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Constructability Research Trends: A Review and Future Directions

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Abstract: Implementing constructability concepts in a project can bring many benefits such as reduced project cost & duration, enhanced project quality, and improved site management. There were numerous research on constructability concepts since its introduction in late 1970. However, there are limited contemporary literature to review the research on constructability in a structured way. Therefore, this paper aims to review the literature with respective to the constructability concepts. The trend of constructability development, limitations of current research, research gaps and future direction will be briefly presented. Constructability development internationally will be discussed first before the limitation of the constructability research conducted in Malaysia are presented. The literature review reveals that the constructability research in Malaysia are still limited. Apart from building projects, there is a need for more constructability studies with respect to infrastructure projects. The trend of constructability development had moved towards the use of quantitative models. For future direction, quantitative models related to infrastructure projects in Malaysia can be developed. There is a potential of the quantitative models to be embedded with Building Information Modelling (BIM) so that automated assessment is made possible.

Keywords: Constructability; buildability; quantitative model

1. Introduction

The construction industry is fragmented (Amin et al., 2017; Ya'acob, Rahim, & Zainon, 2018) and plagued by various problems related to cost, time and quality. It is important that the constructability concepts are adopted to improve projects' performances. Constructability concepts should be implemented at the early design stage (Stamatiadis, Sturgilla, & Amiridis, 2017; JadidAlEslami, Saghatforoush, & Ravasan, 2018) because it sets the pattern for all that follows and influences the later stages the most (Yitmen & Akyel, 2005). Some of the benefits of "constructability" include reduced project duration & cost (Jadidoleslami, Saghatforoush, Heravi, & Preece, 2018; Sanjaya, Joni, & Frederika, 2019), reduced changes (Pocock, Kuennen, Gambatese, & Rauschkolb, 2006; Saghatforoush, Hassim, Jaafar, & Trigunarsyah, 2010), better design (Saghatforoush et al., 2010; Khan, 2018), and improved construction efficiency (Lee, Cho, Hwang, Han, & Kim, 2018; Sanjaya et al., 2019). Although there were numerous research on constructability concepts since its introduction in late 1970, there are limited contemporary literature to review the research on constructability in a more structured way. In the Malaysian context, a few researchers (Zin, 2004; Hassan, 2005; Jelodar, 2009; Nawi et al., 2009; Mydin, Zin, Majid, Zahidi, & Memon, 2011)

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had pointed out that the research on constructability are limited. Therefore, this paper aims to review the literature with respect to the constructability concepts. This paper also indicates the future research direction for the researchers in Malaysia so that more research can be done to fill the gap of literature and thus contributing to enhance the quality of the Malaysian construction industry.

2. Research Methodology

The research method of this paper involved the process of collecting, filtering, and storing relevant articles. Fig. 1 illustrates the research procedure of this study. For the systematic review, the main source of information were obtained from Ebscohost, Emerald, ScienceDirect, ResearchGate and Google Scholar databases. The aim of this paper is to review the literature related to the constructability concept. The keywords "constructability", "buildability", "constructability Malaysia", and "buildability Malaysia" were used to search for journals and conference proceedings. Firstly, the returned publications were examined by looking at the titles and abstracts. Those which were not relevant to constructability were excluded. After that, the abstracts and contents of the remaining publications were browsed through. In total, there were 154 relevant publications being reviewed. Based on the in-depth review, it was discovered that there is a trend for the constructability research to shift from the exploration of theoretical concept to the development of quantifiable assessment tools. Therefore, the above mentioned databases were again searched for the relevant publications. In total, 16 papers/publications, 3 PhD thesis related to the quantitative constructability assessment tools were found. A few publications from Building and Construction Authority (BCA) Singapore related to Buildable Design Appraisal System (BDAS) were also found. After the publication related to the constructability models were reviewed, a research gap was discovered and presented under section 9.

