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# Exploring transaction costs in the prefabricated housing supply chain in China

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ABSTRACT

The growing environmental problems, the rapid urbanization, and the disappearance of the demographic dividend in China has brought unprecedented opportunities to the development of prefabricated housing (PH). However, many barriers are hindering the promotion of PH, for instance, cost, lack of regulations, and the shortage of knowledge, among which cost is identified as one of the most critical barriers. Unlike previous studies focused only on production costs, this research aims to investigate transaction costs (TCs), e.g., searching costs, negotiation costs, and enforcement costs. First, this paper develops a theoretical TCs framework of the PH supply chain, based on an extensive literature review. Secondly, an empirical study was conducted on two cases in Chongqing to validate the TCs framework. Key stakeholders are identified by Social Network Analysis (SNA). Subsequently, 25 semi-structured interviews were conducted with key stakeholders, both to verify the new TCs framework and to explore stakeholder concerns about TCs. The centrality metrics by SNA identified six key stakeholders who have a significant influence on TCs. It is found from the interviews that both the conceptual phase and the construction phase are stages where the majority of TCs occur. Both the developer and the general contractor are paying for more TCs compared to the other stakeholders. This study contributes to theory by initially introducing the concepts of TCs to the PH field, and the findings bring implications on the governance of PH supply chain to both private stakeholders and the government.



## 1. Introduction

Facing the increasing pressure from the energy and environmental challenges, globally, there are high expectations on project stakeholders to realise sustainability. In the construction industry, prefabrication has become a promising recommendation to approach sustainability and cleaner production. Prefabrication in construction refers to the practice of producing building components in a manufacturing factory, transporting complete components or semi-components to construction sites, and finally assembling the components to create buildings (Tam et al., 2007). In China, prefabrication is nowadays mostly applied in the housing construction sector (Ji et al., 2017). Prefabricated Housing (PH) is defined as residential buildings that are assembled onsite using prefabricated components (MOHURD, 2017b). Moving some of the construction process to a factory, PH promises many significant sustainable advantages: lower labour and material costs, higher speed of construction, improved waste reduction, enhanced building quality, along with a cleaner working environment (Arif and Egbu, 2010). Yet, the promise of such benefits is not always realised. Research done in China revealed that the benefits of waste reduction from adopting prefabrication is 52%, and it achieves an average 15% and 16% reduction on construction time and labour requirement, respectively (Jaillon and Poon, 2008). Timber formwork and concrete works can be reduced by 74%–87% and 51%–60% respectively (Pan et al., 2007). Li and Jiang (2017) found that the PH can reduce the dust and noise on-site by about 9.5%, and with 68% less carbon dioxide generation.

Given the benefits of PH, globally, there is a trend of diffusion on PH uptake. In 2013, 9% of new residential building permits in Germany were for PH. In Japan, the proportion of all new dwellings prefabricated has remained steady between 12% and 16% in the last decade (Steinhardt and Manley, 2016). In the USA, PH was expected to reach 140,000 units in 2017, representing 14% annual growth from 2012 (Tumminia et al., 2018). Similar growing adoption of PH also appears in Australia, Sweden, UK, Netherlands, etc. (Steinhardt

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and Manley, 2016).

Driven by the theme of green development, there is also a growing interest from the Chinese authority to promote PH (Hong et al., 2018). Notably, PH was emphasized as one of the prominent themes by the Plan on Green Building (MOHURD, 2013) and the National Plan on New Urbanization 2014–2020 (GOSC, 2014). Recently, the State Council of the People's Republic of China announced that the incentive policies for prefabrication would be enforced, and new prefabricated buildings are expected to reach 30% of total construction within approximately 10 years (GOSC, 2016). However, the development of PH in China is still in the initial stage. As of 2015, the prefabricated productivity in China can supply only 2% of annual construction scale (Chang et al., 2018). The current realities of the implementation of PH has come along with many problems regarding cost control (Xue et al., 2018), low process efficiency (Zhai et al., 2014), and the lack of regulations (Mao et al., 2015), etc. Among them, the cost is identified as one of the most critical barriers (Hong et al., 2018). A recent study in China indicated that the capital cost of the prefabrication was 10%–20% higher compared with the in-situ (on-site) construction in China (Mao et al., 2016).

In this context, the cost reduction has become a major issue to promote PH in China. However, attention is focused only on the capital costs, while the hidden costs are overlooked in both the industry practice and the academic theories. For example, with a profits-boost intention, 85% of the enterprises pay attention to the capital investment, overlooking hidden costs in the production process (Jiang et al., 2018). Recent studies by Xue et al. (2018) and Mao et al. (2016) excluded hidden costs, such as land acquisition costs, commissioning and handover costs, and client overheads. The ignored costs are called Transaction Costs (TCs) by economists.

TCs refer to the costs of trade beyond the materials cost of the product, such as the costs of searching for projects, estimating, selecting project partners, negotiation, monitoring, regulatory approval and dealing with any deviations from contract conditions (Antinori and Sathaye, 2007). By their very nature, TCs, are relatively obscure when compared with direct construction costs, but they do account for a quite large amount (Qian et al., 2015a). Using six case studies, Whittington (2008) found that the post-contract TCs for the design-bid-build project delivery system are on average 12.6% of the contract value. TCs of energy-efficient buildings have been estimated to be as high as 20% of the investment cost (Gooding and Gul, 2016).

As an innovative industry process, the use of prefabrication in construction generates extra TCs owing to the mismatching between the new technology and the management process. The increase in TCs, in turn, can lead to cost overrun, disputes, abandonment and low efficiency in the supply chain. High TCs do not only hinder the implementation of prefabrication technologies in the building sector but also prevent market stakeholders from entering the sustainable market. However, there are even no studies available to understand the TCs of PH since TCs is a concept that has never been applied in this context. Therefore, the goal of our research is to understand the barriers of PH through the lenses of TCs theory and find ways to ultimately reduce TCs and to improve the efficiency of the supply chain.

To summarise the background argument thus far, the authors can state that this study aims to identify TCs throughout the PH supply chain and to examine how they appear in stakeholder production. The structure of this paper is organized as follow: Section 2 builds a theoretical TCs framework based on the review work on topics of barriers in the PH supply chain and TCs in construction. Section 3 describes the methodology of this study, which includes the case study, questionnaire survey, and the interviews. Section 4 shows the results of the data analysis using Social Network Analysis (SNA), and explains the findings on the aspects of identifying key stakeholders, validating the TCs framework and exploring stakeholder TCs. The discussion follows in Section 5, giving analyses of TCs by stakeholder, by supply chain and by nature, and further offers implications for project governance. Conclusions are presented in the last section.

## 2. Literature review

### 2.1. Barriers in the supply chain of PH

Based on the traditional definition of a supply chain (Christopher, 1992) and the definition of a construction supply chain by Wang et al. (2018), this study defines the supply chain of PH as: ***A transaction process that manages the flows of prefabricated housing, through upstream and downstream phases, providing value in the form of products and services to stakeholders***. Based on the practice of PH in China, the transaction process of PH projects can be defined as five phases: 1) concept; 2) planning and design; 3) manufacturing; 4) construction, and 5) operation and maintenance.

A stakeholder in the construction industry is a person or group of people who have a vested interest in the success of a project and the environment within which the project operates (Olander and Landin, 2005). Table 1 gives definitions of 15 commonly involved stakeholders in PH projects. And there are links between stakeholders with different natures. Xing and Deng (2017) defined the links of a green supply chain as logistics and information. In a market approach, as opposed to a hierarchy - see (Williamson, 1975) - transactions in the PH production process are based on contractual relations and also include the exchange of information and materials (Liu et al., 2018). Therefore, in this study, links between stakeholders of the PH supply chain are defined as contractual, information and materials flow, as shown in Fig. 1.

