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SIGNIFICANT FACTORS OF IMPLEMENTING OPEN BUILDING SYSTEMS IN MALAYSIA

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ABSTRACT

Changes in the built environment are inevitable due to diversity in human needs over time and it is suggested by scientists to consider flexibility and adaptability under concept of Open Building Systems (OBS) to mitigate impacts on environment and to satisfy the end-user. However, conventional methods are still common due to the lack of knowledge in OBS, resistance to change, monopoly of conventional building material manufacturing, insufficient legislations and lack of awareness of end-users.

This study initially aimed to identify the significant factors of OBS concept that positively influence the construction industry of Malaysia and to verify the factors based on expert's view and ultimately to develop a conceptual framework. Both quantitative and qualitative research methods was employed to achieve these objectives including a comprehensive literature review on OBS to identify the main factors before verifying them by experts' perspective through Delphi method and developing the conceptual framework through ANP decision-making methods. This research was done specifically for construction industry in Malaysia but it has contributions in similar methods worldwide. Outcome of the literature review signifies 48 factors. These factors were later verified by selected experts of the area and the result revealed that 44 factors were confirmed and classified under 8 main clusters.

The findings show that "design for change" is the main influential variant among the main clusters followed by "standardization", "manufacturing of OBS components", "level of decision-making", "theory of level", "end-user oriented design", "enhanced post construction maintenance", "level of independency of building systems and subsystems", and "OBS factors influencing sustainability development".

The main category of "design for change" includes the most influential factors such as "design for adaptability", design for flexibility", "design for generality", "design for assembly", "design for disassembly", and "design based on service life span". Some other significant sub factors include "modular coordination", "identifying level of decision-making", "end-user involvement", "identifying ordering principles", and "replace-ability". This research will help practitioners in the construction industry to implement Open Building concept to achieve more adaptable Built Environment.

Keywords: *Adaptability, Flexibility, Industrialized Building System, Open Building Systems, Modular Buildings*

INTRODUCTION

Constant need-for-change in the construction industry and social trends has resulted in more demand for studying, developing, designing, and implementing adaptable building systems. The concept of Open Building was first introduced in 1960 to improve adaptability in the Built Environment. Back then, the whole world had been practicing this method by implementing different construction techniques.

Industrialized Building Systems (IBS), as a popular technique currently being used in Malaysia, also known as prefabrication, is the most similar building system in terms of implementing OBS. However, it has shortages and needs corrections to represent OBS. This paper aims to find the main significant factors that can positively improve IBS projects in order to fulfill the Open Building goals.

CRITICAL REVIEW OF PREVIOUS STUDIES

The theory of the Open Building is virtually stressed in one of John Habraken's statements: "We should not to forecast what will happen, but try to make provisions for the unforeseen" [1]. "Levels of control" and "controlled hierarchies" have been suggested by Habraken in order to enable building adaptations for future changes. He also recommended introducing the controlled hierarchies of building parts in building design and always emphasized promoting "Open Building" concept since 1960 [1].

IBS application, as a method that follows OBS characters, started in the1960s. This was during the launching of a project that was targeted towards the quality of construction, fast track and affordable housing project. IBS is now used for several purposes and currently there are more reputable manufacturers in the production of IBS worldwide [2]. IBS is believed to be the best option for the increased in productivity with high quality, effective use of time, being environmentally friendly as well as a reasonable cost of production. Therefore, conventional methods are best to be replaced by IBS to achieve these advantages [3]. However, the implementation of IBS is greatly expanded in many countries.

Abdullah et al in 2009 defines IBS as a holistic view that is different from a system, an approach, a process, or industrial philosophy perspective. IBS is also known globally as off-site production (OSP), industrialized building, modern method of construction (MMC), off-site manufacturing (OSM), off-site construction (OSC), pre-assembly, modularization and prefabrication [4]. IBS is in fact the industrialized and prefabrication construction being practiced in Malaysia and it is said to shift from the prefabricated systems paradigm to the modern construction concept application using manufacturing principle [5].

According to Hamid et. al., prefabrication is the major IBS characteristics while the rest of the IBS characteristics are the off-site production as well as mass production [2]. Prefabrication is defined by Sarja as the components of a building produced in factories. There is either a full production of these components, full fabrication or a partly manufactured production of the components, composite construction and afterwards, they are assembled on site. This system will make use of components as well as that are produced by a plant series to build on the site [6].