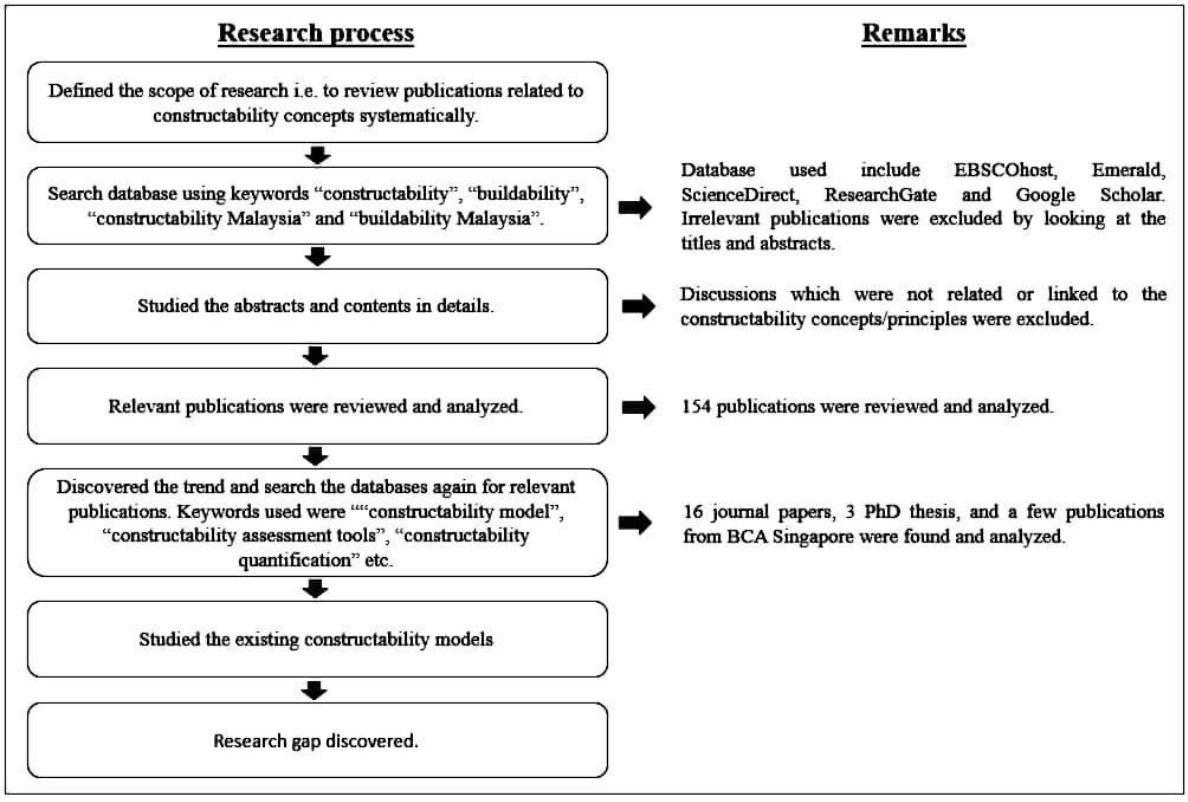

Fig. 1 - Research process for the present study

3. Background of "Constructability"

During 1960 to 1970, the construction industries in many places were having difficulties due to declining in project quality and cost efficiency (Uhlik and Lores, 1998). As a result, United States and United Kingdom endeavored to make changes by including contractors during the design stage. In United States, construction management method had emerged whereas in United Kingdom, procurement strategy similar to design and build was used (Uhlik and Lores, 1998). After a variety of studies on the problem of the disintegration of design and construction, the term "buildability" and "constructability" had emerged in UK and US respectively (Wong, Lam, Chan, & Shen, 2007). In year 1996, Construction Industry Institute (CII) Australia published the Constructability Manual which encompasses 12 principles to provide guidelines to implement constructability program (CII Australia, 1996). Singapore also enacted legislation in

year 2001 to measure the buildability performance of designs. Apart from the above mentioned, there were numerous research being conducted over the past decades to enhance the projects' performance

4. Definitions of "Constructability" and "Buildability"

There are many definitions of "constructability" and "buildability". The literature shows that different countries adopt different terms. Generally, "constructability" is more frequently used in Australia and Malaysia whereas "buildability" is adopted by Hong Kong and Singapore. The United States use both terms interchangeably. Some of the definitions of "constructability" are presented in Table 1.

Table 1 - Definitions of "constructability" and "buildability".

