledge-based expert system requires the utilization of expert knowledge rather than past data (Murtaza et al., 1993). The main contribution of this paper stems from the evaluation, quantification of the impact and importance of a holistic set of the most important shared decision-making factors leveraging international expert knowledge. Thus, the developed framework could provide decision support to project management teams when deciding to use IC in their projects. It is hoped that the framework could support more informed decision-making and guide towards realizing the full benefits of IC in buildings, civil engineering, and infrastructure projects.

## 2. Theoretical and conceptual background

### *2.1 Overview of industrialized construction*

IC seeks to advance and innovate construction processes through integrating prefabrication, mechanization, automation, robotics, and reproduction (Richard, 2005). In the broadest perspective, it is a construction system that leverages more innovative, disruptive, and integrated techniques, such as prefabrication, additive manufacturing, robotics, internet of things, big data, artificial intelligence, predictive analytics, building information modelling, sensors, unmanned aerial systems, virtual reality (VR), and augmented reality (AR) to improve project performances. Thus, IC is a construction approach that employs more innovative processes, techniques, and technologies, whereby projects are designed with enhanced manufacturing and assembly characteristics to support offsite production of the structural components and onsite assembly of the project (Gibb and Isack, 2003; Richard, 2005).

IC is an all-encompassing concept describing the use of innovative processes in the design, manufacture, transportation, and assembly of components and structures. In this study, IC includes all levels of prefabrication, modular construction, industrialized building systems, and offsite construction practices that deploy innovative processes, technical solutions, business models, and techniques in the delivery of building, civil engineering, and infrastructure projects (Engström, 2012). However, it excludes pre-design and post-construction activities, including market analysis, bidding, material property testing, building operations, and maintenance.

### *2.2 Knowledge-based decision support theory*

Knowledge-based decision making have roots in the organizational, behavioural, and decision sciences (Bahl and Hunt, 1984). There are various decision making theories, such as bounded rationality, organizational information processing theory, and behavioural decision theory (Engström, 2012). Knowledge-based decision support (KBDS) theory postulates that information systems and technologies can be designed to assist decision makers to reduce miscalibration and improve decision confidence when deciding an action course in a non-routine, episodic situation that requires judgement about multiple and complex considerations (Kasper, 1996). KBDS theory recognize the existence of miscalibration in which decision-makers could have great confidence in their fallible judgement and are often quite confident in very poor decisions (ibid). Critical to the KBDS theory is the Herbert Simon's bounded rationality - a concept that recognized the limits of human information processing and the consequent inability of managers to make optimal decisions in an economically rational way (March and Simon, 1958). Realistically, the decision-maker has cognitive limitations in terms of knowledge and computational capacity (Arnott and Pervan, 2014).

Yet, it is extremely essential for the decision-maker to ascertain the compatibility and feasibility of using IC for a project to make informed investment decisions (Engström, 2012). Usually, the decision-maker has mixed roles and must consider the interests of relevant project partners, project requirements, organizational goals, and other specific considerations (Wuni and Shen, 2019a). Thus, deciding to implement IC in a project is a complex problem and a function of multiple considerations, in which an informed decision requires collecting, processing, and managing information to reduce uncertainty and bridging the gap between available and needed information at the decision-making point (Engström, 2012). However, the IC investment decisions are usually made with incomplete information based on uncertain data at the conceptual stage, and the judgement confidence of the decision-makers are bounded in their rationality (March and Simon, 1958). Though the attempt is usually made to arrive at optimal decisions, the decision-maker seldom have the knowledge and cognitive means to accomplish such aim (Engström, 2012). KBDS systems address that human cognitive limitations through leveraging the computational power of machines to deal with the complex decision-making process (Hwang et al., 2018). However, an integral part of the KBDS system involves identifying and prioritizing the multiple, and often, conflicting decision-making criteria. This study focused on establishing a framework of such multiple conflicting factors that must be considered when assessing whether IC is compatible or feasible for a construction project.

### *2.3 Review of decision support factors for industrialized construction projects*

There are considerable documentation and literature on the factors and conditions that could influence the decision to implement IC in a project. This section provides a chronological comprehensive review of the decision support factors (DSFs) for implementing ICPs. The literature research revealed a host of empirical studies that effectively identified the DSFs for ICPs. Table 1 summarizes the common categories of DSFS reported in the literature. Murtaza et al. (1993) developed a comprehensive list of plant location, project characteristics, project risks, organizational factors, and labour considerations that influence the decision to implement IC in a petrochemical or power plant. Chen et al. (2010) summarized the site conditions, project requirements, market attributes, and building regulations that should be considered when deciding to use industrialized or traditional solutions in building projects.

Zhai et al. (2014) assessed buildability attributes, social climate and attitudes, costs factors, architectural design requirements, preparatory works, and supply chain factors that impede the implementation of IC in construction projects in China. Sharafi et al. (2018) evaluated the constructability and design attributes, cost and sustainability considerations, productivity and efficiency requirements, and quality and safety factors that influence the level of IC to be implemented in a project. Hwang et al. (2018) prioritized 19 decision-making factors that influence the adoption of IC for building and construction projects in Singapore. Zakaria et al. (2018) evaluated 14 structural, contextual, and behavioural factors that influence the decision to implement IC in Malaysia.

Wuni and Shen (2019a) employed a literature research to identify 51 decision-making factors ICPs. Daget and Zhang (2019) evaluated 30 customer needs, construction industry attributes, supply chain factors, infrastructure types, socio-political attributes, and environmental factors that influence the decision to implement IC in Ethiopia.

**Table 1**. Decision support factors for implementing ICPs reported in the literature

| Code | Decision support factors/sub-attributes | Reference |
|---|---|---|
| *PR* | *Project requirements* | |
| PR1 | Demanding and tight project schedule | Blismas and Wakefield (2009) |
| PR2 | Strict construction safety requirement | Murtaza et al. (1993) |
| PR3 | Stringent requirement for project quality control | Wuni and Shen (2019a) |
| PR4 | Stringent project cost and budget constraints | Zhai et al. (2014) |
| PR5 | Higher environmental and sustainability standards | Chen et al. (2010) |
| PR6 | Overall cost control requirement | Sharafi et al. (2018) |
| PR7 | Certainty of project completion date | Blismas and Wakefield (2009) |
| PR8 | High standard of quality of internal and external finishes | Chen et al. (2010) |
| PR9 | Project contract type | Wuni and Shen (2019a) |
| PR10 | Need to minimize field construction cost | Abdul Nabi and El-Adaway (2020) |
| PR11 | Presence of repetitive design layout and construction | Murtaza et al. (1993) |
| PR12 | Suitability of design for industrialized solutions | Hwang et al. (2018) |
| PR13 | Construction equipment quality and availability | Abdul Nabi and El-Adaway (2020) |
| PR14 | Need to minimize field construction time | Wuni and Shen (2019a) |

