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Barriers to the transition towards off-site construction in China: An Interpretive structural modeling approach

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A R T I C L E I N F O

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A B S T R A C T

Off-site construction (OSC) has been recognized as an approach to transform the construction sector from a labor–intensive to a modernized and green industry. Despite a number of advantages, the development of OSC still remains its infancy in China due to various interactive barriers. Some studies have been conducted to explore the barriers to the OSC adoption. However, very few studies attempted to investigate the complex interrelationships among these barriers. In order to fill this gap, this study adopts Interpretive Structural Model (ISM) technique to explore the interrelationships amongst barriers to the OSC adoption in China. Firstly, critical barriers were identified through literature review and semi-structured interviews with various stakeholders. Then, the overall structure amongst barriers was revealed through ISM technique. By using the Matriced' Impacts Croise's Multiplication Appliquée a UN Classement (MICMAC) technique, the barriers were classified into four groups according to their driving-power and dependence power. The results indicate that specific attentions should be given to inadequate policy and regulations, lacking knowledge and expertise, dominated traditional project process as well as low standardization. The research findings provide valuable information for policy-makers on the overall structure amongst barriers. These results shed lights on effectively developing measures to facilitate the OSC adoption in the construction sector.

1. Introduction

It is well acknowledged that China has one of the largest construction industries over the world (Chang et al., 2016). Along with significant economic contribution, the Chinese construction industry is facing challenge in pursuing the goal of sustainable development. For instance, the construction industry accounted for 20% of the total energy consumption in China in 2015 (Hong et al., 2017). This proportion might be even higher due to the largest urbanization is experienced in China which is expected to a historic of 60% by 2020 (Gan et al., 2017a, b). It is estimated that around 30 billion m^2 of building area will be newly constructed by 2020 according to the *National New-type Urbanization Plan (2014–2020)* (Gan et al., 2015; SC, 2014). Meanwhile, the labor shortage of on-site construction workers have emerged in major cities of China due to intensive workloads, long working hours and poor living conditions (Wang et al., 2016). There are a number of issues associated with traditional on-site construction method such as low productivity, high waste, heavy environmental burden and poor safety (Teng et al., 2017; Huo and Yu, 2017).

Under off-site construction (OSC), a certain amount of building components are manufactured in a controlled environment, transported to the construction site and assembled into buildings (Hong et al., 2018; Mao et al., 2015). Originated from the manufactured industry, OSC is a radical innovation to replace conventional in-situ construction method (Kamali and Hewage, 2017; Phillips et al., 2016). Currently, the adoption of OSC has made considerable progress in countries and regions such as Japan, Denmark, Netherlands, Sweden, Germany, Hong Kong, Singapore and so on (Jaillon and Poon, 2010; Mao et al., 2016). Lessons derived from these countries and regions highlight the inherent benefits of the OSC, including reducing construction waste, improving quality control, reducing noise and dust, improving health and safety, saving times and costs, lowing labor demand, reducing resource depletion, and a consequence increasing in predictability,

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productivity, whole-life performance, and profitability (Li et al., 2014a, b, 2016). This indicates that the OSC adoption can be regarded as a good alternative to meet housing demand timely as well as to facilitate the shifting the dependence of construction industry on labor towards a “knowledge -based” industry (Nadim and Goulding, 2011).

The Chinese government has recognized these benefits and regarded the adoption of OSC as an effective tool to facilitate the industrialization of construction industry. OSC is expected to account for 30% of total construction within the next decade (SC, 2014). It is mandatory to adopt OSC for affordable housing development in many jurisdictions, such as Chongqing, Beijing, and Shenzhen. The total floor area of OSC housing is expected to exceed 40million m^2 by 2017. Meanwhile, in the context of urbanization, the massive housing demand within limited time framework creates best opportunity for its extensive adoption.

The construction industry is well-known for its low level of innovation (Xue et al., 2017). The promotion of adopting OSC is indeed a formidable task for the construction industry as its “lock-in” to the conventional in-site construction method (Lovell and Smith, 2010). As a sequence, the projected market share of OSC in China remains below 2% of its entire construction sector, far below the national target (Mao et al., 2016). This has motivated studies to explore individual barriers to the OSC adoption in China (Luo et al., 2015; Zhang et al., 2014). However, the interrelated relationships among barriers have been largely overlooked. Liu et al. (2016b) argued that the OSC adoption as innovation is featured with complex, dynamic and non-linear. As extraordinary variety of materials required for the products, the construction is a complex product system (Xue et al., 2014). The distinguished characteristic of complex product system is that many interconnected elements are organized in a hierarchical way, with nonlinear and continuously emerging properties (Miller et al., 1995). The OSC adoption will introduce changes into this complex system which creates a ripple effect of secondary and tertiary impacts (Slaughter, 2000). Therefore, it is imperative to understand the interrelationships among these barriers so that effective strategies could be developed accordingly. This has been underscored by previous studies that suggested the interactive relationships among barriers to the adoption of construction innovations (Rajaprasad and Chalapathi, 2015; Luthra et al., 2014; Dalvi-Esfahani et al., 2017). An examination of these interactive relationships provides a comprehensive picture regarding the overall structure of barriers (Wang et al., 2008).