Definitions of "constructability"	Definitions of "buildability"
The optimum use of construction knowledge and experience in the conceptual planning, detailed engineering, procurement and field operations phases to achieve the overall project objectives (Construction Industry Institute (CII) US (1986).	The extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building. Construction Industry Research Information Association (Construction Industry Research and Information Association (CIRIA), 1983)
Constructability is a project management technique for reviewing construction processes from start to finish during the pre-construction phrase. It will identify obstacles before a project is actually built to reduce or prevent error, delays and cost overruns. (The Institution of Professional Engineers New Zealand Incorporated (IPENZ), 2008)	The extent to which a building design facilitates efficient use of construction resources and enhances the ease and safety of construction on site whilst the client's requirements are met (Wong, 2007)
Constructability is one of the project management methods to evaluate the whole construction process. It is defined as a concept with relative, not absolute, value to increase optimization capacity of resources, such as workforce, time, cost, quality and working environment conditions (JadidAlEslami et al., 2018)	The extent to which the design of a building facilitates ease of construction as well as the extent to which the adoption of construction techniques and processes affects the productivity level of building works (BCA, 2017)

Based on the various definitions of constructability, the most frequently used keywords are "integration of construction knowledge/expertise" and "optimum use of construction knowledge and experience". As for buildability, the keywords appear to be "ease of construction". Although constructability and buildability can be used interchangeably (Kannan and Santhi, 2018), differences between them can still be found. The researchers found that buildability concerns more on design (Khan, 2018) whereas constructability encompasses wider scope (Alinaitwe, Nyamutale, & Tindiwensi, 2014) and it embraces management functions/systems (JadidAlEslami et al., 2018). This paper adopts the term "constructability" wherever possible since it encompasses wider scope. However, for the discussion on the existing literature that adopted the term "buildability", the term was kept as it is to ensure the accuracy of knowledge shared.

5. Constructability Principles

Nima, Abdul-Kadir, Jaafar, and Alghulamp (2001a) categorized 23 constructability principles into 3 main categories namely, principles during conceptual planning phase, principles during design and procurement phases, and principles during field operations phase. These principles are frequently mentioned and quoted by the subsequent researchers. In year 1996, CII Australia identified 12 principles in the Constructability Manual. Some of the principles introduced include integration of constructability into project plan, involvement of construction knowledge in a project, design takes into account available resources and consideration of construction methodology at the project design phase (CII Australia, 1996). In Singapore, legislation was enacted in year 2001 to quantify the buildability performance of designs. According to BCA Singapore (2017), the three principles of buildable design are standardisation, simplicity, single integrated elements. Apart from the above-mentioned principles, there are many other principles introduced by various institutions or researchers over the past decades. Some of the most frequently mentioned constructability principles are (i) project elements should be standardized (Nima et al., 2001a; BCA, 2017) (ii) consider the accessibility of construction personnel, materials and equipment (Yitmen and Akyel, 2006; Alinaitwe et al., 2014) (iii) design simplification and design review (Mydin et al., 2011; BCA, 2017) and (iv) design should facilitate construction during adverse weather conditions (Mydin et al., 2011; Alinaitwe et al., 2014).

6. Criticisms on Constructability Principles and The Need of Quantitative Assessment Tools

Some researchers commented that constructability can be an abstract concept to be understood (Wong, 2007; Zhang, Zayed, Hijazi, & Alkass, 2016; Fadoul, Tizani, & Koch, 2018) and the assessment can be based on merely subjective scale (Wong, Lam, Chan, & Wong, 2006; Zhang et al., 2016; Fadoul et al., 2018). Yang, Wang, Dulaimi, and Low. (2003) thought that the decision making at the design stage is unsystematic and ill-structured. Ghaleenoe, Saghatforoush, JadidolEslami, and Preece (2017) and JadidAlEslami et al. (2018) also mentioned that there is lack of quantitative evaluation related to constructability. Therefore, quantitative methods are needed to measure constructability in a more structured way. Wong et al. (2006) believed that the quantitative assessment methods are more achievable and practical. Lam and Wong (2011) also concurred with the opinion, adding that the quantitative method is not only more manageable but also enable the comparisons of constructability to be made objectively. Zin (2004) asserted that this method is easier to apply especially for those who have limited constructability knowledge. Furthermore, Liu and Low (2007) acknowledged the importance of quantitative method by recommending that the Singapore's buildable design appraisal system (BDAS) be modified for implementation in China.