| | | |
|---|---|---|
| PR15 | Defined project scope and budget parameters | Chen et al. (2010) |
| PR16 | Size and type of project | Wuni and Shen (2019a) |
| *LS* | *Location and site attributes* | |
| LS1 | Availability of sound transport infrastructure and equipment | Hwang et al. (2018) |
| LS2 | Remote and difficult site location | Murtaza et al. (1993) |
| LS3 | Site accessibility | Abdul Nabi and El-Adaway (2020) |
| LS4 | Site conditions, constraints and attributes | Murtaza et al. (1993) |
| LS5 | Availability of manufacturing plant or suppliers | Zhai et al. (2014) |
| LS6 | Severe local area condition, harsh weather and climate | Murtaza et al. (1993) |
| LS7 | Reducing traffic movement | Wuni and Shen (2019a) |
| LS8 | Supportive building codes and industrialized design guides | Zhai et al. (2014) |
| LS9 | Capability of local industrialized construction supply chain | Daget and Zhang (2019) |
| LS10 | Site layout and presence of space for modules | Murtaza et al. (1993) |
| *LC* | *Labour consideration* | |
| LC1 | Presence of skilled and experience factory labour force | Wuni and Shen (2019a) |
| LC2 | Availability of competent and skilled management team | Wuni and Shen (2019a) |
| LC3 | Availability of skilled onsite labour | Wuni and Shen (2019a) |
| LC4 | Labour cost at site location | Abdul Nabi and El-Adaway (2020) |
| LC5 | Presence of relevant stakeholders at early stages | Wuni and Shen (2019a) |
| LC6 | Availability and capacity of fabricators and suppliers | Wuni and Shen (2019a) |
| LC7 | Presence of competent inspectors for supervising modules | Zhai et al. (2014) |
| *OF* | *Organizational factors* | |
| OF1 | Need to reduce neighbourhood noise and business disruption | Chen et al. (2010) |
| OF2 | Client receptivity to industrialized solutions | Blismas and Wakefield (2009) |
| OF3 | Organizational readiness and competences in ICPs | Bendi et al. (2020) |
| OF4 | Presence of relevant supportive technology (e.g. BIM) | Daget and Zhang (2019) |
| OF5 | Business needs, owner requirement and regulatory demand | Daget and Zhang (2019) |
| OF6 | Communication and collaborative culture | Wuni and Shen (2019a) |
| OF7 | Construction equipment availability and accessibility | Wuni and Shen (2019a) |

Abdul Nabi and El-Adaway (2020) employed a literature research to identify 50 decision-making factors that could influence the adoption of IC in construction projects, and Bendi et al. (2020) evaluated 17 decision-making factors that should be considered when Indian construction organizations evaluate their readiness to implement IC. The foregoing literature synthesis provides three revelations. First, although multiple factors could influence the decision to implement IC, some DSFs are shared between project types and territories but vary in their relative importance. Second, DSFs are grouped into different categories based on factor analysis or the discretion and experience of the researchers. Third, no study evaluated the DSFs based on international expert knowledge and developed a generalized knowledge-based decision support framework for implementing IC for building, civil engineering, and infrastructure project.

As shown in Table 1, the literature research resulted in the identification of 40 shared DSFs for implementing ICPs which are categorized into project requirements, location and site attributes, labour considerations, and organizational factors. The last most important category that was excluded is economic factors (project costs and risks). It was excluded because the economic factors require the development of detailed metrics for quantifying the host tangible and intangible costs and benefits of either using traditional or industrialized construction and was outside the scope of this paper. Although a factor analysis is usually required for clustering micro attributes into macro attributes, the guided classification in this research was based on two reasons. First, these categories were the most reported groups and shared between project types and territories. Second, the four categories are established project management considerations and could help reduce the cognitive challenge required to handle the host of DFs.

## 3. Research methods and approach

The research implemented a 6-phase methodological framework. Phase 1 involved a comprehensive literature review to recruit the DSFs for ICPs. Phase 2 involved the recruitment of the appropriate international industrialized construction experts as potential respondents. Phase 3 involved the invitation of three experienced experts to review the theoretically recruited list of DSFs to verify their appropriateness, relevance, and practicality. Phase 4 involved the design and administration of questionnaires to the international experts to capture their knowledge-based evaluations of the verified DSFs. Phase 5 involved the statistical pretesting of the collected quantitative dataset for reliability, distribution, and variations in the responses. Phase 6 involved the mean scoring, weighted analysis, and development of the proposed decision support framework. The six methodological phases are elaborated in the following subsections.

### *3.1 Identification of international industrialized construction experts*

An expert approach was leveraged to evaluate the DSFs for implementing ICPs. The target population was international industrialized construction practitioners and academics. However, there is no central database of such international experts. The lack of a central database for the international experts rendered the use of probabilistic sampling techniques impractical (Saunders et al., 2016). Consistent with existing international survey studies (Sachs et al., 2007; Zhang, 2005), the paper employed the purposive sampling technique to identify the relevant experts. As recommended by Wuni and Shen (2020b), contact details of the experts were retrieved from published industrialized construction papers, conference reports, industry reports, and websites of construction industry councils, authorities, and institutes in many countries, based on accessibility. Drawing on the works of Wuni and Shen (2020b), the following criteria were used to select the final list of experts: (i) the expert had extensive theoretical and practical knowledge of ICPs; (ii) the expert had detailed knowledge of the decision-making processes of ICPs; and (iii) the expert had been involved in at least one industrialized construction project. Based on these criteria, the details of 400 experts were retrieved within nine months.

*3.2 Questionnaire survey of international experts*

A survey approach was adopted to evaluate DSFs for ICPs because the research aimed to leverage expert knowledge of practitioners and academics to measure the relative importance of the DSFs rather than the use of (Murtaza et al., 1993). The survey research design is widely used in construction management research and the dominant instruments used to gather the views of practitioners include questionnaires, interviews, and focus group discussions (Saunders et al., 2016). This paper employed questionnaires to collect the expert data because it can be administered as a non-invasive instrument; facilitates the collection of quantitative data; provides wider coverage within a short time frame; and have been dominantly used in evaluating the DSFs in the reviewed literature.

Prior to the questionnaire development, three experts from Australia, Hong Kong, and Canada were invited to review the lists of DSFs to ascertain their practicality and representativeness of the complex decision-making environment of ICPs. The pilot review confirmed the practicality of the list, but their unanimous recommendations resulted in the removal of PR8, PR15, LS7, LS9, LC3, and OF6 for reasons of repetitions and irrelevance and the addition of 'Early upfront support for use of IC.' These modifications distorted the ordering of the codes and were renamed subsequently. The final list of 35 DSFs contained 14 Project requirements, 8 location and site attributes, 6 labour considerations, and 7 organizational factors. The questionnaire contained two sections. Section I requested some relevant information of the respondents for cross-validation of their suitability as respondents. Section II requested the experts to assess the importance of each DSF when deciding to implement IC in a project on a 5-point rating scale (1=very insignificant, 2=insignificant, 3=slightly significant, 4=significant, and 5=very significant). The questionnaire was transformed into an online survey form using the Survey Monkey platform. The link to the survey was sent to all the 400 experts through personalized emails and requested them to complete the survey in 4 weeks. After two rounds of reminders, a total of 56 valid responses were received. Albeit small, the sample size was considered adequate for reasonable statistical analysis because it was greater than the minimum threshold of 30 responses for the central limit theorem and higher than samples in similar published international survey studies such as 29 (Sachs et al., 2007) and 46 (Zhang, 2005).