1) The contractual flows are always bidirectional in construction projects (Zhang et al., 2016). Contractual relationships in the PH supply chain include services contract, construction contracts, and properties transfer contracts, etc. For instance, as shown in Fig. 1, the service contracts are between the developer and: the surveyor, the supervision company, the sales agent, etc. Typical construction contracts are between the developer and the general contractor, between the general contractor and subcontractors. Properties rights transfer contracts existed when the state-owned land use contracts signed between the developer and the local government, which also appear between the developer and the residents.
2) The information flow in the PH supply chain represents the bilateral communication and information sharing between buyer and suppliers along the entire transaction process (Liu et al., 2018). The exchange of information is rooted in transaction activities. For instance, a PH project starts with the information exchange between the developer and the local government. The design requirements then flow from the developer through the architecture and the component suppliers to the general contractor.
3) In the PH supply chain, the materials flow indicates the unidirectional streams of the raw materials, prefabricated materials, and also final products. The raw materials are supplied by the materials suppliers to the components suppliers; meanwhile, there are also raw materials delivered to the general contractor to build the non-prefabricated parts. The prefabricated components or modules are then transported to the general contractor to be assembled. In the end, the buildings are delivered from the

**Table 1**
Stakeholders in PH projects.

| Stakeholder | Definition |
|---|---|
| Developer | Initiates the project, explores the consumers' demands and sets up the project organization; Links with designers, contractors, government regulatory bodies and the public. In the Chinese context, developers are sometimes taking the role of the clients. |
| General Contractor | Responsible for arranging the project timeline, the assembly, construction, and working with other stakeholders, including providing the adjusted technology proposal for architects. |
| Subcontractors | Engaged for technical or specialized works such as interior decoration, landscaping, and sewage systems. |
| Local government | Approves permits for new developments and monitors the production. |
| Architect | Responsible for preliminary design, final brief, and detailed design. |
| Surveyor | Responsible for engineering surveying; hydrogeology investigation; geotechnical engineering. |
| Consultants | Involved in the prior stages of projects development, like feasibility study consultant, design management and critique, development cost planning and control, and construction contract administration. |
| Supervision company | Guarantees the schedule, quality, and cost of the project on behalf of the client. |
| Components supplier(s) | Produces prefab components or units according to the detailed design from the architect. |
| Materials supplier(s) | Provides materials for construction activities. |
| Logistic company | The main task of a logistics company in a PH project is delivering the prefab components from the factory to the construction site with professional transportation and labor. |
| Financial institution | Provides capital to the client (developer). It can be a bank, a trust company or an asset-management company. |
| Residents (End-Users/ Occupiers) | The consumers and habitants of the final PH projects. |
| Sales agent | Sells houses to residents on behalf of developers (sometimes developers do the sales work by themselves). |
| Property management company | Manages the maintenance of prefabricated houses on behalf of clients (after handover). |

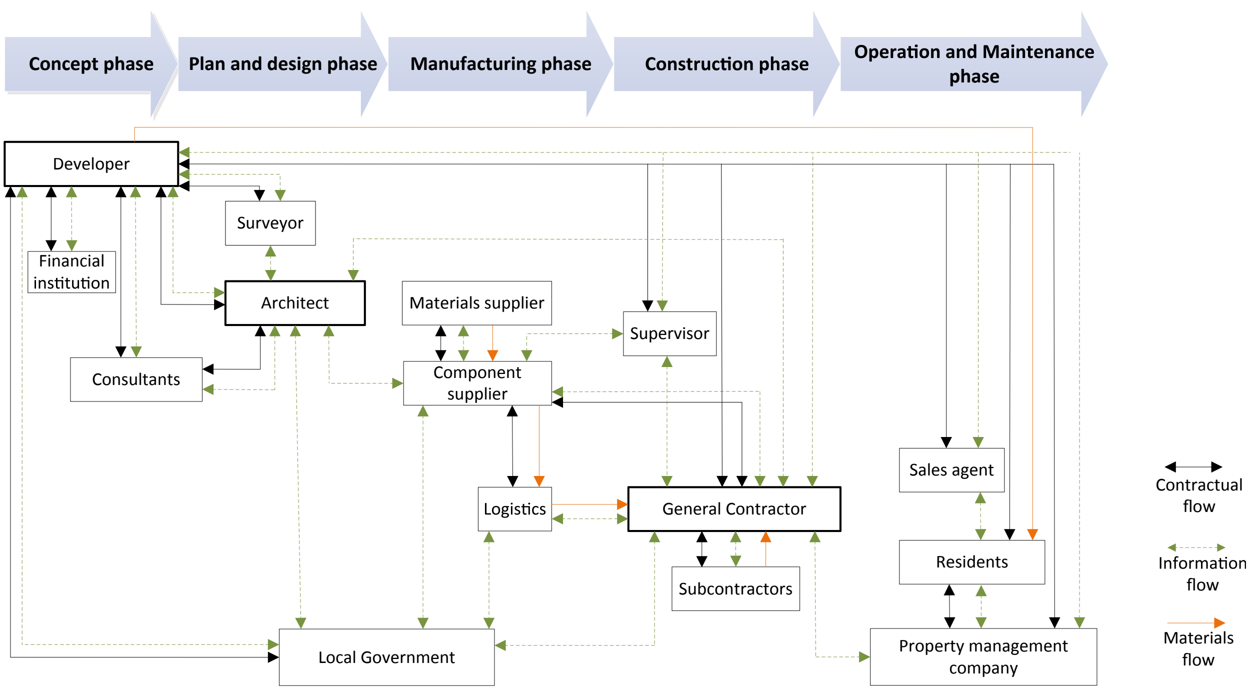


**Fig. 1.** DBB supply chain of PH in China (by the authors).

clients (developers) to the buyer after the sale. There are no logistics through the local government (Xing and Deng, 2017).

Moreover, the supply chain under different procurement modes is different due to the significant influence from the procurement mode on the transaction process (Liu et al., 2018). Fig. 1 demonstrates a supply chain under the DBB (Design-Bid-Build), which is most commonly applied in PH projects in China. In the DBB supply chain, the design and construction are achieved by separate contracts. Another major procurement method in China is EPC (Engineering-Procurement-Construction), which is a turnkey contract that places all design, procurement and construction responsibilities on one contractor. EPC is now advocated by the China State Council because it helps to achieve an integrated supply chain (GOSC, 2016).

The supply chain of PH in China is reforming from conventional to a prefabrication mode, where numerous difficulties are arising at every phase of the supply chain. Some examples are provided here for illustration, and may not cover all barriers experienced in reality:

1) In the concept phase, the barriers of identifying experienced partners, negotiating consultant fees, and decision-making have been given attention. A lack of availability of knowledgeable and experienced experts makes it challenging to find partners (Kamali and Hewage, 2016). Besides, the lack of professional consultants is a particular barrier, which directly leads to extra searching time and high consulting fee (Mao et al., 2015).

Furthermore, the long lead-in time for decision-making is recognized as a hindrance in the early stage of a PH project (Goodier and Gibb, 2005).