One of the crucial differences that existed between a closed and an open system is the ability to make use of different components from different manufacturers. The closed system is usually done by one manufacturer and builders does not have the opportunity to receive the product components from other manufacturers This closed system can be used in the production of products that are unique. The open system on the other hand, allowed the builder to select the components from other different manufacturers and this comes with the advantages like accessing spare parts and reduction of cost [3]. IBS is also defined as a process of construction that makes use of a building or component systems that includes on-site installation or prefabricated components.

These components are processed and manufactured in an environment that is highly controlled, after which it is assembled and delivered to the construction site with a minimal additional work [5].

Richard defined industrialization as the organization offering a complicated product whose design catered for diverse custom buildings [7]. The building system is a group of elements that work together to create unique structures. In essence, the industrialized system provides the team constructing the buildings to have access to fabricated standardized elements from other locations, which have a basis in conventional building design. The duty of a designer is very important through the implementation of an IBS project. The designer must ensure that the production of the prefabricated building parts is effective and efficient. There are 5 sub-systems to consider within the IBS design. This includes structure, envelope, partitions, services, and equipment.

Conventional approaches to IBS projects are still popular in Malaysia. These conventional stages often feature separate design and construction stages as illustrated in Figure 1. The design stage primarily involved the relevant meeting and consultation between the client, designer, and other experts including Architects. This stage is where many design decisions are made concerning the size and appearance of the building. Following this process is the construction stage where the process included the production of components as well as construction activities [8].

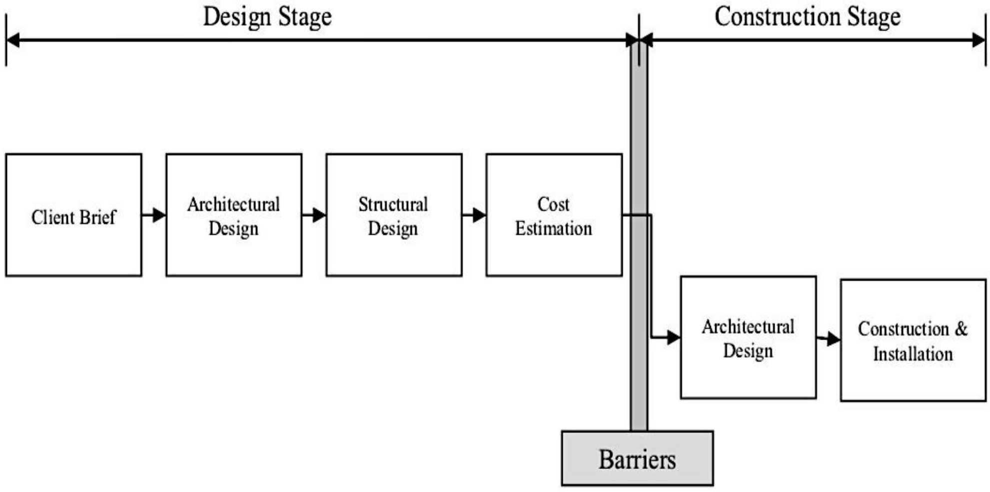

Figure 1: Conventional IBS stages [9]

In this approach, the stakeholders are separated according to their functions and do not participate in all the processes. For example, the contractors are not part in the design phase and only to provide labor for the project or simply to complete the design presented to them. This can affect how the project participants interacted with each other and therefore limited their abilities to work together.

Hamid et al. states that the lack of cooperation can severely influence the future and cost of a project by forcing redesign decision [2]. Previous researcher found that cooperation among parties in the IBS projects is crucial to assuring the success of the implementation of OBS practices in building construction [10].

RESEARCH METHODS

Both quantitative and qualitative methods were used as a multi-methodology research design to improve understanding of complicated elements of this investigation. Methods such as critical literature reviews, questionnaire-based data collections, Mean Index Analysis tools, and Delphi method were applied in this paper. A comprehensive literature review had been done to find out the initial significant factors affecting OBS implementation. Then, experts verified outcome factors by adopting the Delphi method were carried out.

Literature review

A fundamental primary stage of directing research is studying and inspecting the relevant theory and literature [11]. Some intensive reviews of relevant subjects were conducted in order to clear up the research problems prior to setting up the objectives and employing research approaches.