*3.3 Statistical pretesting of the dataset*

The dataset was pretested for several statistical indicators with the aid of the Statistical Package for the Social Sciences (SPSS v.20). The Cronbach's Alpha was used to test the internal consistency and reliability of the dataset. The Shapiro-Wilk test was used to investigate the distribution of the dataset (Chou et al., 1998), and the Mann Whitney U-test; an ordinal-based non-parametric test was used to assess whether there are significant variations in the responses of the dataset because it is suitable when the dataset is non-normally distributed, contains responses from two categorical independent groups (experts from academia and industry), and the dependent variables (DSFs) are measured at the ordinal level using a rating scale (Norusis, 2008).

*3.4 Methods of data analysis*

The solutions to multicriteria decision-making problems are commonly derived using techniques such as mathematical programming, simulation, classification or discriminant analysis, decision analysis, analytical hierarchy process, analytical network process, artificial intelligence, expert systems, et cetera (Murtaza et al., 1993). However, for construction method selection, published papers have employed the analytical hierarchy process (Daget and Zhang, 2019), weighted-factor method (Chen et al., 2010), mean scores, expert systems (Hwang et al., 2018), and hybrid expert systems (Murtaza et al., 1993) to analyse the decision-making factors. This paper employed mean score ranking and weighted analysis to prioritize the DSFs for ICPs because they are the most widely used approaches in construction engineering and management research to prioritize decision-making factors when developing decision support systems and frameworks (Chen et al., 2010; Hwang et al., 2018; Murtaza et al., 1993).

The analytical hierarchy process and other multicriteria decision methods were not used because the paper did not seek to ascertain the best combinations of DSFs that influence the adoption of ICPs, but to develop a knowledge-based decision support framework that prioritizes several DSFs under the different categories to aid flexible decision-making across different project types and territories. The combination of the two methods was aimed at providing cross-validation in the prioritization. The mean index for each DSF was computed using equation (1) and the weightings of the DSFs within each category were computed using equation (2).

$$\text{Mean (M)} = \frac{\sum(\text{E x S})}{\text{N}} \quad (1)$$

Where; M denotes the mean index of a DSF; E represents the number of ratings (i.e. 1-5) for the DSF; S denotes the scores assigned to a DSF by the experts ranging from 1 to 5; and N denotes the total number of responses obtained by a DSF.

$$\text{Weight } (\text{W}_i) = \frac{\text{M}_i}{\sum_{i=1}^{n} \text{M}_i} \quad (2)$$

Where; $W_i$ denotes the weight of a DSF within a category; $M_i$ represents the mean index of a DSF within a category; and $\Sigma(M_i)$ denotes the summation of the mean indices of all DSFs within a category.

## 4. Results and discussions

### *4.1 Background information of the international experts*

Over 51% of the international experts who participated in the survey had over 5 years of experience working on ICPs in different countries. A sizable proportion of the experts (48.2%) had at most 5 years of work experience. This was expected because the use of IC is only beginning to gain momentum during the last two decades, with some countries at the earliest stage of the learning curve and implementing pilot projects.

**Table 2**. Relevant Information of the surveyed experts

| Attribute | Sub-attribute | Responses | % Responses |
|---|---|---|---|
| Years of ICPs work experience | Below 5 years | 27 | 48.2 |
| | 5 - 10 years | 13 | 23.2 |
| | 11 - 15 years | 5 | 8.9 |
| | 16 - 20 years | 2 | 3.6 |
| | 21years and above | 9 | 16.1 |
| | ***Total*** | ***56*** | ***100.0*** |
| Country | United States | 10 | 17.9 |
| | Canada | 8 | 14.3 |
| | China | 7 | 12.5 |
| | Hong Kong | 7 | 12.5 |
| | Australia | 5 | 8.9 |
| | Malaysia | 4 | 7.1 |
| | United Kingdom | 4 | 7.2 |
| | Brazil | 1 | 1.8 |
| | Finland | 1 | 1.8 |

| | | | |
|---|---|---|---|
| | Germany | 1 | 1.8 |
| | Greece | 1 | 1.8 |
| | Lebanon | 1 | 1.8 |
| | Singapore | 1 | 1.8 |
| | Slovakia | 1 | 1.8 |
| | Spain | 1 | 1.8 |
| | Sweden | 1 | 1.8 |
| | Switzerland | 1 | 1.8 |
| | Tanzania | 1 | 1.8 |
| | ***Total*** | ***56*** | ***100.0*** |
| Projects participated | Housing/ real estate | 40 | 71.43 |
| | Commercial/Office projects (banks, hotels, castles, headquarters) | 17 | 30.36 |
| | Schools/education | 15 | 26.79 |
| | Industrial Projects | 13 | 23.21 |
| | Health/hospital projects | 10 | 17.86 |
| | Energy/ Power projects | 9 | 16.07 |
| | Transportation (roads, bridges, rails, tunnels etc) | 5 | 8.93 |
| | Prisons/ Défense | 3 | 5.36 |
| | Water treatment plant/ Sewage projects | 3 | 5.36 |
| | Other (please specify) | 6 | 10.71 |

Experts from the United States (17.9%), Canada (14.3%), China (12.5%), Hong Kong (12.5%), Australia (8.9%), Malaysia (7.1%), and the United Kingdom (7.1%) dominated the study. Based on continental distributions, experts from Asia and Pacific (19, 33.9%), North America (18, 32.2%), and Europe (11, 19.6%) dominated the surveyed sample. These continents are noted for their higher and advanced levels of industrialization of construction and their dominance provided an opportunity increased reliability of the evaluations of the DSFs. The fewer responses from South America (1, 1.8%) and Africa (2, 3.6%) were expected because these territories are noted for their lower level of industrialization of construction and their under-representation may not impact the reliability of the results. Table 2 also shows that the respondents have been involved in several types of ICPs, with the majority having experiences in residential ICPs. As such, the experts rated the DSFs primarily based on relevant practical knowledge and hands-on experiences working on projects that employed some degrees of IC.