2) In the planning and design phase, architectural design and detailed design consume additional efforts. A significant challenge of PH projects is the need for intensive pre-project planning and engineering, which is a high requirement on the architectural design (Kamali and Hewage, 2016). Likewise, the detailed design for PH projects is more complicated than conventional projects. In addition to the complexity of component design itself, further considerations are needed when incorporating different components, and then when they are lifted, transported, placed on the foundation, and joined to form the building (O'Connor et al., 2015).
3) In the manufacturing phase, barriers are hiring skilled labor, components quality assessment, transportation, and risk of inappropriate delivery. The demand for machine-oriented skills increases both on-site and in the factory when adopting prefabrication. It involves hiring skilled workers and local labor training (Chiang et al., 2006). Besides, the lack of uniform design codes and accredited assessing organizations for PH results in considerable uncertainties, and further leads to unexpected costs (Mao et al., 2015). Also, transportation is identified as another vital challenge, which is the task that connects the off-site manufacture and on-site construction (Kamali and Hewage, 2016). Larsson and Simonsson (2012) identified "storage of prefabricated elements" as a difficulty for enterprises to applicate prefabricated technologies, which brings extra space requirements and labor costs.
4) In the construction phase, generally, the costs of educating/training labor are recognized as a big issue in China (Jiang et al., 2018). The implementing of PH has an even higher requirement on workers because of its innovative techniques and new production process. More education/training fees, therefore, occur in the construction phase to improve professional knowledge and skills (Zhai et al., 2014).
5) The operation and maintenance phase of PH projects does not differ much from conventional projects. No apparent barriers have been emphasized in the literature.

Apart from the barriers mentioned in each phase, frequent communication and effective coordination among stakeholders are needed throughout the whole supply chain. PH projects consume more efforts of participants on conveying design information, understanding of more complex transportation requirements, and schedules coordination (O'Connor et al., 2015).

### 2.2. TCs theory application in construction

The TCs theory was introduced by Coase in 1937 and has been successfully applied in various industries to improve economic efficiency (Rajeh et al., 2015). In the construction industry, TCs theory has also received considerable attention by scholars. It has been applied to solve problems in the aspects of project management (Walker and Kwong Wing, 1999), institutional governance (Lai and Tang, 2016), procurement management (Carbonara et al., 2016), and policy management (Fan et al., 2018).

The common basis for researchers was to build a TCs category to define the concept and classification of TCs. Antinori and Sathaye (2007) provide a framework of TCs in the greenhouse gas emissions projects: search costs, negotiation costs, approval costs, monitoring costs, enforcement costs, and insurance costs. Mundaca T et al. (2013) categorized TCs in energy efficiency projects as a) due diligence, b) negotiation, c) approval and certification, d) monitoring and verification and e) trading. In passive house renovations, TCs were defined by Kiss (2016) into three categories: due diligence, negotiation, and monitoring. By comprehensive review, TCs in the construction industry are summarized into three categories, see Table 2.

1) Due diligence costs: It refers to the investigation of information, including the search for and the assessment of the acquired information. For instance, the form of collaboration, partners, technically and economically, and feasible technical solutions (Kiss, 2016).
2) Negotiation costs: It includes costs of obtaining permits, arranging finance, negotiating contracts and approval. In addition to direct fees for permits, these costs are often estimated as compensation for labor time allocated to these tasks (Antinori and Sathaye, 2007).
3) Monitoring and enforcement costs: Costs for the preparation of a monitoring plan, continual monitoring of production performance, and other activities to enforce contracts (Rajeh et al., 2015).

### 2.3. Theoretical TCs framework of PH

By reviewing topics of TCs in construction and barriers of PH projects a theoretical framework with 32 sources of TCs in PH was constructed. See Table 3. Prefabrication represents a new mode of doing the transaction (Steinhardt and Manley, 2016). Numerous difficulties arise when the transaction process is experiencing a reform. Then transaction process does not operate as smooth as expected because of the difficulties. TCs occur when extra efforts are needed to reduce frictions.

## 3. Methodology

The theoretical TCs framework formed the foundation for the empirical study. As shown in Fig. 2, the methodology of this research is based on case studies, including a questionnaire survey and semi-structured interviews. Two PH projects in Chongqing were selected as cases. First, a questionnaire survey was conducted to collect data for identifying key stakeholders by Social Network Analysis (SNA). Second, 25 semi-structured interviews with key stakeholders were held to validate the TCs framework and to

**Table 2**
TCs in the construction industry.

| Transaction Costs | References |
|---|---|
| 1. Due diligence Costs | |
| Identifying the project | Antinori and Sathaye (2007) |
| Identifying project partners | Kiss (2016) |
| Consultations with stakeholders | Rajeh et al. (2013) |
| Identification of customers | Mundaca (2007) |
| Prefeasibility study | Antinori and Sathaye (2007) |
| Procurement of subcontractors | Kiss (2016) |
| New technology solutions | Kiss (2016) |
| Project risk insurance | Mundaca (2007) |
| Decision-making costs | Qian et al. (2015a) |
| 2. Negotiations Costs | |
| Co-ordination costs | Mundaca (2007) |
| Permit costs | Mundaca (2007) |
| Arranging financing | Qian et al. (2015a) |
| Dispute solution | Lu et al. (2015) |
| Setting up the project organization | Qian et al. (2015a) |
| 3. Monitoring and enforcement Costs | |
| Monitoring agreements and contracts | Walker and Kwong Wing (1999) |
| Random quality checks | Mundaca (2007) |

Providing a general understanding of TCs application in the construction industry, this TCs framework, however, does not cover all TCs in PH projects.

understand the content and nature of TCs from different stakeholder perspective.

### 3.1. Case studies

Case studies were conducted in Chongqing, which is one of the four municipalities under the direct governance of China central government. Chongqing plays an essential and strategic role in Western China, and it is in a favorable economic situation to lay a good foundation for the development of PH (Pan and Xiong, 2009). Taking Chongqing as the study city helps to get an objective understanding of PH practices in China cities. Although Chongqing is not one of the 30 "*Demonstration Cities*" announced by the Central Government in 2017 (MOHURD, 2017a), it nevertheless represents the current general status of prefabrication in more than 600 Chinese cities. Since 2016, 54 prefabricated projects were announced by the Chongqing Municipal Construction Committee as prefabrication demonstration projects. Being advised by the Director of *Chongqing Construction Technology Development Centre*, two demonstration projects were selected as the cases for this study. Locations of them are shown in Fig. 3.

Case A is a commercial-residential project located in Chongqing. It was the first demonstration project by a real estate company in Chongqing. With a total gross floor area of 140,318 $m^2$, the project was planned in 2014 and completed in August 2017. Prefabricated components installed in this project include bay windows, partition walls, and bathroom units. The procurement mode of this project is DBB.

Case B is a public housing project in Chongqing. The total gross floor area is 39,240 $m^2$. Prefabricated parts of this project include the staircases, floor slabs, beams, and walls. The project started in 2015 and is still ongoing. The procurement method for this project is EPC.

### 3.2. Questionnaire survey

To complete the questionnaire survey, interviews with experts who were project managers of the two cases were conducted to collect professional opinions on refining the theoretical stakeholder list. Apart from the 15 stakeholders defined in the theoretical list, in Case A there are 5 other stakeholders. Added stakeholders in Case A are decoration designer, decoration contractor, landscape designer, and landscape contractor because it is a hardbound housing project. In Case B, the property management company is not presented, because the construction of the project has not been completed yet.

During regular project meetings with representatives of all stakeholders, a questionnaire survey was distributed to attendees. The purpose of this survey was to evaluate the connections between the stakeholders, being the input data for the SNA. To ensure the reliability of the questionnaire survey, there was at least one evaluation from each stakeholder representative. The strength of connections was measured using a Five-point Likert scale, where 1 represents 'no connection at all' and 5 means 'very strong connections'. UCINET, an SNA analysis and visualization package, was then used to process data and to display the social network.

