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# Overcoming barriers to off-site construction through engaging stakeholders: A two-mode social network analysis

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ABSTRACT

Rapid urbanization and the issue of environmental degradation compel developing countries to find a cleaner approach to replace or complement the traditional on-site construction method. Off-site construction (OSC) with its various advantages has been regarded as a promising approach to address the problems confronted in developing countries. However, promoting the adoption of OSC is indeed a tough task that still faces multiple barriers. It is stakeholder collaboration by integrating diverse resources within the construction industry that can potentially address these barriers. Although multiple studies have been conducted from various perspectives, the issue of stakeholder collaboration, as the key to promoting OSC adoption, has been overlooked. This research aims to explore stakeholders' influencing power over such barriers using two-mode social network analysis. Firstly, 13 barriers to the OSC adoption, as well as 15 stakeholders with the power to overcome these barriers, were identified based on literature and expert judgments. Subsequently, a questionnaire survey was conducted comprising 39 responses from experts with rich experience in OSC in Chongqing, China. Centrality and core-periphery structure analyses were adopted to study the network. The results show that the government and developers have the highest degree centrality, betweenness centrality, and eigenvector centrality, and thus are the most influential stakeholders in the network. Similarly, the lack of knowledge and expertise, and the dominant conventional project process have the highest values of centrality among all barriers. With the density of interaction being 0.814, core stakeholders and barriers have intensive relationships, and the network shows an apparent core-periphery structure. Theoretically, this study demonstrates the use of the two-mode social network in construction research, and practically, this study sheds lights on how to effectively drive the adoption of OSC in developing countries through promoting stakeholder collaboration.



## 1. Introduction

Global resources are being used up at an alarming rate, causing not just greenhouse gas emissions but also environmental degradation (Olubunmi et al., 2016). To a large extent, building activities with high energy consumption have contributed to various environmental issues (Lu et al., 2017; Teng et al., 2017). For instance, globally, the construction industry consumes 40% of total energy production, 12–16% of all water available, 32% of non-renewable and renewable resources, 25% of all timber, 40% of all raw materials, produces 30–40% of all solid wastes, and emits 35–40% of $CO_2$ (Darko et al., 2017). Moreover, the extent of the impacts of building stock on the environment could be exaggerated due to the rapid urbanization and associated development activities in developing regions (Shi et al., 2015). On the one hand, according to Gan et al. (2017), the urban population in developing countries is expected to be 2.538 billion in 2050. Driven by migrations from rural to urban areas, massive housing construction will continue in the future. On the other hand, a number of problems confront the construction industry in developing countries, especially low productivity caused by the conventional cast in-situ method (Teng et al., 2017). It is not only inadequate in adjusting to increasing housing demands, but also at odds with the goals of improving environmental sustainability (Lovell and Smith, 2010). Therefore, it is urgent to find a new approach not only satisfying surging housing demands timely but also alleviating environmental impacts associated with

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conventional construction methods.

The off-site construction (OSC), an idea borrowed from the manufacturing industry, is a construction approach in which a certain amount of building components are manufactured in a controlled environment, transported to the construction site and assembled into buildings (Mao et al., 2015). It is a radical innovation within the building sector as the construction methods for completing projects are entirely transformed (Steinhardt et al., 2013). Several advantages of adopting OSC have been reported, such as building faster, i.e., a 30-storey hotel erected in only 15 days (Gao and Low, 2014), reducing embodied carbon and construction waste up to 34% and 74% respectively (Mao et al., 2013), cost saving up to 58% (Arditi et al., 2000), and less labour requirement up to 30% (Jaillon and Poon, 2008). The OSC adoption can not only meet the increasing demand for housing, but also improve the environmental sustainability of the construction industry. More importantly, it can facilitate the shifting of the construction industry from a labor-intensive to a "knowledge-based" industry (Nadim and Goulding, 2011; O'Neill and Organ, 2016). OSC is considered as an ideal alternative replacing the conventional construction method and addressing the challenge confronted by the construction industry in developing countries.