Realizing the advantage of quantitative assessment, Zhang et al. (2016) also proposed a model "which transforms the subjective assessment of constructability knowledge to a quantified value so that it is easy to analyze and improve building design". A more recent paper by Fadoul et al. (2018) found that the quantitative assessment is one of the most commonly used methods to review constructability. According to Lam and Wong (2011) and Fadoul et al. (2018), the quantitative assessment methods are more practical and manageable.

7. Existing Quantitative Assessment Models

Table 2 - Quantitative constructability assessment models in Malaysia

Assessment model	Description	Scope	Comments from previous researchers and/or the authors of the paper
1. Beam-design constructability assessment framework (Zin, 2004; Zin, Majid, Fadhil, Putra, & Mohammed, 2004)	A beam-design constructability assessment framework, which is based on the relationship between the degree of application of constructability principles and design constructability. Models of beam-design constructability assessment were developed by applying Artificial Neural Network (ANN) and regression methods.	For beam design only; limited to building projects	1. The study is only limited to the assessment of one design element i.e. beam design (Zin, 2004). 2. Data collection process from drawings and specifications are time consuming (Zin, 2004; Wong, 2007) Authors' comment: 1. The assessor needs to possess in-depth understandings on Artificial Neural Network (ANN) and regression methods for the assessment of the beam-design constructability.
2. Conceptual Model to Assess the Buildability of Building Structure (Nourbakhsh et al., 2012)	Common Construction Systems (i.e. RC slab, precast slab, steel slab, etc.) are assigned with Weight (W). Mathematical equations are used to generate the buildability index. Higher score indicates better buildability.	For building projects.	1. The researchers claimed to have make an original contribution as there was no such assessment model previously in Malaysia (Nourbakhsh et al., 2012). Authors' comments: 1. Comprehensive as it cover all common construction system such as structural frame, slab, internal & external wall, staircase and roof. Bonus point was also included in the equation for any innovative application of buildability. 2. Data collection from drawings and specifications can be time consuming. 3. It is easier to apply/understand compare to complex modelling.

A quantitative assessment model allows the assessors to derive constructability score out of the design of a project. Since the constructability is quantified, the assessor will be able to tell how construct-able a project is. Based on the in-depth review, it was discovered that there is a trend for the constructability research to shift from the exploration of theoretical concept to the development of quantifiable assessment tools. By searching the database, it was found that currently there are at least 18 quantitative constructability assessment models (Fig. 3). Out of these 18 models, only 2 models were developed in Malaysia. A brief explanation of the 2 models were shown in Table 2. Most of the 18 models were designed for building projects. It was also found that there is no perfect building assessment model available. The most common criticisms being time consuming in assessment process, model hard to understand, lack of objectivity during the assessment and knowledge on specific tool/software is required.

8. Previous Constructability Research in Malaysia

In total, 14 research related to constructability in Malaysia were found and tabulated in chronological order in Table 3. Based on the literature review and analysis, the following deficiencies of previous research were identified:

1. Most of the papers only assessed the degree of the applications of the constructability concepts and the familiarity of construction actors with constructability. Some papers had identified the significant constructability principles to be used at the design stage. Identifying important/critical constructability principles is not enough because some argued that constructability can be an abstract concept to be understood (Wong, 2007; Kuo, 2015) and the assessment at the design stage can be subjective (Wong et al., 2006; Zhang et al., 2016), unsystematic and ill-structured (Yang et al., 2003). Therefore, an assessment tool is required.

2. There are limited papers to discuss constructability from the infrastructure perspective. There are only a few papers to discuss the constructability of bridge and highway projects.

3. The two assessment models are designed for building projects only. There is a need to extend the models to cover infrastructure projects, as suggested by Nourbakhsh et al. (2012).

Table 3 - Previous constructability research in Malaysia.