### 3.3. Semi-structured interviews

To examine the rationality and comprehensiveness of the theoretical TCs framework and to understand more about the nature of the content of TCs, 25 semi-structured interviews with representatives of the key stakeholders from the two cases were held. Experience profiles of the interviewees are shown in Table 4. All interviewees are operating at the management level to ensure that they are professionals who have a sophisticated understanding of the whole supply chain, and have gained rich practical experience on PH.

The exchange of ideas during the interviews consisted of three major areas: (1) Validation of the theoretical TCs framework; (2) The content of TCs and associated stakeholders in PH; and (3) Significance of TCs from the interviewee perspectives. To make the interviews more intelligible, the professional term *Transaction Costs* was not used. Instead, questions were asked such as: "What are the extra costs for these activities?"; "Can you please introduce the extra efforts that you have made to fulfill this task?" and "What are the difficulties when carrying out this work?"

## 4. Data analysis and findings

### 4.1. Key stakeholders identification

A valuable angle to understand TCs is through key stakeholders (Qian et al., 2015b). It is known that many stakeholders are involved in a project, but not all stakeholders can influence the transaction process and the TCs (Mettepenningen et al., 2011). Therefore, this study first identifies key stakeholders to provide a basis for the following TCs content exploration.

The SNA method is applied to identify critical stakeholders. SNA forms a structured social network that represents all interrelationships between the actors, and the data subsequently illustrates the significance of individual action within the social structure (Burt et al., 1983). Node-level metrics of SNA measure how important the individual nodes are, given their positions in the network (Kim et al., 2011). This study measures the importance of stakeholders from the node-level by focusing on centrality analysis. Specifically, degree centrality describes the strength of the direct connection between one node and others and reflects the influence of subjects in the network (Freeman, 1979). Betweenness centrality explains how many times an actor may interact on a short path connecting two others which are themselves disconnected. In consequence, degree centrality and betweenness centrality are both calculated in this study to describe the centrality position of stakeholders and measure the resources-control power of stakeholders.

Stakeholders' network for Cases A and B are mapped in Figs. 4 and 5. The network is non-directional and thus mutually symmetrical. The results of measures of degree centrality and betweenness centrality are displayed in Table 4.

As shown in Table 5, centrality analysis of both Case A and Case B identified the developer, general contractor, local government, supervisor, architect, and components supplier as the top 6 central stakeholders in the PH supply chain.

The results from degree centrality identified developers as the most influential stakeholder in PH projects. It can be observed that developers have a degree centrality of 17 and 8 in Case A and Case B, respectively. It indicates that developers have strong direct connections with other stakeholders, therefore could have a significant impact on transactions. This can be explained by the dominant role of developers in China PH market, where developers are the ones who are leading the whole projects. They are sponsoring and organizing the whole construction process, who therefore have more contractual relationships and information interactions with the others.

Betweenness centrality helps to identify stakeholders who have control over information and resources passing through it. With betweenness centrality values of 30.02 and 56.43 (highest in Case B), the general contractors own the most powerful source-control ability in the transaction networks. For instance, the general contractor in Case B is the one responsible for both design and the

**Table 3**
Theoretical TCs framework in the PH supply chain.

| Phases | NO. | Sources of TCs | Content in PH projects | Sources | Source(s) | |
|---|---|---|---|---|---|---|
| | | | | | TCs in construction | Barriers |
| Concept | 1 | Project proposal | Examine the project's financial, site location, and environmental reasonableness. Also known as the preparation of a Project Brief. | Antinori and Sathaye (2007) | | ✓ |
| | 2 | Feasibility study | Solicit, review and select firms to work on the supplement, design, manufacture, construction, etc. | Antinori and Sathaye (2007) | ✓ | |
| | 3 | Identify partners with PH experience | Costs for partners' identification are incurred by information searching and communication. | (Kamali and Hewage, 2016; Larsson and Simonsson, 2012) | ✓ | ✓ |
| | 4 | Consultant fee | Explore special technical solutions. | Mao et al. (2015) | | ✓ |
| | 5 | Decision-making fee | Market analysis, discussion, and negotiation in the form of meetings. | (Blismas et al., 2005; Goodier and Gibb, 2005) | | ✓ |
| | 6 | Land bidding | Publish the public announcement for bidding; organize the auction, candidate evaluation. | Buitelaar (2004) | ✓ | |
| | 7 | Sign the contract | Prepare the contract, negotiation on the terms. | Buitelaar (2004) | ✓ | |
| | 8 | Permit cost | Costs paid by the developer to get a construction land-use planning permit and a land- use title certificate. Permit cost is often estimated as compensation for labor time allocated to these tasks. | Mundaca (2007) | ✓ | |
| | 9 | Arrange the finance | Fill out loan applications, discuss the project with lenders, review alternative loan terms, and respond to financial due diligence questions. Study the extra financial risk (financing institution). | Qian et al. (2015a) | ✓ | |
| Plan and design | 1 | Land Surveying | Information collection and analysis | Kiss (2016) | ✓ | |
| | 2 | Architectural design | Due to the complexity of PH projects, more intensive pre-project planning and engineering are needed. | Kamali and Hewage (2016) | | ✓ |
| | 3 | Detailed design | In addition to the complexity of modules' design, further considerations are needed when incorporating different components within a module. | O'Connor et al. (2015) | | ✓ |
| | 4 | Professional consultant | Consultant in terms of structure, landscape, architectural equipment, etc. | Mao et al. (2015) | | ✓ |
| | 5 | Permit costs | Approval of the construction project planning and design plan from the responsible Urban Planning Department. | Qian et al. (2015a) | ✓ | |
| | 6 | Procurement of subcontractors | Organize the bidding, preparation for the call, assessment of subcontractors, signing the contracts with subcontractors. | Kiss (2016) | ✓ | |
| | 7 | Propose solutions for prefabrication | A particular technology scheme is needed when adopting prefab technology. | (Kiss, 2016; Qian et al., 2015a) | ✓ | ✓ |
| | 8 | Set up the PH project organization | Organization of project management, including hiring new workers, setting new institutions, and new offices. | Qian et al. (2015a) | ✓ | |
| Manufacturing | 1 | Hire skilled labor | Cost for searching or training workers in the factory | Chiang et al. (2006) | | ✓ |
| | 2 | Production supervision | Supervising company and designer will monitor the manufacture in the factory | Mundaca (2007) | ✓ | |
| | 3 | Components quality assessment | Lack of accredited and tested organizations that assess the quality of prefabricated components, which results in great uncertainty and leads to unexpected TCs. | Mao et al. (2015) | | ✓ |
| | 4 | Arrange the transportation | Intensive coordinating among the component supplier, logistics company and the general contractor | Kamali and Hewage (2016). | | ✓ |
| | 5 | Risk of delivery early or delay | Early production of building elements when they are not needed increases the storage costs. Loss of work stoppage, the slowdown caused by the delivery delay. | Larsson and Simonsson (2012) | | ✓ |
| Construction | 1 | Labour education costs | PH has higher requirements for workers because of its innovative techniques and process of production compared with conventional projects. | Jiang et al. (2018) | | ✓ |
| | 2 | Insurance | Insurance costs are those associated with project risk insurance and the costs of natural disaster or accident. | Antinori and Sathaye (2007) | ✓ | |
| | 3 | Monitor construction | Including safety supervision, time control, and quality supervision | Li et al. (2012) | ✓ | |
| | 4 | Design change | Extra workloads regarding redesign, negotiation, the arrangement of new components production and new construction plan, | Tam et al. (2015) | | ✓ |
| | 5 | Dispute solution | Non-value-adding costs arising from dispute resolution in PH projects. | Lu et al. (2015) | ✓ | |
| | 6 | Permit costs | Certificate of safety operation, construction permit. | Kiss (2016) | ✓ | |
| Operation and maintenance | 1 | Identify the potential buyers | Residents identification, market information searching, and analysis. | (Mundaca, 2007; Qian et al., 2015a) | ✓ | |
| | 2 | Contract signing | Contract preparation, negotiation and signing | Mundaca (2007) | ✓ | |
| | 3 | Permit costs | Housing sale permit or Pre-sale permit. | Mundaca (2007) | ✓ | |
| | 4 | Taxation | Business Tax, City Maintenance and Construction Tax, Educational Surtax, Land Added Value Tax, Property Tax, Income tax | Xue et al. (2018) | | ✓ |