Initial review of literatures is mostly studied from CIB W104 (Implementing Open Building) and published reports from CIDB as well as some other relevant credited books and publications. Open Building concepts, IBS, and relevant research throughout the world are the prominent topics of this segment of the research.

The secondary review was mainly done to find the main characters of the Open Building concept, which can then be applied to the current IBS method in Malaysia as the variable of this research. Some subjects that have been studied are named as follows: OBS implementation, Industrialized Flexible Building (IFD) systems, IBS, OBS towards sustainability, adaptability in construction design, expandability and replicability in construction methods, Modular Coordination (MC) and standardization, decision-making supports tools and application developments, long-last building, end-user oriented methods of construction, and barriers in implementing OBS.

Delphi method

Delphi method is usually being adopted when the number of experts is limited in the research field. This technique of data assessment was introduced by Hallowell and Gambates in 2009 [12]. Delphi is a simplified approach that employed for developing variable assessment and also known as a method that analytically combined expert outlooks in order to evaluate conflicts about a complicated issue or a group of variables [13]. This method includes a series of sequential questionnaires or as called rounds, interposed by well-ordered feedback, in order to find the most reliable harmony in a group of experts [14].

ANP method

Organizing the research concern is the first step of ANP just similar to its older version AHP (Analytical Hierarchy Process), and it leads the analysis to an initial model that signifies the interaction and belonging of principles involved to a higher model or achieving the ultimate target.

The initial ANP model was designed as a hierarchy which includes the primary factors and the sub-factors to evaluate Open Building deliverable factors in Malaysia construction industry [15]. Super-decision software is a tool to illustrate ANP results and to facilitate decision making. This software aids decision-makers to model AHP or ANP outcomes. It also enables pairwise comparison among decision concern factors with developing Supermatrix based on ANP network structures for further studies [16].

RESULTS AND DISCUSSIONS

Initial significant factors

To answer the concerns of the first aim of this research, a comprehensive literature review was done to demonstrate all important Open Building concept factors that affect construction projects in Malaysia.

The following Table shows a summary of the significant factors of Open Building implementation. In other words, the influential factors of OBS implementation mentioned in earlier investigations were collected here. Table 1.