*4.2 Results of statistical pretesting of the dataset*

The results of the internal consistency and reliability test, Shapiro-Wilk H-test (p-values), and the Mann-Whitney U-test (p-values) of 35 DSFs comprising 14 Project requirements, 8 location and site attributes, 6 labour considerations, and 7 organizational factors are shown in Table 3. The reliability test generated a Cronbach's Alpha of 0.866 for the overall dataset, which was higher than the minimum acceptable value of 0.7 (Tavakol and Dennick, 2011), indicating there was very high internal consistency in the responses of the experts. As shown in Table 3, the reliability analysis of the different groups of DSFs generated Cronbach's Alphas greater than the minimum threshold of 0.7. As shown in Table 3, The Shapiro-Wilk test generated p-values less than 0.05 for all DSFs at a 95% confidence interval, indicating that the dataset is non-normally distributed and required the use of non-parametric techniques (i.e. Mann-Whitney U-test) to further analyse the dataset. The asymptotic significance (2-tailed) p-values of the Mann-Whitney U-test in Table 3 are greater than 0.05 for all the factors (except LS4) at a 95% confidence interval. This implied that except for LS4, there were no statistically significant variations in the responses of the different experts, suggesting that the responses for all DSFs, but LS4 can be treated holistically. However, LS4 was still considered and discussed because it recorded a significant mean score. These indicators provided a basis for further analysing the dataset.

**Table 3**. Results of reliability test, Shapiro-Wilk H-test, and Mann Whitney U-test

| Code | Decision support factors/sub-attributes | α | Shapiro - Wilk H-test | Mann Whitney U-test |
|---|---|---|---|---|
| *PR* | *Project requirements* | *0.802* | | |
| PR1 | Demanding and tight project schedule | | 0.000* | 0.818 |
| PR2 | Strict construction safety requirement | | 0.001* | 0.553 |
| PR3 | Stringent requirement for project quality control | | 0.000* | 0.739 |
| PR4 | Stringent project cost and budget constraints | | 0.000* | 0.897 |
| PR5 | Higher environmental and sustainability standards | | 0.001* | 0.620 |
| PR6 | Overall cost control requirement | | 0.000* | 0.958 |
| PR7 | Certainty of project completion date | | 0.000* | 0.834 |
| PR8 | Project contract type | | 0.000* | |
| PR9 | Need to minimize field construction cost | | 0.000* | 0.089 |
| PR10 | Presence of repetitive design layout and construction | | 0.000* | 0.752 |
| PR11 | Suitability of design for industrialized solutions | | 0.000* | 0.834 |
| PR12 | Structural stability of individual and assembled modules | | 0.001* | 0.600 |
| PR13 | Need to minimize field construction time | | 0.000* | 0.747 |
| PR14 | Size and type of project | | 0.000* | 0.850 |
| *LS* | *Location and site attributes* | *0.813* | | |
| LS1 | Availability of sound transport infrastructure and equipment | | 0.000* | 0.457 |
| LS2 | Remote and difficult site location | | 0.000* | 0.145 |
| LS3 | Site accessibility | | 0.000* | 0.233 |
| LS4 | Site conditions, constraints and attributes | | 0.001* | 0.028* |
| LS5 | Availability of fabrication plant within economic distance | | 0.000* | 0.198 |
| LS6 | Severe local area condition, harsh weather and climate | | 0.001* | 0.983 |

| | | | | |
|---|---|---|---|---|
| LS7 | Supportive building codes and industrialized design guides | | 0.000* | 0.053 |
| LS8 | Site layout and presence of space for modules | | 0.000* | 0.627 |
| *LC* | *Labour consideration* | *0.826* | | |
| LC1 | Presence of skilled and experienced onsite labour force | | 0.000* | 0.256 |
| LC2 | Availability of competent and skilled management team | | 0.000* | 0.174 |
| LC3 | Labour cost at site location | | 0.000* | 0.810 |
| LC4 | Presence of relevant stakeholders at early stages | | 0.000* | 0.069 |
| LC5 | Presence of skilled and experienced fabricators or suppliers | | 0.000* | 0.633 |
| LC6 | Presence of competent inspectors for supervising of modules | | 0.000* | 0.331 |
| *OF* | *Organizational factors* | *0.701* | | |
| OF1 | Need to reduce neighbourhood noise and business disruption | | 0.001* | 0.649 |
| OF2 | Client receptivity to industrialized solutions | | 0.000* | 0.900 |
| OF3 | Organizational readiness and competences in ICPs | | 0.000* | 0.538 |
| OF4 | Presence of relevant supportive technology (e.g. BIM) | | 0.000* | 0.099 |
| OF5 | Business needs, owner requirement and regulatory demand | | 0.000* | 0.405 |
| OF6 | Construction equipment availability and accessibility | | 0.000* | 0.868 |
| OF7 | Early upfront support for use of industrialized solution | | 0.000* | 0.500 |

* The Shapiro-Wilk test was significant at the significance level of 0.05, suggesting the data were not normally distributed

### *4.3 Rankings of DSFs for implementing ICPs*

The mean scores, standard deviations, weightings, and rankings of the DSFs for implementing ICPs are presented in Table 4. The weightings and ranking are computed for each DSF within a given group. Based on the fuzzy linguistic terms assigned to the grades of the implemented 5-point rating scale, DSFs with mean scores of at least 3.0 were considered significant and important (Wuni and Shen, 2020b; Zafar et al., 2019) to the experts when deciding to implement IC in a project. In Table 4, the least important DSFs are severe local area conditions, harsh weather and climate (LS6), and presence of relevant supportive technology (e.g. BIM) (OF4) with mean scores less than 3.0. The lower mean index for OF4 was not expected because the use of building information modelling is essential and perhaps mandatory for any meaningful industrialized construction project (Wuni and Shen, 2020c). The lower score could be due to the presence of some experts with fewer years of experience in ICPs. Overall, the top 5 most significant DSFs are stringent requirement for project quality control (PR3), suitability of design for IC (PR11), organizational readiness and competences in ICPs (OF3), client receptivity to IC (OF2), and need to minimize field construction time (PR13).

**Table 4**. Mean scores, standard deviations and weightings of the DSFs for ICPs

| Code | Decision support factors/sub-attributes | Mean | SD | Weight | Rank |
|---|---|---|---|---|---|
| *PR* | *Project requirements* | | | | |
| PR1 | Demanding and tight project schedule | 3.661 | 0.978 | 0.0752 | 4 |
| PR2 | Strict construction safety requirement | 3.036 | 1.250 | 0.0623 | 14 |
| PR3 | Stringent requirement for project quality control | 3.857 | 4.110 | 0.0792 | 1 |
| PR4 | Stringent project cost and budget constraints | 3.357 | 0.943 | 0.0689 | 9 |
| PR5 | Higher environmental and sustainability standards | 3.340 | 1.133 | 0.0686 | 10 |