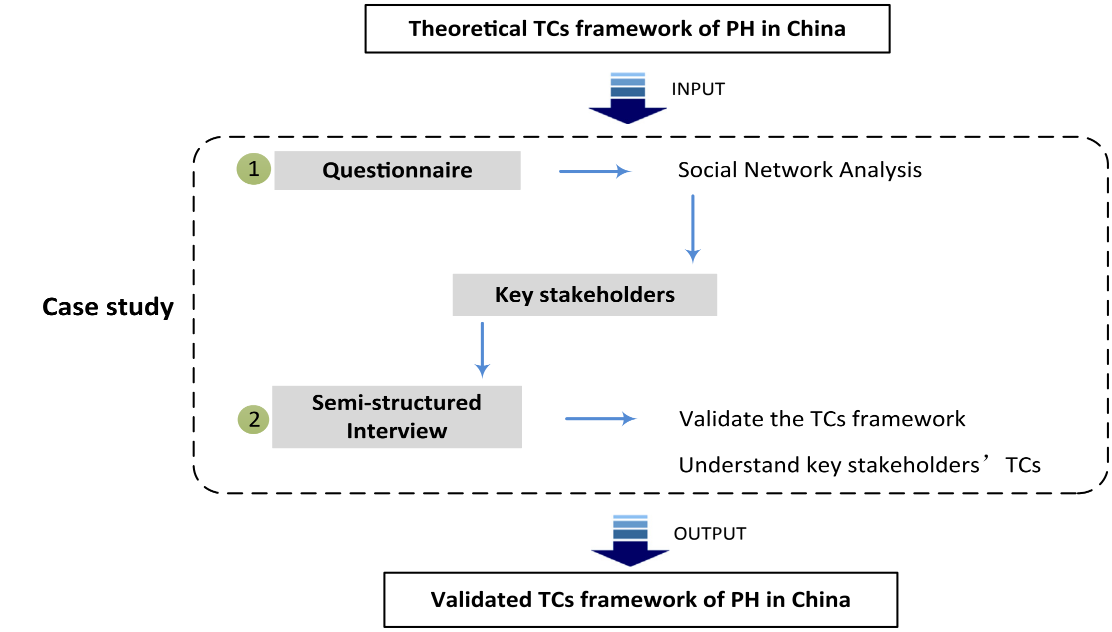


**Fig. 2.** Overview of the research design.


**Fig. 3.** Location of cases in Chongqing.

whole construction, which therefore involved in a lot of information transfer and materials exchanges.

Besides, the local government is one of the most central roles in the PH supply chain, which has very solid power in decision-making. The importance of architects in PH projects is also noticeable due to their more involvement in the procurement, manufacture and construction phases. It should also be noticed that component suppliers also have a relatively central position in the network, significant that they are new actors in PH projects, compared with conventional projects.

There are some differences in the centrality of 6 key stakeholders between the two cases. Case A is a DBB project, in which the developer plays a very central role with a degree and betweenness centrality of 17 and 58.95 respectively. By contrast, in Case B, the developer is ranked at the third central place. Both the general contractor and the local government in Case B are ranked above the developer as the most central stakeholders. It is because the procurement method of Case B is EPC, in which the general contractor is playing an absolutely dominant role. Also, it is a typical government-led public project, which explains why the local

**Table 4**
Profiles of interviewees.

| Stakeholder | No. | Profile |
|---|---|---|
| Local Government | L1 | Officer, Municipal Commission of Urban-Rural Development |
| | L2 | Officer, Construction Technology Development Centre |
| | L3 | Engineer, Construction Industry Modernization Department |
| | L4 | Officer, Municipal Commission of Urban-Rural Development |
| Developer | D1 | Senior engineer, Real Estate Company |
| | D2 | Operation Manager, Real Estate Company |
| | D3 | Manager, Department of investment and development, Real Estate Company |
| | D4 | Quantity Surveyor, Real Estate Company |
| | D5 | Quantity Surveyor, Local District Development Group |
| | D6 | Quantity Surveyor, Local District development Group |
| | D7 | Engineer, Local district development Group |
| | D8 | Engineer, Local district development Group |
| General contractor | G1 | Construction engineer, Construction Engineering Company |
| | G2 | Project Manager, Construction Engineering Company |
| | G3 | Project Manager, Construction Engineering Company |
| | G4 | Quantity Surveyor, Construction Engineering Company |
| Component supplier | C1 | Manufacturing Manager, Precast Concrete Components company |
| | C2 | Senior manager, Precast Concrete Components Company |
| | C3 | Architect, High-tech Building Material Company |
| | C4 | Production manager, High-tech Building Material Company |
| Architect | A1 | Design director, Design Company |
| | A2 | Researcher, Design Company |
| | A3 | Designer, Design and Research Institute of Construction Engineering Group |
| Supervisor | S1 | Chief supervision engineer, Engineering Supervision Company |
| | S2 | Supervision engineer, Engineering Construction Supervision Company |

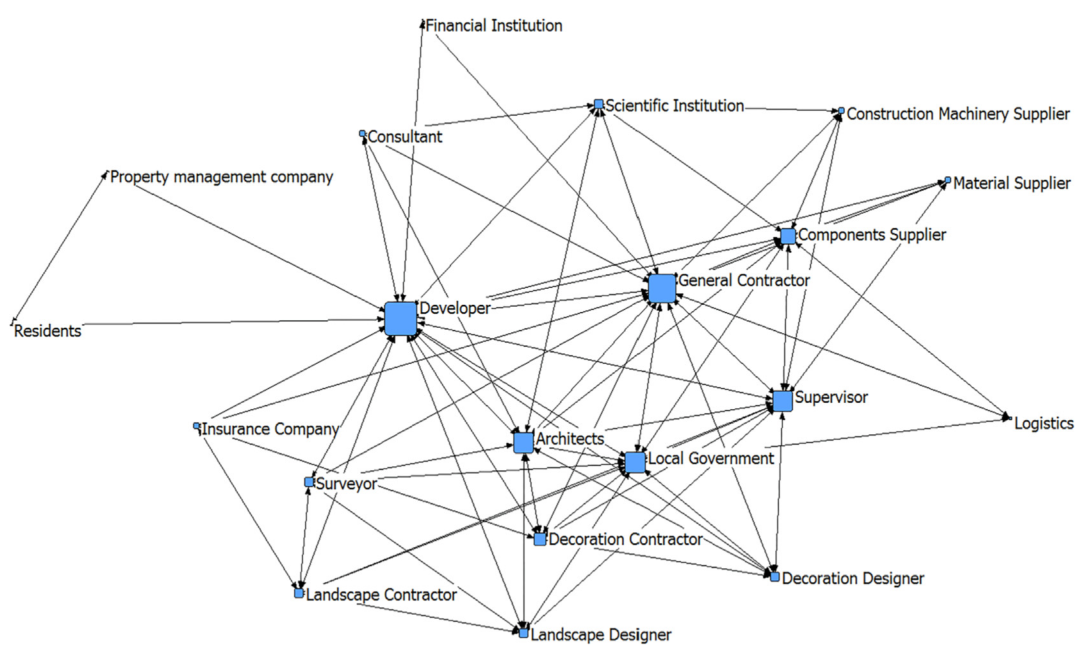


**Fig. 4.** Social network (centrality) of stakeholders in Case A

government is so crucial in the stakeholder network.