Therefore, this study aims to fill this gap by developing a comprehensive model depicting the barriers and their interactive relationships via the Interactive Structural Modeling (ISM) and Matrice d'impacts croises-multipication appliqué a classement (MICMAC) technique. Specific objectives of this research are: 1) identifying the critical barriers to the OSC adoption; 2) determining the interactive relationships amongst these barriers; 3) prioritizing these barriers. In light of the significant role and urgent need of OSC in the rapid urbanization in China, the research findings help decision makers to visualize the barriers through revealing the overall structure while the model facilitates the identification of high-priority barriers. Corresponding strategies can be developed consequently. This sheds lights on how to facilitate the OSC adoption in developing countries.

2. Research methods

To achieve these research objectives, a hybrid research method (Fig. 1) was adopted in this study. Firstly, a comprehensive literature review was conducted to identify the barriers to the OSC adoption. This is followed by a questionnaire survey to elicit the perceptions of experts regarding the contextual relationships amongst these barriers. By using Interpretive Structural Model (ISM) technique, the Adjacency Matrix and the Reachability Matrix can be constructed and the hierarchy structure can be depicted after checking transitivity by power iteration analysis. Finally, these barriers were classified according to driving power and dependence power by using the Matrice d' Impacts Croises - Multipication Appliqué a classement (MICMAC) technique.

2.1. ISM

Interpretive Structural Model (ISM) was first proposed by Warfield in 1974. It is an interpretive modeling technique based on the judgment of working participants in a group to decide whether and how the factors of complex situation are related together (Dalvi-Esfahani et al., 2017). ISM provides an effective method to recognize relationships among various items of a complex system (Abuzeinab et al., 2017; Luthra et al., 2014). Meanwhile, ISM has been adopted to highlight the courses of actions to solve the target problem (Dalvi-Esfahani et al., 2017). Currently, ISM has been adopted in the field of construction innovation, e.g. investigating barriers to sustainable business models in UK (Abuzeinab et al., 2017); exploring the interactions among barriers of adoption of smart grid technologies (Luthra et al., 2014); probing the interactions of barriers to implementing OHSAS 18001 in India (Rajaprasad and Chalapathi, 2015). With a reference of these studies, the basic steps to develop the ISM are as follows (Abuzeinab et al., 2017; Luthra et al., 2014):

Step 1: Variables related to the problems or issues under consideration are identified.

Step 2: Identifying the contextual relationship among variables identified in Step 1. The Adjacency Matrix (AM) suggests the contextual relationship among variables that collected opinions from experts. The contextual relationships presenting the pair wise relationships between variables in AM can be described by using the letters of V, X, A, O. *V* means that variable *i* led to variable *j*; *A* means variable *j* led to variable i; *X* means variables *i* and *j* led to each other; *O* means variables *i* and *j* were unrelated.

Step 3: Developing a Reachability Matrix (RM). The Adjacency Matrix (AM) demonstrates the direct relationships among barriers, while the Reachability Matrix suggests not only the direct relationships among barriers but also the indirect relationships. Based on the AM, two steps were implemented to develop the RM. Firstly, the initial RM (R_i) was developed by using the following rules that the binary values 1 and 0 are adopted to replace V, A, X, O in AM (Shen et al., 2016):

- If the cell (*i, j*) entry in the AM was V, the cell (*i, j*) entry in the Reachability Matrix became 1 and the cell (*j, i*) entry became 0.
- If the cell (*i, j*) entry in the AM was A, the cell (*i, j*) entry in the Reachability Matrix become 0 and the cell (*j, i*) became 1.
- If the cell (*i, j*) in the AM was X, the cell (*i, j*) entry in the Reachability Matrix became 1 and the cell (*j, i*) became 1.
- If the cell (*i, j*) entry in the AM was O, the cell (*i, j*) entry in the Reachability Matrix became 0 and the cell (*j, i*) also became 0.

As the initial RM based on AM only demonstrates the direct relationships among variables without telling the indirect relationships, it is necessary to conduct the power iteration analysis. This aims to check transitivity rules, e.g., if A→B and B→C, then A→C, to reveal the indirect relationships amongst variables. By adding the transitivity to the initial Reachability Matrix through Boolean operation which involved self-multiplication of matrix until it reached a stable state, the final Reachability Matrix can be