| | | | | | |
|---|---|---|---|---|---|
| PR6 | Overall cost control requirement | 3.339 | 0.959 | 0.0686 | 11 |
| PR7 | Certainty of project completion date | 3.661 | 1.032 | 0.0752 | 4 |
| PR8 | Project contract type | 3.214 | 1.202 | 0.0660 | 13 |
| PR9 | Need to minimize field construction cost | 3.464 | 1.078 | 0.0711 | 7 |
| PR10 | Presence of repetitive design layout and construction | 3.607 | 0.985 | 0.0741 | 6 |
| PR11 | Suitability of design for industrialized solutions | 3.786 | 0.967 | 0.0777 | 2 |
| PR12 | Structural stability of individual and assembled modules | 3.286 | 1.202 | 0.0675 | 12 |
| PR13 | Need to minimize field construction time | 3.679 | 0.993 | 0.0755 | 3 |
| PR14 | Size and type of project | 3.411 | 1.023 | 0.0700 | 8 |
| *LS* | *Location and site attributes* | | | | |
| LS1 | Availability of sound transport infrastructure and equipment | 3.179 | 1.208 | 0.1214 | 7 |
| LS2 | Remote and difficult site location | 3.232 | 1.144 | 0.1234 | 6 |
| LS3 | Site accessibility | 3.375 | 1.088 | 0.1288 | 2 |
| LS4 | Site conditions, constraints and attributes | 3.321 | 1.011 | 0.1268 | 4 |
| LS5 | Availability of fabrication plant within economic distance | 3.375 | 0.964 | 0.1288 | 2 |
| LS6 | Severe local area condition, harsh weather and climate | 2.946 | 1.102 | 0.1125 | 8 |
| LS7 | Supportive building codes and industrialized design guides | 3.482 | 1.191 | 0.1329 | 1 |
| LS8 | Site layout and presence of space for modules | 3.286 | 0.889 | 0.1254 | 5 |
| *LC* | *Labour consideration* | | | | |
| LC1 | Presence of skilled and experienced onsite labour force | 3.250 | 0.995 | 0.1602 | 5 |
| LC2 | Availability of competent and skilled management team | 3.411 | 0.968 | 0.1681 | 4 |
| LC3 | Labour cost at site location | 3.589 | 1.075 | 0.1769 | 1 |
| LC4 | Presence of relevant stakeholders at early stages | 3.554 | 0.952 | 0.1752 | 2 |
| LC5 | Presence of skilled and experienced fabricators or suppliers | 3.464 | 1.044 | 0.1708 | 3 |
| LC6 | Presence of competent inspectors for supervising of modules | 3.018 | 0.963 | 0.1488 | 6 |
| *OF* | *Organizational factors* | | | | |
| OF1 | Need to reduce neighbourhood noise and business disruption | 3.089 | 1.116 | 0.1318 | 6 |
| OF2 | Client receptivity to industrialized solutions | 3.768 | 1.027 | 0.1607 | 2 |
| OF3 | Organizational readiness and competences in ICPs | 3.782 | 0.896 | 0.1613 | 1 |
| OF4 | Presence of relevant supportive technology (e.g. BIM) | 2.893 | 0.947 | 0.1234 | 7 |
| OF5 | Business needs, owner requirement and regulatory demand | 3.339 | 0.996 | 0.1424 | 3 |
| OF6 | Construction equipment availability and accessibility | 3.250 | 0.995 | 0.1386 | 5 |
| OF7 | Early upfront support for use of industrialized solution | 3.321 | 0.855 | 0.1417 | 4 |

Table 4 shows that the experts perceived the DSFs within project requirements to be the most important and significant factors when deciding to implement IC in projects, followed by the organizational factors, labour considerations, and finally, location and site attributes. The aim of the weightings in Table 4 is not to prioritize the groupings, but to ascertain the most important DSFs to be considered within each category when deciding to implement IC. This explains why this research did not focus on the overall rankings of the DSFs. The results in Table 4 are discussed below.

*Project requirements*: The top 5 most significant project characteristics and requirements that could influence the decision to implement IC in a project include stringent requirement for quality control (PR3), suitability of the design for IC (PR11), need to minimize field construction time (PR13), demanding and tight project schedule (PR1), and certainty of project completion date (PR7) as the most important and significant factors. Due to the controlled factory-environment in which the industrialized items are prototyped, tested and fabricated, industrialized construction improves construction quality control (Blismas et al., 2006). Thus, if there is a strict requirement for significantly fewer defects and quality problems in the project, IC may be considered an ideal option to meet the quality specification. Additionally, some projects designs are not suitable for IC and though advancement in industrialized construction architecture supports the conversion of a traditional project design into an industrialized alternative even after the project had commenced (Modular Building Institute, 2017), it may not generate the expected full benefits and performance improvements and such changes are often obscure and expensive to implement (Blismas, 2007; Wuni and Shen, 2020d). Thus, it is essential to evaluate the suitability of the design for IC because detailed bespoke engineering designs for ICPs have cascading implications on the success of subsequent stages and the entire project (Murtaza et al., 1993). Generally, industrialized construction is suited to repetitive components, where high volumes prevail with repeated processes and deliver full benefits in projects with repetitive design features such as schools, hospitals, hotels, prisons, social housing, apartments, and student residences.

Considering that schedule delays are pervasive in traditional construction projects with attendant problems such as increased cost, conflicts, and clients' dissatisfaction (Zafar et al., 2019), industrialized solution may constitute an ideal option where the client: demands certainty of the project completion date, presents a demanding schedule and requires minimal field construction time. Additionally, IC may be ideal when clients propose to deliver projects, requiring the use of a construction method that could minimize field construction time to meet demanding schedules, control cost, and reduce health and safety issues. For instance, IC were widely used to build health centres, hospitals and quarantines centres in China, Hong Kong, the United States, the United Kingdom and elsewhere during the Covid-19 pandemic because there was the need to provide such facilities within a shorter time frame as response mechanisms (Luo et al., 2020); a requirement which could not be addressed using traditional construction methods. The remaining nine DSFs within the project requirements category have also been rated as significant based on the mean scores.

*Location and site attributes*: The top 5 most significant location and site attributes when deciding to implement IC in a project include supportive design codes and industrialized design guides (LS7), site accessibility (LS3), availability of fabrication plant or suppliers with economic transport distance (LS5), site conditions, constraints and attributes (LS4), and site layout and presence of space for modules (LS8). Like traditional construction projects, the designs of ICPs require statutory approvals and permitting. Thus, when deciding to implement IC in a project, it is essential to ascertain whether there are supportive local building codes, approved local industrialized design codes of practice, technical guidelines, standards, and specifications for the design team to reference when developing the ICP design. In some cases, there may be no local industrialized design guide, but the local codes support the use of IC in the project. For instance, Ghana does not have local industrialized design standards, but Hilton Inc developed the first Africa Modular Hotel in the regional capital of Ghana because the local building codes support the adoption of IC (Wuni and Shen, 2019b).