The promotion of OSC adoption is indeed a tough task as the construction industry always lags behind other sectors in adopting technological innovations (Chang et al., 2017; Lovell and Smith, 2010; Nadim and Goulding, 2010). In order to promote OSC adoption, a number of studies have been conducted from various perspectives, including (1) investigating the opportunities for OSC adoption (Arif and Egbu, 2010); (2) analyzing the status of OSC adoption (Ji et al., 2017); (3) examining the barriers to OSC adoption (Polat, 2010; Zhang et al., 2014); (4) examining the performance and impacts of OSC adoption in various aspects, such as cost, energy, construction waste, and life cycle performance (Hong et al., 2016; Kamali and Hewage, 2016; Liu et al., 2014); (5) identifying complementary technologies for OSC adoption, such as Building Information Modelling, and Radio Frequency Identification (Li et al., 2017); (6) developing decision methods for OSC adoption (Pan et al., 2012); and (7) exploring the business models, design, transportation, production, and assembly of OSC (Li et al., 2014b; Liu et al., 2016) These existing studies provide valuable information for developing countries in formulating policies to promote OSC adoption.

However, stakeholder collaboration as the key to promote OSC adoption has been overlooked by previous studies. Construction innovation involves multiple participants collaborating at the project level (Xue et al., 2014). The unique features of construction, e.g., one-of-a-kind nature of construction projects and temporary organization, seriously impede stakeholder collaboration for technology development in construction (Reichstein et al., 2005; Xue et al., 2017). Driven by self-interest, traditionally stakeholders are more likely to invest scarce resources towards their individual goals rather than making a joint effort (Cheng et al., 2001). If undesired consequence happens, stakeholders tend to shirk from responsibilities and pass the responsibility to others (Saito and Ruhanen, 2017). Thus, problems relevant to the adoption of innovative technology in construction largely stem from inadequate stakeholder collaboration (Dewick and Miozzo, 2004). To establish effective stakeholder collaboration of OSC adoption, it is necessary to firstly clarify stakeholders' power in eliminating the associated barriers. Power is the key attribute reflecting stakeholders' ability to tackle certain issues in the industry (Lin et al., 2017). Powerful stakeholders should undertake the leading responsibility to deal with relevant barriers to OSC. Otherwise, conflicts could happen due to the imbalance between power and responsibility. Therefore, stakeholders should undertake the corresponding responsibility based on their power and capabilities, which is the prerequisite to establishing effective stakeholder collaboration for OSC adoption.

Few studies investigated the issue of stakeholder collaboration in OSC broadly, and the stakeholders' power to tackle the barriers to OSC specifically. With the aim to fill this gap of knowledge, this study adopts a stakeholder-barrier analysis to identify stakeholders' power status on the barriers to OSC adoption using a two-mode social network approach. The specific objectives of this study are outlined as follows:

(1) to identify the related stakeholders and barriers to OSC adoption;
(2) to explore the stakeholders' power status over the barriers to OSC adoption;
(3) to investigate the network characteristics of stakeholder collaboration and depict the network structure.

Unlike traditional social network analysis examining the interrelationships within the same set of entities (one-mode network analysis), the two-mode network analysis explores the relationships between two sets of entities. Therefore, it is able to demonstrate the stakeholders who are linked with each other through the barriers that they could jointly tackle, as well as the barriers that are linked with each other through the stakeholders who have the power to influence them. Consequently, not only the network characteristics of stakeholder collaboration can be revealed, but also a roadmap for stakeholder collaboration to promote OSC can be depicted. The innovative perspective of this study sheds light on supporting the development of OSC not only in China but also other developing countries.

## 2. Literature review

### *2.1. Barriers to the OSC adoption*

The key feature of OSC is the relocation of most building activities from onsite to an offsite factory (Polat, 2008; Zhai et al., 2014). Despite its significant benefits, OSC development remains slower than anticipated. Several studies have been undertaken to explore the barriers to OSC adoption across various countries. Drawn on previous studies such as Chang et al. (2016), a directed content analysis of the literature for identifying these barriers was conducted in a systematic manner. Firstly, related journals and conference articles were searched in the databases of "Web of Science", "Compendex Engineering Village" and ASCE library using some combinations of keywords such as "barriers", "factors", "offsite construction", "prefabricated construction", "precast concrete building", "modern methods of construction", "industrialized building", and "offsite prefabrication". The retrieved articles were further screened through reviewing their abstracts and conclusions to determine their relevance to this study. Then, content analysis was employed to analyze the selected articles based on the TOE (Technology-Organization-Environment) framework. This framework has been extensively adopted in the studies of construction innovation (Nadim and Goulding, 2011; Xue et al., 2017). According to this framework, the barriers to OSC adoption were summarized into three perspectives, namely technological barriers, organizational barriers, social and market barriers.

#### *2.1.1. Technological barriers*

The immature technology of OSC could lead to various aspects of issues related to cost, logistic, quality, and aesthetic performance. Firstly, there is a general census that higher cost is one of the most influential factors impacting the adoption of OSC (Elnaas et al., 2014). The higher cost is caused by the manufacturing,