Table 1. List of OBS factors with references

No	Factors	Reference(s)
1	Accessibility of components	(Durmisevic, 2006) [17] (Richard, 2006) [7] (Russell et al.,2001) [18] (Kendall, S., 2016) [19] (Habraken, N. J, 2003) [20] (Kamar et al., 2009) [5] (Chen, Y., et al., 2010) [21] (Chiang, Y.-H., et al., 2006) [22] (Gorgolewski, M. T., 2005) [23] (Kedir, F. and Hall, D.M., 2021) [58]
2	Agility	(Arge, 2005) [24] (Kayali, 2008) [25] (Kendall, S., 2016) [19] (Russell et al.,2001) [18] (Fellows and Liu, 2015) [11]
3	Applying Just in Time (JIT) methods	(Blismas & Wakefield, 2009) [26] (Kamar et al., 2009) [5] (Chiang, Y.-H., et al., 2006) [22] (Domingues P, et al., 2016) [27] (Estaji, H., 2017) [57]
4	Automation	(Habraken, N. J, 2003) [20] (Baldwin, et al., 2008) [28] (Chen, Y, et al., 2010a) [21] (Jaillon, L., & Poon, C. S., 2009) [29] (Fellows and Liu, 2015) [11] (Kim, C. et al., 2009) [30] (Richard, R.-B., 2005) [7] (Domingues P, et al., 2016) [27] (Ahmadi-Karvigh S, et al., 2017) [31] (Kamar et al., 2009) [5] (Chiang, Y.-H., et al., 2006) [22] (Hussein, 2009) [32]
5	Building movability	(Manubuild, 2008) [33] (Kendall, S, 2004) [34] (Kendall, S., 2016) [19]
6	Convertibility	(Kouichi SATO et al.,2005) [35] (Habraken, N. J., 2008) [36] (Russell et al.,2001) [18] (Duffy and Brand 1998) [37] (Chen, Y., et al., 2010) [21] (Estaji, H., 2017) [57]
7	Demountable components	(Richard, R. B., 2006b) [7] (van Gassel, 2003) [38] (Scheublin, 2005) [39] (Durmisevic, 2006) [17] (Kendall, S., 2016) [19] (Jaillon, L., & Poon, C.-S., 2010) [50]
8	Design based on service life span	(Kendall & Teicher, 2000) [47] (Cuperus, 2003) [41] (Habraken, 2003) [20] (Kendall, 2004) [34] (Durmisevic, 2006) [17] (Kamar et al., 2009) [5] (Estaji, H., 2017) [57] (Kedir, F. and Hall, D.M., 2021) [58]
9	Design for Adaptability	(Durmisevic, 2006) [17] (Russell et al.,2001) [18] (B. Leupen, 2006) [41] (Karni, 1995) [42] (Atlas and Ozsoy,1998) [43] (Conejos, S, 2014) [44]
10	Design for Assembly (DfA)	(Kendall, S., 2016) [19] (Karni, 1995) [42] (Atlas and Ozsoy,1998) [43] (Habraken, N. J., 2008) [36] (Olie, 1996) [45] (Sarja, 1998) [6] (Blismas & Wakefield, 2009) [26] (Kamar et al., 2009) [5] (Chiang, Y.-H., et al., 2006) [22] (Hussein, 2009) [32]
11	Design for disassembly (DfD)	(Richard, R. B., 2006b) [7] (Fellows and Liu, 2015) [11] (van Gassel, 2003) [38] (Scheublin, 2005) [39] (Durmisevic, 2006) [17] (Habraken, N. J., 2008) [36] (Jaillon, L., & Poon, C. S., 2009) [29] (Kayali, 2008) [25] (Kendall, S, 2004) [34] (Domingues P, et al., 2016) [27] (Kendall, S., 2016) [19] (Habraken, N. J., 2008) [36] (Yitmen, I., 2005) [46] (Jaillon, L., & Poon, C. S., 2008) [48]
12	Design for Flexibility	(Kendall & Teicher, 2000) [47] (Cuperus, 2003) [40] (Russell et al.,2001) [18] (Atlas and Ozsoy,1998) [43] (Habraken, 2003) [20] (Kendall, 2004) [34] (Durmisevic, 2006) [17] (Kendall, S., 2016) [19] (Karni, 1995) [42] (Habraken, N. J., 2008) [36] (Saari, A. and Heikkila, P., 2008) [49] (Olie, 1996) [45] (Kamar et al., 2009) [5] (Duffy and Brand 1998) [37] (He, R et al, 2021) [56]
13	Design for Generality	(Gorgolewski, M. T., 2005) [23] (Jaillon, L., & Poon, C.-S., 2010) [50] (Durmisevic, 2006) [17] (Chiang, Y.-H., et al., 2006) [22] (Russell et al.,2001) [18] (B. Leupen, 2006) [41] (Karni, 1995) [42] (Atlas and Ozsoy,1998) [43] (Conejos, S, 2014) [44] (Chagas, L.S.V.B., et al 2020) [59]
14	Design for local typology based on local users' needs	(Durmisevic, 2006) [17] (Azuma et al., 2007) [54] (Kendall, S., 2016) [19] (Domingues P, et al., 2016) [27] (Hussein, 2009) [32]
15	Design for longer base building life span	(Kendall, 2004) [34] (Durmisevic, 2006) [17] (Kendall, S., 2016) [19] (Jaillon, L., & Poon, C.-S., 2010) [50] (Fellows and Liu, 2015) [11] (Chagas, L.S.V.B., et al 2020) [59]
16	Disaster preparedness	(Verweij, S., Voorbij, L., 2007) [51]