### 4.2. Validated TCs framework for the PH supply chain

The validated TCs framework of PH projects in China is given in Table 6, with 33 items in total.

Based on the responses from the interviewees, the authors added five TCs sources to the framework: learning, frequent communication for manufacturing, assembly, design change, and advertising. Additionally, TCs of identifying the potential house buyers in operation and maintenance phase is suggested to be deleted by the interviewees (D2, D3, D4), because these have been fulfilled in the concept phase.

### 4.3. TCs of key stakeholders

The empirical findings in relation to the research questions address how interviewees perceive tasks with high TCs.

1) Developer - Feasibility study, learning, and permission

The first source of TCs incurred by developers is the feasibility study. As clients of PH projects in China, developers invest capital, labor and other resources in evaluating the project's feasibility.

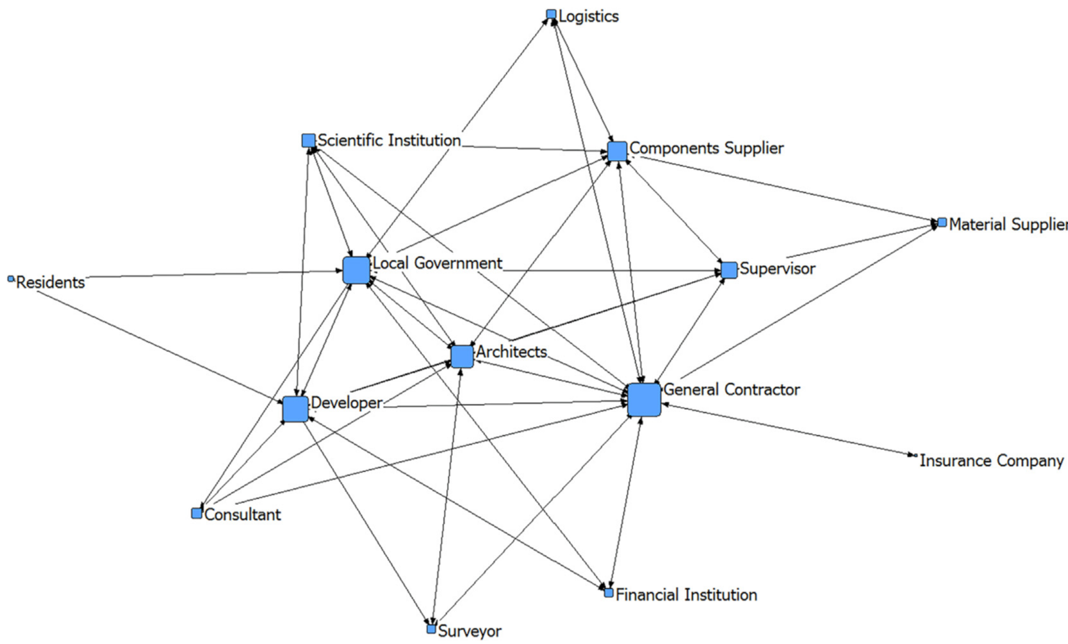


**Fig. 5.** Social network (centrality) of stakeholders in Case B.

**Table 5**
Results of stakeholder centrality analysis.

| Case A | Stakeholders | Degree centrality | Betweenness centrality | Case B | Stakeholders | Degree centrality | Betweenness centrality |
|---|---|---|---|---|---|---|---|
| 1 | Developer | 17 | 58.95 | 1 | General Contractor | 12 | 56.43 |
| 2 | General Contractor | 15 | 30.02 | 2 | Local Government | 9 | 21.67 |
| 3 | Local Government | 11 | 8.75 | 3 | Developer | 8 | 16.37 |
| 4 | Architect | 11 | 6.63 | 4 | Architect | 8 | 8.47 |
| 5 | Supervisor | 11 | 9.50 | 5 | Components Supplier | 7 | 6.13 |
| 6 | Components Supplier | 9 | 6.12 | 6 | Supervisor | 6 | 3.53 |
| 7 | Decoration Contractor | 7 | 1.17 | 7 | Scientific Institution | 5 | 0.40 |
| 8 | Scientific Institution | 6 | 1.75 | 8 | Consultant | 3 | 0.00 |
| 9 | Decoration Designer | 6 | 0.00 | 9 | Financial Institution | 4 | 0.00 |
| 10 | Landscape Designer | 6 | 0.37 | 10 | Material Supplier | 3 | 0.00 |
| 11 | Landscape Contractor | 6 | 1.50 | 11 | Logistics company | 3 | 0.00 |
| 12 | Surveyor | 6 | 0.60 | 12 | Surveyor | 3 | 0.00 |
| 13 | Material Supplier | 4 | 0.00 | 13 | Residents | 2 | 0.00 |
| 14 | Construction Machinery Supplier | 4 | 0.20 | 14 | Insurance Company | 1 | 0.00 |
| 15 | Insurance Company | 4 | 0.45 | | | | |
| 16 | Consultant | 4 | 0.00 | | | | |
| 17 | Logistics company | 3 | 0.00 | | | | |
| 18 | Financial Institution | 2 | 0.00 | | | | |
| 19 | Residents | 2 | 0.00 | | | | |
| 20 | Property management company | 2 | 0.00 | | | | |

According to the interviewees, the structure of feasibility studies of PH projects is the same as conventional projects, including a technical, economic and social feasibility assessment. The difference is that the content of a feasibility study in a PH project is more complicated. When doing an economic feasibility study, the challenge is to estimate a precise project budget because of a lack of experience and the absence of official PH project budget quota. Interviews from Case B showed that the target allowance from the local government is 10–50 CNY/m2, whereas the increase of costs by adopting prefabrication is between 50 and 100 CNY/m2 (prefabrication ratio[1] <= 10%) and 300 CNY/m2 (prefabrication ratio > 30%). It brings difficulty for developers to achieve a balance between allowance and costs.

The second source, highlighted TCs by developers, is learning. At the early phase of a project, learning behaviors are taken to prepare for the project execution. In the conceptual phase of Case A, expert groups were organized to get insights from PH demonstration projects in Shenyang and Shenzhen (D4). In the implementation process of PH projects, learning costs from the side of developers are spent but not reflected. Learning costs occur when staffs with the only experience on conventional projects need to switch their work to adapt to the prefabrication mode. Time and efforts are devoted to collaboration with new partners, learning the new technology and digest new information.

Another source of TCs from the developers' side is costs of permission and approval, which exist at every phase of the supply chain. There are permit costs for getting approvals of the project

[1] Prefabrication ratio: The integrated prefabricated proportion of main structures above the outdoor terrace of the individual building, such as the surrounding wall, the interior partition wall, decoration and the equipment pipeline. For the calculation formula, see (MOHURD, 2017b).