	Papers/publications	Researchers	Description	Categories	Type of survey
1	Evaluation of the engineer's personnel's role in enhancing the project constructability	Nima, Abdul-Kadir, & Jaafar (1999)	▪ To discuss the roles of different construction actors in enhancing the project constructability.	More relevant to building	Discussion/ explanatory paper
2	Constructability implementation, a survey in the Malaysian construction industry	Nima et al. (2001a)	▪ To assess (i) the importance of the constructability concepts and (ii) the degree of the constructability concepts application from the viewpoint of the Malaysian Engineers	Not specifically stated	To assess degree of constructability application
3	Evaluation of the role of the contractor's personnel in enhancing the project constructability	Nima, Abdul-Kadir, & Jaafar (2001b)	▪ To discuss the roles of different construction actors in enhancing the project constructability.	More relevant to building	Discussion/ explanatory papers
4	Constructability Concepts in West Port Highway in Malaysia	Nima, Abdul-Kadir, & Jaafar (2002)	▪ Presents a case study of the applications and non-applications of constructability concepts to illustrate the impact of those concepts on a project's success	Infrastructure	To assess degree of constructability application

5	Constructability Concepts in Kuala Selangor Cable-Stayed Bridge in Malaysia	Nima, Abdul-Kadir, & Jaafar, & Alghulami (2004)	▪ To examine the application of the constructability concepts particularly during the conceptual planning and the design phases of the project.	Infrastructure	To assess degree of constructability application
6	Design Phase constructability assessment model (PhD thesis, also published in journal)	Zin (2004); Zin et al. (2004)	▪ To develop model that can be used to assess design constructability based on the different principles of constructability. ▪ Artificial Neural Network (ANN) and regression techniques were used in the model development.	Building (assessment model)	To develop assessment models
7	Design phase constructability concepts for highway construction	Zin and Hassan (2006)	▪ To explore the level of constructability implementation in highway projects in the Malaysian construction industry. The degree of importance and application of constructability concepts were investigated.	Infrastructure	To assess degree of constructability application
8	Assessment of Critical Constructability Activities Among Malaysian Building Contractors	Saghatforoush , Hassim, Jaafar, &Kadir (2009a)	▪ To assess the degree of involvement in Critical Constructability Activities (CCA) according to various types of contractors, projects and contracts.	Building	To assess the degree of involvement in CCA
9	Constructability Implementation Among Malaysian Building Contractors	Saghaforoush, Hassim, Jaafar, & Kadir (2009b)	▪ To assess the familiarity of Malaysian building contractors with constructability concept and activities; then to test their general opinions on its implementation in different construction phases and projects.	Building	To assess the familiarity with constructability
10	Enhancement of constructability concept: An experience in offsite Malaysia Construction Industry	Nawi et al. (2009)	▪ Describes the development of techniques and strategies to support the constructability during design phase through the adoption of industrialisation building system – IBS as a new or modern construction method.	More relevant to building	Discussion/ explanatory papers
11	Critical constructability activities in building projects	Saghatforoush et al. (2010)	▪ To identify the CCA in building projects	Building	To identify the CCA
12	Buildability Attributes at Design Phase in Malaysian Building Construction	Mydin et al. (2011)	▪ To identify buildability attributes in building design phase for Malaysian construction industry and to assess the level of importance of those attributes	Building	To identify buildability attributes at the design phase
13	A Conceptual Model to Assess the Buildability of Building Structure at Design Stage in Malaysia	Nourbakhsh et al. (2012)	▪ To develop a model to assess the buildability of the buildings within Malaysian construction projects.	Building (assessment model)	To develop assessment models

14	The extent to which constructability concepts are integrated into the project design phase and the barriers to its implementation: A research based in Sarawak (Master's project, unpublished).	Ding (2015)	▪ To examine the extent to which constructability concepts are integrated into the design phase in Sarawak and the barriers to its implementation.	Building	To assess (i) the familiarity with constructability and (ii) the degree of constructability application

9. Research Gap & Future Direction

Based on literature review, a theoretical framework (Fig. 2) was developed to summarize the process of implementing constructability and the advantages and disadvantages of the two major assessment methods. As discussed early on, quantitative models are more recommended by previous researchers for constructability assessment. Based on extensive review, it was found that the existing quantitative constructability assessment models and the previous research in Malaysia were mostly focused on building projects. As illustrated in Fig. 3, a gap was identified because the quantitative assessment methods for infrastructure projects are limited.