Although ICPs can be delivered in a site with relatively limited space, it is essential to ascertain whether the construction site for the proposed ICP is accessible to trucks and cranes for transportation and installation of the modules, respectively. Moreover, industrialized items or modules are the main drivers of ICPs and can significantly determine the overall cost of the project. It is essential to ascertain whether the manufacturing plant or suppliers are within an economic transport distance to reduce the cost of transportation on the project. In countries with incomplete supply chains, requiring cross-border transportation of modules, transportation expenditure could constitute a significant component of the contract sum of the project (Pan and Hon, 2018). Depending on the industrialized solution – steel, RC concrete, or hybrid option, the load-bearing capacity of the site and other attributes may not support the delivery of ICPs. As a result, the suitability of site conditions, constraints, and attributes for IC should be evaluated before construction. In some unique project environments, such as remote sites and harsh weather conditions, requiring minimal field construction time to meet an urgent building or infrastructure need whilst reducing health issues, IC may be the only feasible choice (Wuni and Shen, 2019a). For this reason, although LS6 was rated as insignificant, a developer may decide to implement IC because of severe local area conditions, harsh weather, and climate which does not support longer project durations since such could threaten the safety of construction workers.

Similarly, proposed projects in remote and difficult site locations could render industrialized solution a practical, feasible, and economic option. Generally, industrialized options may be obvious when certain project constraints prevail, such as underdeveloped and remote construction site, a construction site with hostile environmental conditions, a construction project requiring special tools, skills or techniques that are only available in a control factory environment (Murtaza et al., 1993). In these circumstances, IC are an economic and feasible option because fewer, less-skilled field workforce is required; fabrication, assembly, and testing of major sections of the plant are accomplished by skilled labour in an environmentally controlled factory, which often results in a more reliable, higher-quality plant; and the minimized field construction time results in overall cost savings and a better rate of return (Murtaza et al., 1993). It is also essential to evaluate whether the transport network and highway regulations permit the hauling of the heavy industrialized item, especially concrete modules by the heavy-duty trucks.

*Labour considerations*: The top 5 most important shared labour considerations when deciding to implement IC in a project include labour cost at site location (LC3), presence of relevant stakeholders at early stages (LC4), presence of skilled and experienced fabricators or suppliers (LC5), availability of skilled and competent management team (LC2), and availability of skilled and experienced onsite labour force (LC1). Although relatively fewer construction workers are engaged in ICPs (Blismas et al., 2006), high level of technical knowledge and skills are required at all levels of the delivery chain from the accurate design to the use of advanced and precise modular production technology through to the use of powerful cranes for systematic assembly the modules on site (Wuni and Shen, 2020b). The cost of skilled labour could be very high, especially in countries with scarce skilled industrialized construction workforce. Thus, it is essential to consider the cost of onsite and offsite labour at the site location before commencing the project. The success of ICPs usually requires early commitment and engagement of the key participants at the early stages, especially at the planning and design stages of the project lifecycle (Wuni and Shen, 2020d). Consequently, the project team should evaluate the availability of key players such as ICP designers, architects, engineers, consultants, fabricators or suppliers, and contractors to provide input at the early stages. This consideration is crucial because the delivery chain stages of ICPs are distinct but interdependent and so, the failure of early stages could compromise the success of upstream segments (Wuni et al., 2019). The absence of these relevant stakeholders at the early stage could increase the lead times, resulting in prohibitively expensive delays within the tighter schedules of ICPs.

It is also crucial to investigate the availability of skilled and competent fabricators or suppliers prior to implementing IC. The quality of ICPs depends on the quality of the industrialized items or modules, which in turn depends on the technical expertise and experience of the fabricators or suppliers (Fraser et al., 2015). For instance, a competent fabricator should have technical expertise in the design and production of modules and a sound understanding of the concepts of production engineering, design for manufacture and assembly, and process efficiency. There is also the need to investigate the availability of skilled and competent management team and onsite labour force. It is also extremely important to investigate the availability of competent inspectors for supervising of modules. These inspectors, usually a team from the local building authority inspect the modules at the factory and onsite for quality control and to ensure adherence to building standards.

*Organizational factors*: The top 5 organizational factors that could influence the decision to implement IC in projects include organizational readiness and competences in ICPs (OF3), client receptivity to IC (OF2), business needs, owner requirement, and regulatory demand (OF5), early upfront support for use of industrialized solution (OF7), and construction equipment availability and accessibility (OF6). Prior to implementing IC, it is essential to ascertain the capacity, readiness, and competence of local contractors to implement IC (Bendi et al., 2020; Fraser et al., 2015). This is crucial because ICPs require some technical competences and specialist knowledge to deliver value in projects. IC could also be implemented in a project where the client request for use of IC in a project (Blismas et al., 2005; Blismas and Wakefield, 2009), but in this circumstance, there is the need for early commitment to develop design suitable compatible with the principles of ICPs. In some economies such as Hong Kong, Singapore, and the United Kingdom, building regulations encourage the use of some amount of IC in public buildings, civil engineering, and infrastructure projects (Wuni and Shen, 2020a). Thus, IC may be used in a project because of the need to meet regulatory requirements.

It is also essential to ascertain whether there is early upfront support of top management to use IC in a project. This support is necessary to facilitate early commitment to IC at the early stage of the project lifecycle. The delivery of ICPs involves the use of equipment and tools such as moulds, carcass, jigs, cranes, and heavy-duty trucks. These tools are essential for the effective delivery of the ICPs. Thus, in deciding to implement IC, management needs to investigate the availability and accessibility of the required construction equipment. IC may also be implemented in a project if there is a need to reduce noise pollution and avoid disruptions in business continuity. For instance, IC were used in the Queensland's Prep School Capital Works

Project in 2004 to deliver the educational facilities required for the Prep School without disrupting the academic calendar (Blismas, 2007). It is also crucial to investigate the availability of supportive technologies because building information modelling constitutes a mandatory tool for large-scale ICPs (Hwang et al., 2018; Wuni and Shen, 2019a). The role of BIM in ICPs goes beyond clash detection analysis and visualizations purposes to encompass management of the project from a lifecycle perspective, including the planning, design of each industrialized item, formwork, rebar and even tile pattern, and supply chain management (Li et al., 2017).

### *4.4 The Four-pronged decision support framework for implementing ICPs*

The rankings of the DSFs within each group in Table 4 formed the basis of the proposed four-pronged decision support framework for implementing ICPs in Figure 1. The framework is intended to be used by consulting engineers as well as project, construction site, project control, construction and operation managers during the conceptual design and planning stages of the project lifecycle (Hwang et al., 2018; Murtaza et al., 1993; Wuni and Shen, 2019a). The framework aims to assist the construction planning team to ascertain the compatibility and feasibility of using IC in a proposed project. For brevity, the framework shows the top 5 most important and significant DSFs within each category, but some of the least prioritized DSFs could be significant in different contexts and project types. Thus, bespoke assessment should be conducted to prioritize the DSFs (where necessary and possible) prior to implementing the framework.