**Table 6**
Validated TCs Framework and Related Stakeholders

| hase | Sources of TCs | TCs category | High TCs | Emphasized by stakeholders | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | De | GC | Su | Ar | CS | LG |
| | Project proposal | Due diligence | | | | | | | √ |
| | Feasibility study | Due diligence | | √ | | | | | |
| | Identify partners with PH experience | Due diligence | | | | | | | |
| | Consultation | Due diligence | | | | | | | |
| Concept | Learning | Due diligence | | √ | | | | | |
| | Decision-making | Due diligence | | | | | | | |
| | Land bidding | Due diligence | | | | | | | |
| | Procurement of the general contractor | Due diligence | | | | | | | |
| | Permission and approval | Negotiation | | √ | | | | | √ |
| | Arrange the finance | Negotiation | | | | | | | |
| | Land surveying | Due diligence | | | | | | | |
| | Architectural design | Negotiation | | | | | | | |
| | Detailed design | Negotiation | | | | | √ | | |
| Plan and design | Design consultant | Due diligence | | | | | | | |
| | Procurement of subcontractors | Due diligence | | | √ | | | | |
| | Special technical solution for prefabrication | Due diligence | | | | | | | |
| | Set up the PH project organization | Negotiation | | | | | | | |
| | Hire skilled labor | Due diligence | | | | | | | |
| | Frequent communication for component production | Negotiation | | | | | | √ | |
| Manufacturing | Production supervision | Monitoring and enforcement | | | | √ | | | |
| | Component quality test | Monitoring and enforcement | | | | | | | |
| | Arrange the transportation | Negotiation | | | | | | √ | |
| | Risk of delivery early or delay | Negotiation | | | | | | | |
| | Insurance | Due diligence | | | | | | | |
| | Labor education | Due diligence | | | | | | | |
| | Monitor construction activities | Monitoring and enforcement | | | | | | | √ |
| Construction | Dispute solution | Monitoring and enforcement | | | | | | | |
| | Design change | Negotiation | | | √ | | | | |
| | Permission and approval | Monitoring and enforcement | | | | | | | |
| | Assembly | Monitoring and enforcement | | | √ | | | | |
| | Advertising | Monitoring and enforcement | | | | | | | |
| Operation | Contract signing | Due diligence | | | | | | | |
| | Taxation | Negotiation | | | | | | | |

Note:

De=developer; GC=General Contractor; Su=Supervisor Ar=architect; CS=Components Supplier; LG=Local Government.

Note: De = developer; GC = General Contractor; Su = Supervisor Ar = architect; CS=Components Supplier; LG = Local Government.

business proposal from Chongqing Development and Reform Commission, a construction land-use planning permit from Chongqing Urban Planning Department and a land-use title certificate from Chongqing Ministry of Land and Resources, etc. The permit process causes a lot of complaints: *Without proper approvals, it is impossible to undertake a building project in China. Dealing with permits is a time-consuming and … very bureaucratic process although the Chongqing Urban and Rural Construction Commission did give priorities to demonstration projects (D8).*

2) General contractor - Procurement of subcontractors, design changes and assembly

Compared with conventional projects, procurement of subcontractors in PH projects brings more challenges to general contractors. The first challenge is having less choice of subcontractors. In Chongqing, most general contractors have established networks of experienced subcontractors to work with. The application of prefabrication forces general contractors to look for new suppliers to cooperate with, such as component suppliers, and assembly machinery suppliers, all of which consume additional efforts in terms of the main contractor's time and labor. The limited choices amongst new professional companies in the market lead to uncertainties, and so these reduce the profits of general contractors: "*There are only three large component suppliers in Chongqing. We do not have much choice with the consequence of a disadvantageous position for price negotiation*" (G3). And there are a lot of negotiations needed between the general contractor and candidate subcontractors to design the specific contract items about prefabrication.

Besides, general contractors also bear TCs from design changes, which may lead to the redesign, reconstruction or even the modules for components having to be changed. The design change is one of the biggest risks for general contractors, but the scale of these off-site TCs related to it is hard to estimate (G2).

The on-site assembly is another difficult task for general contractors. The assembly of prefabricated components has higher requirements for the skills of workers compared with conventional on-site work. It, therefore, generates extra training costs of workers and lead-in times. For instance, at the beginning of the assembly process in Case A, the installation of one staircase took 1–2 h because both the workers and the engineers were not familiar with the assembly techniques and operation of the 80-tonne tower crane. It was only after one month of perseverance, and learning by trial and error, that the installation time was shortened to 20 min per piece.

3) Architect – Frequent communication

Technically, the component design is not too challenging for architects. What annoys architects is the endless negotiation. Due to the complexity of the component design, more frequent communication is needed. Thus, architects participate in the construction to assist the on-site assembly, even in a DBB project. As the designer (A1) of Case A said, hidden costs, in term of services, time and labor, occur because of a lack of prefabrication experience in Chongqing: *In this project, three of our designers are responsible for communicating with the contractor and client … for every design idea, we need to ask for their practical suggestions. Plans are negotiated over and over … This process lasted for about 2 to* 3 months …

4) Component supplier - Hiring skilled labor and arranging the transportation

As the executor of the manufacturing task, component suppliers are also facing the challenge of hiring skilled labor. From the eyes of the production manager in the factory (C1), forming a new labor team means a transition period with low production and high training costs. Interviewees indicate that nearly 80% of construction workers are rural migrants in Chongqing, with the average age above 45-year-old and average education level of junior middle school. It makes the training process even more difficult.

Another important source of TCs to component suppliers is arranging the transportation. Different from construction materials transportation, the transportation of prefab components is more complicated: *It has higher requirements for the loading, transporting and unloading processes. We even need to learn the transportation regulations, and special traffic control requirements … We must know the limitations on module transportation … And consider the distance and transport methods. It can be influenced by the size, weight, and dimensions of components … Our factory is* 150 km *away from Case B. We spent quite a lot of time and money on transportation (C3).* Risks of extra costs always exist due to the inadequate coordination between the components production and delivery. Early production of building elements increases their storage and conservation costs. On the other hand, any delay in delivering influences on the construction process and increases costs.

5) Supervisor - Components production supervision

The supervision of PH projects includes factory supervision and site supervision. Apart from the usual workload, supervisors in the cases mentioned additional costs related to manufacturing supervision. They do quality detection for both raw materials and component quality tests. To ensure strict quality control on prefab components, regular supervision during manufacturing, quality inspection before delivery and final building acceptance supervision are required. But, "*Extra supervision costs for prefabrication have never been calculated. Because the fixed amount of the supervision engineer's salary has to be paid anyway, no matter what type of project we are working on." (S2).*

6) Local Government – Permission and approval, monitoring and enforcement

To promote the diffusion of PH, local governments are paying extra TCs on permit approval. For instance, they give priorities, such as lower land costs and tax reduction, to enterprises who adopt prefabrication technologies, which decrease the income of local governments. In Chongqing, certification approval costs are undertaken by several government departments. The Safety and Quality Supervision Office issue certificates of safe operation; Chongqing Construction Commission supplies construction permits; Chongqing Urban Planning Department issues construction project planning permits, with joint review and approval by other government authorities including Environmental Protection Authority, Land Administration Authority, Construction Administration Authority and Fire Protection Authority. Furthermore, compared with conventional projects, monitoring costs paid by the local government in PH project are from additional tasks. As to what Case A and Case B have gone through, the local government designed a particular five-step administration for PH demonstration projects: the first review, approval examine and verify, supervision, acceptance, and subsidy (L2). Also, to serve better administration support, a Construction Industry Modernization Department (CIMD) is settled in Chongqing, which is responsible for approval, monitoring and final acceptance of demonstration PH projects.

## 5. Discussion

### 5.1. TCs by stakeholders

The case studies showed the stakeholders' understanding of TCs and their awareness on controlling TCs in the context of China. According to the SNA results, both developers and general contractors are the leading traders that have more contractual relationships with others, while interviews show that they are also bearing more TCs. Specifically, developers pay for most of the TCs in the concept and design phase because of their major sponsoring role in China. General contractors are bearing most TCs in the construction phase. It is because they are the primary responsible stakeholders in the construction phase in either DBB or EPC projects, and so confronted with higher uncertainties that contribute to the increasing of TCs (Li et al., 2014). Besides, the increase of TCs for architects is revealed as well. The responsibilities of architects are broadened beyond those normally expected only in the design phase, which is the result of the immature PH market. Additionally, both the component suppliers and supervision companies highlighted the TCs that they are paying in the manufacturing phase. Different from other stakeholders, the aim of the local government is not to make profits, but to promote PH (Zhai et al., 2014). The most common TCs for the local government are the costs of permits and monitoring, which are rooted in their central position in the transaction network. However, it is hard to define the content of TCs in a particular project from the government viewpoint, since the costs from making policies, regulations, and setting up governance departments are for the industry as a whole.