17	Disentangling building subsystems	(Kendall & Teicher, 2000) [47] (Cuperus, 2003) [40] (Habraken, 2003) [20] (Kendall, 2004) [34] (Durmisevic, 2006) [17] (Richard, R. B., 2006b) [7] (He, R et al, 2021) [56]
18	Distributing decision-making to relevant parties	(Richard, R. B., 2006b) [7] (Fellows and Liu, 2015) [11] (Habraken, N. J., 2008) [36] (Sarja, 1998) [6] (Kamar et al., 2009) [5] (Duffy and Brand 1998) [37] (Habraken, N.J. 1976) [53]
19	Durability	(Kendall & Teicher, 2000) [47] (Cuperus, 2003) [40] (Habraken, 2003) [20] (Kendall, 2004) [34] (Durmisevic, 2006) [17] (Saari, A. and Heikkila, P., 2008) [49] (Blismas & Wakefield, 2009) [26] (Yitmen, I., 2005) [46] (Jaillon, L., & Poon, C.-S., 2010) [50] (Fellows and Liu, 2015) [11] (Navarro-Rubio et al 2019) [55] (Chagas, L.S.V.B., et al 2020) [59]
20	Durable components	(Habraken, N. J, 2003) [20] (Azuma et al., 2007) [54] (Kendall, S., 2016) [19] (Russell & Moffatt, 2001) [18] (Yitmen, I., 2005) [46] (Duffy and Brand 1998) [37] (Chen, Y., et al., 2010) [21] (Gorgolewski, M. T., 2005) [23]
21	Elastic layout design (expandability/shrink-ability)	(Kendall & Teicher, 2000) [47] (Durmisevic, 2006) [17] (Arge, 2005) [24] (Atlas and Ozsoy,1998) [43] (Saari, A. and Heikkila, P., 2008) [49] (Verweij, S., Voorbij, L., 2007) [51] (Estaji, H., 2017) [57]
22	End User involvement	(Habraken, N. J, 2003) [20] (Fellows and Liu, 2015) [11] (Kendall, S., 2016) [19] (Durmisevic, 2006) [17] (Kendall & Teicher, 2000) [47] (Cuperus, 2003) [40] (Karni, 1995) [42] (Atlas and Ozsoy,1998) [43] (Sarja, 1998) [6] (Kamar et al., 2009) [5]
23	Identifying level of decision-making	(Richard, R. B., 2006b) [7] (Kendall & Teicher, 2000) [47] (Olie, 1996) [45]
24	Independent components and Degree of Freedom (DoF)	(Kendall & Teicher, 2000) [47] (Kendall, S., 2016) [19] (Arge, 2005) [24] (Azuma et al., 2007) [54] (Karni, 1995) [42] (Russell & Moffatt, 2001) [18] (Atlas and Ozsoy,1998) [43] (Olie, 1996) [45] (Sarja, 1998) [6] (Duffy and Brand, 1998) [37] (Domingues P, et al., 2016) [27] (Kedir, F. and Hall, D.M., 2021) [58] (Jaillon, L. et al 2008) [8]
25	Industrialization	(Durmisevic, 2006) [17] (Kendall & Teicher, 2000) [47] (Russell et al.,2001) [18] (Cuperus, 2003) [40] (B. Leupen, 2006) [41] (Habraken, 2003) [20] (Kendall, 2004) [34] (Richard, R. B., 2006b) [7] (Saari, A. and Heikkila, P., 2008) [49] (Hamid et al., 2008) [2] (Abdullah, et al., 2009) [4] (Blismas & Wakefield, 2009) [26] (Kamar et al., 2009) [5] (Melanie Stallen, et al., 1994) (Chen, Y., et al., 2010) [21] (Chiang, Y.-H., et al., 2006) [22] (Verweij, S., Voorbij, L., 2007) [51] (Fellows and Liu, 2015) [11]
26	Insulation and soundproofing	(Fellows and Liu, 2015) [11] (Kendall, S., 2016) [19] (Arge, 2005) [24] (B. Leupen, 2006) [41] (Blismas & Wakefield, 2009) [26] (Jaillon, L., & Poon, C.-S., 2010) [50]
27	Integration corresponding among construction industry decision-makers	(Richard, R. B., 2006b) [7] (Habraken, N. J, 2003) [20] (Russell et al.,2001) [18] (Saari, A. and Heikkila, P., 2008) [49] (Fellows and Liu, 2015) [11] (Estaji, H., 2017) [57] (Kedir, F. and Hall, D.M., 2021) [58]
28	Integration of supply chain	(Chen, Y., et al., 2010) [21] (Chiang, Y.-H., et al., 2006) [22] (Gorgolewski, M. T., 2005) [23] (Domingues P, et al., 2016) [27]
29	Joints and Connections compatibility/configurability for different Building Systems	(Kendall & Teicher, 2000) [47] (Kendall, S., 2016) [19] (Durmisevic, 2006) [17] (Kamar et al., 2011) [52] (B. Leupen, 2006) [41] (Conejos, S, 2014) [44] (Verweij, S., Voorbij, L., 2007) [51] (Hussein, 2009) [32]
30	Lightweight components	(Fellows and Liu, 2015) [11] (Kendall, S., 2016) [19] (Blismas & Wakefield, 2009) [26]