Overall, the framework shows that a decision to implement IC in any project depends on at least the specific project requirements, location and site attributes, availability of skilled workforce, and the organizations involved. Thus, the decision-making process constitutes a multicriteria decision problem and usually requires the use of multicriteria decision methods to aid the process. The current paper did not attempt to delineate a defined set of DSFs that must be used when deciding to implement IC because the combinations and their relative importance are sensitive to project types and territories. The framework aimed to delineate the significant mandatory shared DSFs that must be considered when deciding to implement IC in building, civil engineering, and infrastructure projects.

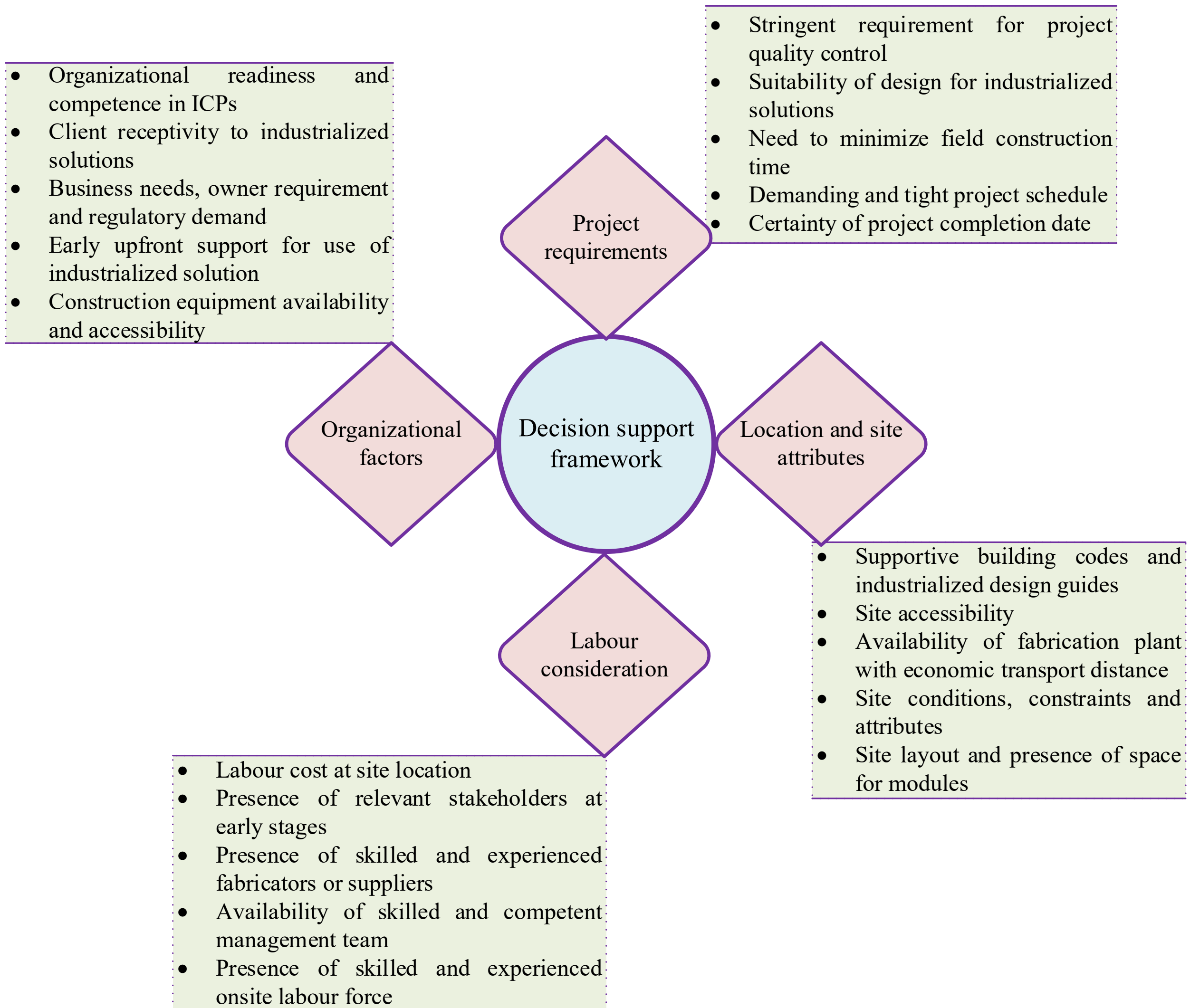


**Figure 1**. Four-pronged knowledge-based decision support framework for implementing ICPs

Although the framework has a four-dimensional structure, there is a logical approach when using its components to inform a decision to implement IC in a project. The decision-making process usually involves three stages – pre-screening and initial feasibility, detailed feasibility, and economic analysis (Murtaza et al., 1993; Wuni and Shen, 2019a). The proposed four-pronged decision support framework will aid the first two stages of the decision-making process. The pre-screening and initial feasibility stage usually aims at ascertaining whether the project lends itself to industrialized construction. It usually offers a preliminary indication of the most ideal and appropriate construction method – industrialized, traditional, or a hybrid option for a proposed project. Where the evaluation indicates that the project does not lend itself to IC, it may be necessary to proceed with the traditional option; otherwise, a more detailed technical feasibility analysis is conducted to inform the decision.

A combination of the DSFs within the 'project requirements' and 'location and site attributes' categories are used to develop the preliminary suitability index for the proposed project. To develop the preliminary suitability index, the consultant can ask the industrialized construction players and experts of the proposed project questions such as 'to what do you think the following project requirements and location attributes (1= Strong oppose, 2= Oppose, 3= Neutral, 4= Favour, 5=Strongly favour) favour the use of IC in the proposed project?' and 'to what extent do you think IC in the proposed project will have (1= Very negative, 2=Negative, 3=Neutral, 4=Positive, 5=Very positive) impact on the realizations of the project requirements and objectives?. Best practices recommend an average weighting of at least 25% at the pre-screening stage ('project requirements' and 'location and site attributes' categories) renders IC suitable for the project (Murtaza et al., 1993). However, the paper recommends that the consensual threshold total weighted score value of the local construction industry council or board be used to guide the decision.

The detailed feasibility stage aims at determining the technical practicability of the proposed industrialized solution. It seeks to determine which design and construction method is more advantageous from a technical perspective and indicates the appropriate degree of IC required in the project. The use of the DSFs within the 'labour considerations' and 'organizational factors' categories will provide a sound indication of the technical feasibility of the project. The technical feasibility index can also be computed by asking appropriate technical feasibility questions based on the DSFs under the labour considerations and organizational factors. It is a standard practice to establish a scoring system within a computerized decision support system to automate the decision-making process and to avoid complexity and potential computational errors associated with manual operations (Hwang et al., 2018; Murtaza et al., 1993). The comprehensive decision support system can be developed using both Microsoft Excel and Microsoft Visual Basic for Applications (Hwang et al., 2018).