### 5.2. TCs in the supply chain

TCs may appear everywhere in the PH supply chain, but not equally distributed among phases. Interviewees told that both the conceptual and the construction phases are where the majority of TCs occur. At the concept phase of PH projects, preparation work such as market analysis, information collection, co-operator identification, and consultants are needed, entailing TCs. The construction phase causes more TCs because both developers and contractors are unfamiliar with concepts, technologies and other matters related to PH, such as forms of collaboration and working processes (Kiss, 2016).

TCs are incurred/generated in a dynamic transaction process (Buckley and Chapman, 1998), showing that they come in the flows of the supply chain. A rule revealed in PH practices is that TCs can be explained by three flows in the PH supply chain. Contractual flows are the prerequisite of transactions where TCs occur (Lai and Tang, 2016). For example, when there are TCs related to contractual relationships between stakeholders, there are TCs from preparing contracts, terms negotiation and contract enforcement before and after contracts. Beside, TCs occur when there are intensive information flows between stakeholders. When conceptual ideas are transmitted to the design phase, frequent communications between the developer and the architect are necessary. Time and labor are devoted to understanding the expectations of each other. Additionally, the flow of materials is along with TCs. The process of component delivery creates interfaces among the component supplier, the general contractor, logistics, supervision companies, and the local government. It means that more time is needed to ensure smooth communication; otherwise, there will be risks in terms of misunderstandings or work delays.

### 5.3. The nature of TCs for PH

Due diligence is the main source of TCs in PH. Among 33 TCs items in the validated framework, 16 of them are costs of due diligence. The content of due diligence in PH relates to information searching, data assessment and preparation work before contracting. This study found that several due diligence costs are related to the specificity of the prefabrication, such as identifying partners with PH experience, proposing prefabrication solutions, labor education, etc.

Negotiation costs appear throughout the supply chain. Among 11 identified important TCs sources, five items are essentially negotiation costs. The scope of negotiation costs in PH includes efforts on communication, negotiation, and coordination. Interviews reflect that negotiation costs are more concerned as labor and time. Manufacturing and design changes are the primary sources of negotiation cost because PH requires high consistency technically (Tam et al., 2015). The permit application, detailed design and transportation are activities that need frequent communications between stakeholders, while intensive meetings are organized to ensure tasks are fulfilled.

TCs of monitoring and enforcement occur in the manufacturing, construction and maintenance phases. It is noteworthy that supervision companies and local governments are the stakeholders bearing most monitoring costs.

### 5.4. Implications on PH projects governance

Uncovering TCs in the supply chain brings implications on project governance to both private stakeholders and the government. It is found that managers in the industry very often do not know what TCs are, but they do take them into account (Buckley and Chapman, 1998). It is believed that the fewer the TCs, the more smooth and efficient the development process (Webster, 1998). The empirical study showed that stakeholders in PH do have the awareness to reduce TCs.

For private stakeholders, reducing uncertainty in the early phases is a solution to decrease TCs for the whole process. For instance, TCs in the construction phase can be reduced by employing mature design technologies. A good example is having assembly simulations and pipeline interferences by using BIM in Case A, which results in very few design changes being needed. Moreover, TCs of due diligence from information collection and contracting can be reduced by experience learning (Coggan et al., 2013). The effect of cost reduction due to the application of learning strategies cannot be shown but can be assumed (Kiss, 2016). Also, negotiation costs can be lessened by reducing information asymmetry. Some small companies in Chongqing do not have a mature understanding of PH, which attributes to the difficulties of negotiation because of the information asymmetry. To eliminate the information asymmetry, private stakeholders can select partners with prior PH experience and then organize regular project meetings with designers, component suppliers, and contractors.

Implications from the TCs exploration to the government can be highlighted in several layers:

(1) First, to reduce internal TCs that are paid by governments. For instance, permit costs can be reduced by developing more explicit administrating rules to streamline the permit process and enhancing the electronic integration (e.g., administrating using information technology of the Internet) (Lajili and Mahoney, 2006);
(2) The second intention for the government should reduce TCs from a project level. As the administrator, local governments have a unique birds-eye view of the entire supply chain. It means that the local government can minimize the TCs of the project as a whole. Through resource allocation, the local

government can set up an accredited technical worker qualification system. Whilst this may increase the cost of hiring professional workers, it will reduce laborers (worker) education costs for contractors and will effectively reduce future quality problems in construction (Hong et al., 2018);

(3) The top layer, also the most advanced intervention, to reduce TCs is the policymaking. One of the most expected policies is to unify the design code for prefabrication (Zhai et al., 2014). Then negotiation costs in the design phase and information costs at the interfaces between designers and components supplier can be significantly reduced. Adapting official engineering pricing specifications to take account of and anticipate prefabrication can improve the efficiency of the bidding process and reduce the uncertainty to the contractors. Although policymaking leads to an increase in TCs of the government itself, it reduces the overall costs to the industry and improves social benefits.

## 6. Conclusions

Perceived as a clean, efficient and economical production method, Prefabricated Housing (PH) has been vigorously promoted in China. However, invisible or hidden costs in the PH supply chain cause low economic efficiency to stakeholders, and these hamper the advancement of the industry. Consequently, in order to improve the governance of the supply chain and to make projects more financially attractive, Transaction Costs (TCs) in PH projects must be better understood and ultimately reduced.

This study explores TCs in the supply chain of PH projects in China by a review of past theory, followed by an empirical study. The results of Social Network Analysis (SNA) indicate that stakeholders in the network of PH projects with a significant influence include developers, general contractors, architects, local governments, supervisors and component suppliers. High centralities in the supply chain give them a stronger resource control ability that can influence the transaction process and TCs. Besides, an improved empirically-based TCs framework was proposed after semi-structured interviews. Interviews show that both developers and general contractors are recognized as bearing more TCs compared with the other stakeholders. During the concept and the construction phases, more TCs are appearing than in the other phases. Due diligence is the most significant source of TCs in PH. To improve the governance of PH projects, both public and private stakeholders can take action. Private stakeholders can minimize TCs by reducing uncertainties, learning from experience and cooperating with experienced partners. Likewise, public stakeholders, such as local governments, can optimize their own TCs and those of other stakeholders by: (1) updating their internal administration systems; (2) re-allocating resources on the project level; and (3) policy-making to regulate the entire industry.

The contribution of this study is being the first research addressing the theory of TCs of the supply chain of PH projects. Barriers of PH development have been repeatedly studied, but few studies have reflected on neglected hidden costs from the perspective of institutional economics. Another contribution to the theory of this study is to develop a new and validated TCs framework that can identify TCs in PH. For stakeholders, a better understanding of TCs provides a basis to reduce TCs in the projects and thus to improve the economic efficiency of the PH supply chain. Nevertheless, as the first step to understand TCs in PH, there are still several limitations of this study. First, the applicability of the results may be restricted for the reason that the empirical study was limited to two cases in Chongqing. Further research in other cities in China is expected to provide validation. Second, this study relies on a survey of opinions rather than actual records of costs and other quantifiable data. To quantify TCs in PH projects, future research could make use of longitudinal data records.

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