Some researchers (Ugwu, Anumba, & Thorpe, 2004; Nourbakhsh et al., 2012; Lam, Wong, Chan, Shea, & Lau, 2012) had recommended to extend their building design assessment methods to cover infrastructure projects. The assessment methods for buildings are not suitable for infrastructure projects because the elements, construction systems and construction method for infrastructure projects are different from building projects. In this regard, new models which are specifically designed for infrastructure projects such as bridges, highways and roads are required to quantify the constructability.

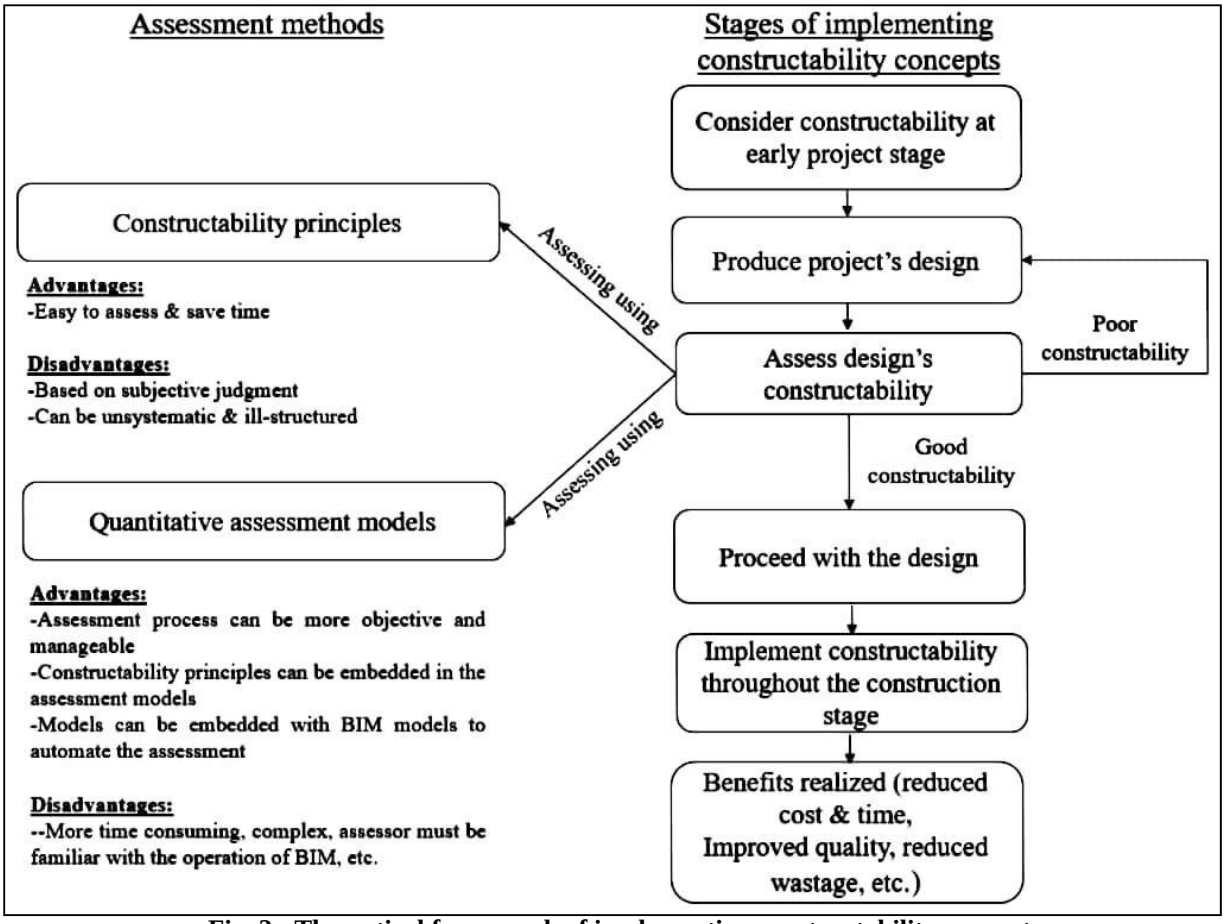

Fig. 2 - Theoretical framework of implementing constructability concept

Developing assessment models for infrastructure projects will help to fill the gap of the current literature. Besides, an effective quantitative assessment model can help the assessor to generate constructability score for a project. As the constructability is quantified, the assessor will be able to tell how construct-able a project is. Through the use of different models, the assessment of projects' constructability can be done in more objective, systematic, structured and manageable ways. Furthermore, the future research can also focus on the integration of BIM software with constructability concept in assessing the constructability of infrastructure projects.