Although the stage-gate approach to the assessment is desirable (Wuni and Shen, 2019a), it is convenient to conduct overall scoring of the relevant prioritized DSFs to generate holistic suitability or compatibility score to inform the decision to implement the IC in a proposed project (Hwang et al., 2018). To make an overall assessment of the DSFs with or without the use of a computerised decision support system, the following protocols should be implemented.

- Step 1 involves identifying, evaluating, and prioritizing the most important and significant DSFs within each category that could influence the decision to implement IC in the proposed project, using a rating scale (e.g. 5-point).
- Step 2 involves integrating the prioritized DSFs within each category into an integrated list of decision-making factors.
- In step 3, the project team should then rate the extent to which each of the integrated list influences the decision to implement IC in a project, drawing on some of the appropriate questions aforementioned and using a rating scale, preferably a 5-point rating scale. However, the linear fuzzy linguistic alternatives of the 5-point rating scale (e.g. 1= Strong oppose and 5=Strongly favour or 1= Very negative and 5=Very positive) to be used in rating the integrated list of DSFs should be converted into a linear percentage scale of 20% – 100%, where 20% corresponds to the lowest level of influence and 100% denotes the maximum level of influence. Effectively, 1, 2, 3, 4, and 5 grades of the 5-point rating scale corresponds to 20%, 40%, 60%, 80%, and 100%, respectively.
- Step 4 involves rating the influence of each DSF for implementing IC in the proposed project using the 5-point rating scale and the data should be aggregated.
- Step 5 involves computing the influence Score for each DSFs using equation (3)

$$(IS_i) = \frac{1*R_{i1} + 2*R_{i2} + 3*R_{i3} + 4*R_{i4} + 5*R_{i5}}{R_{i1} + R_{i2} + R_{i3} + R_{i4} + R_{i5}} = \frac{20R_{i1} + 40R_{i2} + 60R_{i3} + 80R_{i4} + 100R_{i5}}{R_{i1} + R_{i2} + R_{i3} + R_{i4} + R_{i5}} \quad (3)$$

Where, $IS_i$ = influence index for the $i^{th}$ DSF; $R_{i1}$ = number of responses for the grading alternative “1” for the $i^{th}$ DSF; and $R_{i5}$ = number of responses for the grading alternative “5” for the $i^{th}$ DSF.

- Step 6 involves computing the overall suitability or compatibility score for the proposed project using equation (4).

$$\text{Suitability Index } (S_i) = \frac{\sum_{i=1}^{n}(IS_i)}{N} \quad (1)$$

Where; $S_i$ denotes the overall ICP suitability or compatibility score and takes the values of 20 to 100; and N denotes the total number of prioritized and evaluated DSFs.

Following the works of Murtaza et al (1993) and Hwang et al. (2018), the maximum attainable suitability index for any proposed project can be perched at 100%, denoting the project best suited for implementing IC (i.e. all DSFs have an assessment of 5 or the highest grade of the rating scale adopted); while the lowest score is set to 20% (i.e., all DSFs have an assessment of 1), representing the project is completely unsuitable for use of IC. With a suitability index of less than 60%, it is recommended to use traditional approach rather than IC for the proposed project. For a suitability score between 60 and 80, it is recommended to modify the design to improve its suitability for IC with reference to similar past ICPs and the engagement of ICP specialists to guide its implementation (Hwang et al., 2018). With a suitability score greater than 80%, it is recommended to implement some actions that could improve the implementation of IC. It is a common practice to appoint ICPs specialists, ensure active participation and commitment of various stakeholders, and arrange visits to site and manufacturing plants to improve the implementation of the IC (Hwang et al., 2018).

The final decision to implement IC in a proposed project must be informed by the economic feasibility analysis, which was not incorporated in the developed framework. This is the final stage of the decision-making process and usually involves a comparative cost-benefit analysis of using either IC or a traditional approach for the proposed project. It helps to determine the level of cost savings and reduction in the construction schedule time achievable with the use of IC. Existing cost-benefit analysis frameworks usually adopt direct cost comparison, resulting IC being prohibitively expensive to justify their adoption (Blismas et al., 2006). This outcome is expected and reasonable because at the current stage of industrialized construction learning curve, significant cost and materials are used to minimize the construction time (Wuni and Shen, 2020a). Thus, a more comprehensive and ideal cost-benefit analysis at the economic feasibility stage should adopt a value-based comparison (Blismas et al., 2006). This will involve identifying, quantifying, monetizing and comparing the expected full costs (tangible and intangible) and benefits (tangible and intangible) of using each solution in the proposed project. Although obscure to quantify and monetize, it is still essential to monetize and incorporate the intangible benefits and costs of the two construction methods in the cost-benefit analysis because some of the intangible benefits (e.g. improved quality control, improved health and safety) may constitute the aspects where IC could offer the most prominent values in a project. Consequently, the non-inclusion of the monetary values of such soft benefits and performance improvements associated with IC during cost-benefit analysis constitutes an incomprehensive economic analysis.

## 5. Conclusions, contributions and limitations of the research

This paper considered the decision-making process of industrialized construction and developed a Four-pronged decision support framework for implementing ICPs. Using a comprehensive literature review, the paper identified 40 project requirements, location and site attributes, labour considerations, and organizational factors that could influence the decision to implement IC in a project. Three experienced ICP experts reviewed the 40 DSFs for relevance and representativeness of the complex decision-making environment of ICPs and shortlisted 35 DSFs shared between countries and project types. Drawing on the survey of international ICP experts, the paper quantified and ranked the DSFs within each category using mean scores and weightings. The paper then developed a Four-pronged decision support framework for ICPs and described its application for practical purposes.

The outcomes of the research have some useful implications. First, the paper has delineated the 35 DSFs which are shared between project types and territories and can be used to investigate the compatibility of using IC in a proposed project. Arguably, the quantified and ranked 35 DSFs constitute the first generic set of decision-making factors assessed through the international dataset and contributes to the empirical checklist of DSFs for ICPs. Second, the proposed framework may help to inform decision-making regarding the adoption of IC in building, civil engineering and infrastructure projects. The prioritized DSFs could be used as a preliminary guide when implementing IC, especially in countries where bespoke decision support system can be developed. There is an opportunity for wider applicability of the framework because it has identified both technical, managerial, and operational aspects of and the required competences for industrialized construction which are shared between project types and territories.

Despite the realization of the study's aim, there are some limitations to the conclusions drawn from the results. First, although adequate and supported with relevant literature, the sample size of the questionnaire survey was small and could compromise the generalizability of the results. Second, the 35 DSFs do not constitute an exhaustive set and the generalized analysis relaxed and overlooked the sensitivities of their relative importance across different project types and territories. Nevertheless, such generalized analysis is meaningful for the wider progress of the industrialized decision-making process and could only be limited when such analysis is conducted to inform a bespoke project implementation in each context. Consequently, future research should conduct bespoke prioritization of the DSFs within each category viz-a-viz local industry requirements and building regulations., before developing a bespoke decision support system for a given country and project type and should endeavour to include the economic feasibility component into the framework.

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