31	Mass Production	(Richard, R. B., 2006b) [7] (Durmisevic, 2006) [17] (Habraken, N. J., 2008) [36] (Saari, A. and Heikkila, P., 2008) [49] (Hamid et al., 2008) [2] (Habraken, N.J. 1989) [54]
32	Modular Coordination (MC)	(Habraken, N. J, 2003) [20] (Richard, R. B., 2006b) [7] (Fellows and Liu, 2015) [11] (van Gassel, 2003) [38] (Scheublin, 2005) [39] (Durmisevic, 2006) [17] (Habraken, N. J., 2008) [36] (Jaillon, L., & Poon, C. S., 2009) [29] (Kayali, 2008) [25] (Kendall, S, 2004) [34] (Domingues P, et al., 2016) [27] (Modular Working Group, 2000) (Saari, A. and Heikkila, P., 2008) [49] (Hamid et al., 2008) [2] (Gorgolewski, M. T., 2005) [23] (Chagas, L.S.V.B., et al 2020) [59]
33	Movable components and Mobility	(Richard, R. B., 2006b) [7] (Durmisevic, 2006) [17] (Kamar et al., 2009) [5] (Russell et al.,2001) [18] (Kendall & Teicher, 2000) [47] (Karni, 1995) [42] (Kedir, F. and Hall, D.M., 2021) [58]
34	Multi-functionality	(Kendall, S., 2016) [19] (Arge, 2005) [24] (Chiang, Y.-H., et al., 2006) [22] (Jaillon, L., & Poon, C.-S., 2010) [50] (Domingues P, et al., 2016) [27] (Fellows and Liu, 2015) [11]
35	Ordering principles	(Durmisevic, 2006) [17] (Habraken, N. J, 2003) [20] (B. Leupen, 2006) [41] (Karni, 1995) [42] (Jaillon, L., & Poon, C.-S., 2010) [50] (Verweij, S., Voorbij, L., 2007) [51] (Estaji, H., 2017) [57]
36	Plug/play components and RTA design (Ready to Assemble)	(Kendall & Teicher, 2000) [47] (Kendall, S., 2016) [19] (Atlas and Ozsoy,1998) [43] (Saari, A. and Heikkila, P., 2008) [49] (Olie, 1996) [45] (Kamar et al., 2009) [5] (Chiang, Y.-H., et al., 2006) [22] (Chagas, L.S.V.B., et al 2020) [59]
37	Prefabrication and off-site works	(Melanie Stallen, et al., 1994) (Chen, Y., et al., 2010) [21] (Chiang, Y.-H., et al., 2006) [22] (Gorgolewski, M. T., 2005) [23] (Jaillon, L., & Poon, C.-S., 2010) [50] (Jaillon, L., & Poon, C. S., 2008) [48] (Jaillon, L., et al., 2009) [29] (Domingues P, et al., 2016) [27]
38	Re-configurability	(Jaillon, L., & Poon, C.-S., 2010) [50] (Domingues P, et al., 2016) [27]
39	Recyclable/Reusable components	(Jaillon, L., & Poon, C. S., 2008) [48]) (Chen et al., 2010) [21]
40	Repeatability of the components	(Chen, Y., et al., 2010) [21] (Gorgolewski, M. T., 2005) [23] (Fellows and Liu, 2015) [11]
41	Replace-ability	(Richard, R. B., 2006b) [7] (Russell et al.,2001) [18] (Karni, 1995) [42] (Jaillon, L., & Poon, C.-S., 2010) [50] (Jaillon, L., et al., 2009) [29]
42	Robustness	(Karni, 1995) [42] (Jaillon, L., & Poon, C.-S., 2010) [50]
43	Separation of support/in-fill	(Habraken, N. J, 2003) [20] (Kendall, S., 2016) [19] (Sarja, 1998) [6] (Kamar et al., 2009) [5]
44	Services accessibility	(Durmisevic, 2006) [17] (B. Leupen, 2006) [41] (Richard, R. B., 2006b) [7] (Verweij, S., Voorbij, L., 2007) [51]
45	Simplicity of base building (support)	(Habraken, N. J, 2003) [20] (Arge, 2005) [24] (Domingues P, et al., 2016) [27] (Saari, A. and Heikkila, P., 2008) [49] (Fellows and Liu, 2015) [11] (Estaji, H., 2017) [57]
46	Standard hybrid interfaces	(Richard, R. B., 2006b) [7] (Russell et al.,2001) [18] (Kamar et al., 2009) [5]
47	Typology of interfaces	(Kendall & Teicher, 2000) [47] (Habraken, N. J, 2003) [20] (Kendall, S., 2016) [19] (Fellows and Liu, 2015) [11] (Arge, 2005) [24] (Atlas and Ozsoy,1998) [43] (Russell et al.,2001) [18] (Saari, A. and Heikkila, P., 2008) [49] (Olie, 1996) [45] (Kamar et al., 2009) [5]
48	Utilizing inspection methods	(Jaillon, L., & Poon, C.-S., 2010) [50] (Kendall, S., 2016) [19] (Fellows and Liu, 2015) [11]