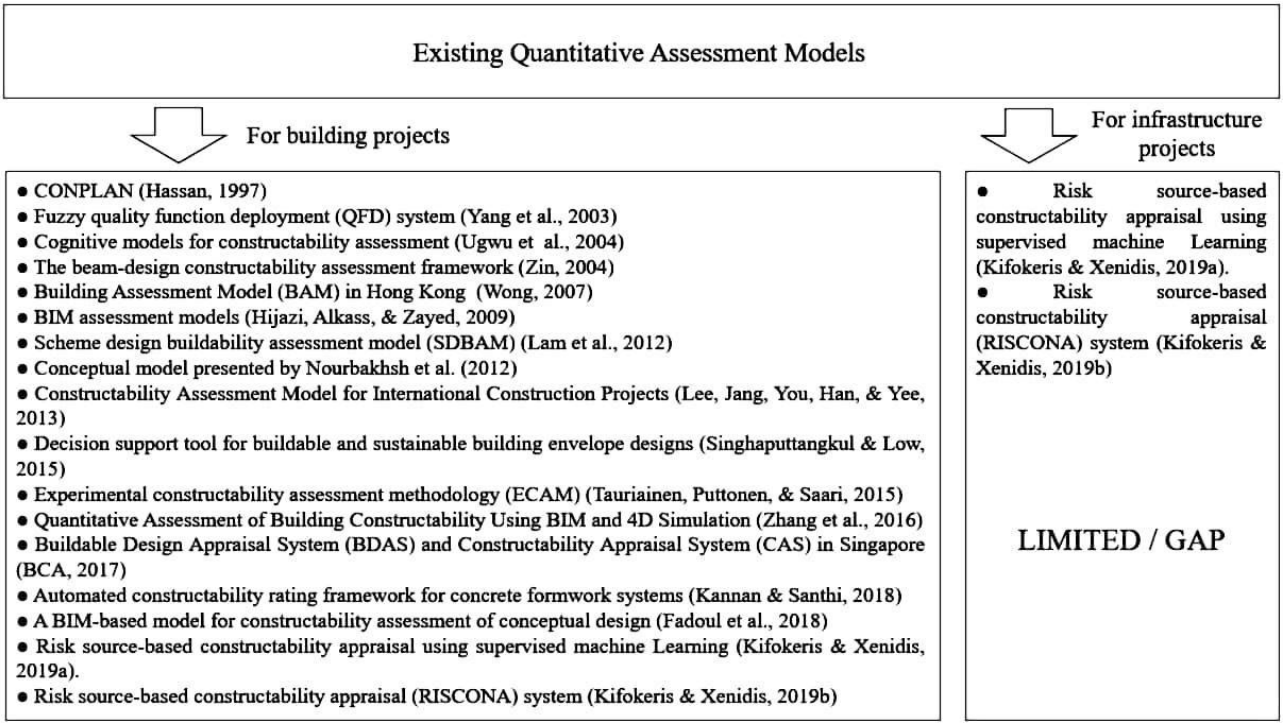

Fig. 3 - Existing quantitative assessment methods and the gap identified.

10. Conclusion

Based on literature review, the constructability research in Malaysia are very limited. Apart from building projects, there is a need for more constructability studies with respect to infrastructure projects. The trend of constructability development had moved towards the use of quantitative assessment models. This research discovered that most of the existing models mostly focused on building projects. Therefore, a few previous researchers had recommended to extend the building design assessment models to cover infrastructure projects. The quantitative assessment model will provide a way for the users to transforms the subjective constructability concepts into quantitative value. As discussed in this paper, many previous researchers supported that quantitative methods allow the constructability assessment to be carried out more objectively, systematically, manageably and practically. It is suggested that the constructability research should be extended to cover for other infrastructure projects like bridges, highways and roads. Furthermore, there is a potential for the developed models to be embedded with BIM model so that automated assessment is made possible and thus contributing to the development of BIM in Malaysia. Through this study, it is anticipated to create awareness among the construction industry to implement constructability concept to improve the productivity/performance of construction projects in Malaysia.

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