Delphi results

There are several limitations for researcher during data collection. In some cases, it may be so difficult to find sufficient number of respondents to count as experts in some fields. Therefore, Delphi had been suggested as an alternative research method that does not necessarily need large sample size. Variables of the first objective were verified by 15 experts. To find the experts, an appointment with CIDB of Malaysia experts was done on September 19, 2016. As a result of the meeting, CIDB staff introduced some professionals mostly involved in IBS projects so that the researchers can contact them via email. A sample size is part of proposed number of respondents and covers some designated unit from the whole group. As the appropriate sample size is taken, the survey resulted in the highest level of accuracy with less error.

As a result of the survey, sample size of 32 was approved. In total 32 experts from government organizations, consultants, contractors, academicians and self-employed were registered. Then, a short screening test with the help of a simple questionnaire was carried out and few questions were asked to the experts and given scores accordingly. Those respondents who attained a score of 4 out of 6 were considered eligible as the appropriate person. Prior to beginning the survey, Delphi method was briefly described in the survey by informing the experts that it needs their cooperation up to 3 rounds. They were also asked to give their honest viewpoints. Meanwhile, they were given an option to choose “I am not a right choice” in the specific part of the survey if they felt that they are not willing to share their knowledge and experience or they might quit the survey anytime in the proceeding rounds because of any particular reason. Table 2 shows the rate of distributions.

Table 2: Distribution rate of the questionnaires of Delphi

Description	Quantity	Percentage (%)
Questionnaire distribute	32	100
Incomplete	8	25
‘Not the right person’	6	18.75
Returned	18	56.25
Qualified as Valid Returned	15	46.9

Delphi method in this research includes 3 rounds. In the first round, the experts were asked to rate each of the variables using a 5-point Likert scale from 1 to 5. In the second round, results of the first round were specified to the experts and they were asked to reconsider their initial answers, and to re-rank their feedbacks if they find it necessary. Finally, in round three, the results achieved from round two were given to the experts to be reconsidered again.

The consistency of the outcomes resulting from the second and third rounds was examined and compared using Kendall’s Concordance Analysis Statistics to ensure consistency. Summary result of the Delphi survey indicates that 4 factors were found irrelevant to OBS. These factors were "Applying Just in Time (JIT) methods" "Building movability" "Disaster preparedness " and "Integration of supply chain" with mean index of 1.66, 1.83, 1.66, and 2.33 respectively. Factors that could not pass the requirements as explained earlier were eliminated from the list as they were not found as important variable in the OBS based on experts view. So, the total number of influential factors dropped down from 48 to 44.

Decision making conceptual framework

After identification of the Open Building variables, the initial model was developed with the aid of the Super Decision Software. Prior to developing an ANP model the structure of a hierarchical decision network for the decision problem must be established and evaluated [16]. An appropriate ANP usually includes two critical phases. Phase one controlled the hierarchy or network of the criteria and its dependents which control the interactions in the proposed system. Phase two covered the network of influences among the main factors and clusters.

The 8 main factors that shape the clusters of the model are the following Open Building influential characters: Design for Change (DfC), Level of decision-making 'Theory of level' (LDM), End-user oriented design (EU), Standardization (St), Manufacturing of OBS components (MC), Level of Independency of Building Systems or subsystems (LoI), Enhanced Post Construction Maintenance (PC), and OBS factors influencing sustainability development (SD). The network depended on the main criterion, so for every single criterion the network of influence is different.

Therefore, the super-matrix of limiting influence must be calculated for each main control criterion in the model. Later, each super-matric must be weighted based on the priority of its control criterion and subsequently the output must be synthesized from the calculation of all the control criteria. Figure 2 shows the conceptual analytical model for the Open Building influential factors in the construction industry with the help of the Super Decision software. First row of the model shows the ultimate goal to be achieved which is evaluation of the Open Building implementation.

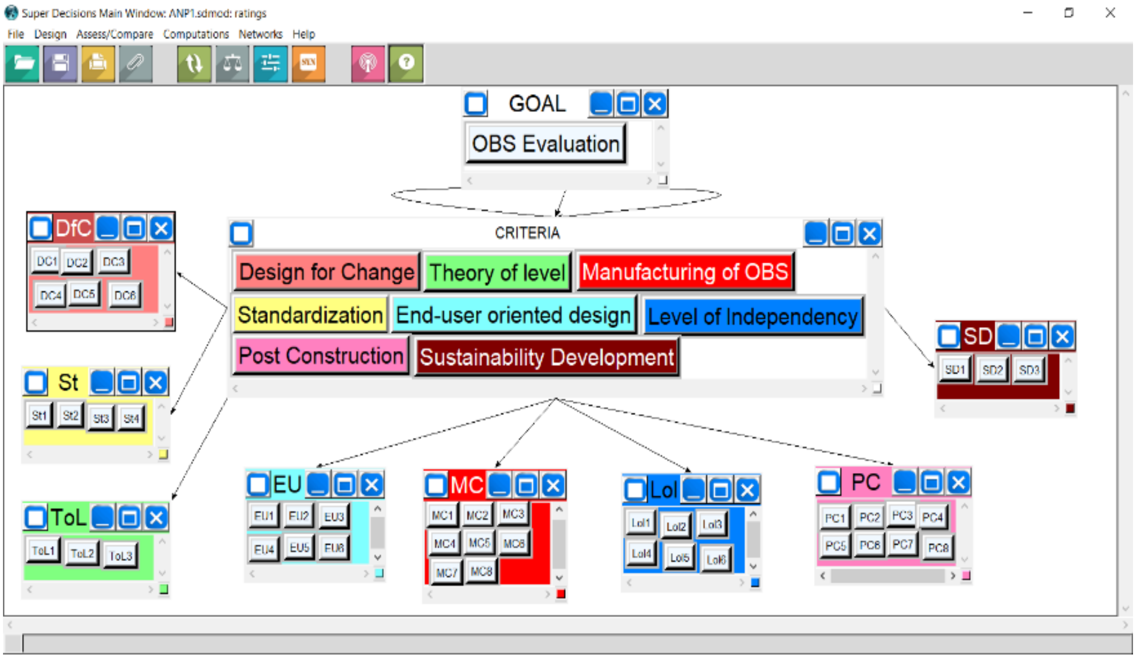

Figure 2: ANP Decision Model for the OBS evaluation in Super Decision Software

CONCLUSION

After reviewing of literature on Open Building Systems, the research identified the main variables of such systems from the findings of the previous research. These variables later were confirmed by experts of the field via a three-round Delphi method. An Analytical Network Process (ANP) method was then employed to assess the weight and values of the variables to develop a conceptual framework utilizing Super Decision software.

The results indicated that among all the OBS main factors (clusters), design for change, standardization, manufacturing of OBS components, level of decision-making 'Theory of Level', end-user oriented design, level of independency of building systems or sub-systems, enhanced post construction maintenance, and OBS factors influencing sustainability development were ranked from the most to the least important.

Also, the sub factor that received the highest fifth ranks and weight were the "design for adaptability", "Modular Coordination (MC)", "identifying level of decision-making", "end-user involvement" and "ordering principles" respectively. Finally, the sub-factors that received the poorest score were "utilizing inspection methods", "repeatability of the components", and "re-configurability" at the end of the list.

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