Challenges of prefabricated housing in China
Supply chain, Stakeholders, and Transaction costs

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Dissertation

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chair of the Board for Doctorates
to be defended publicly on
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by

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This dissertation has been approved by the promotors.

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Summary

Prefabricated housing (PH) was introduced to the property market in China in the 1950s and subsequently experienced several decades of exploration and practice as it was adapted to the local conditions. The China authority currently defines PH as: "**Residential buildings that are assembled on-site using prefabricated components**" (MOHURD, 2018). Nowadays, the adoption of prefabrication in the house building sector is one of the major practices to achieve sustainability while ensuring green construction, innovative products, and higher quality. Given such promised advantages, since 2010, there has been a massive PH programme advocated by the Chinese authorities, accompanied by the sharpest increase of PH policies.

The recent promotion of PH in China by authorities has resulted in a prosperous period. Its market size reached 13.4 % of the new-built buildings in 2019 (STIDC, 2020). Meanwhile, given that China has the largest construction market globally, a potential vast PH market can be expected in China (PRC, 2019) as we go forward. Nevertheless, the full promise of such benefits is not always realized. Recent studies in China indicated that the capital cost of prefabrication was 10%-20% higher compared with in-situ construction methods (Mao et al, 2016). Generally, the development of PH in China is still in an immature state.

Yet, the adoption of prefabrication technologies is considered as adding risks to well-established practices in China. The smooth transition from a labor-intensive onsite method to a highly-integrated prefabrication method requires the China construction industry to overcome a strong lock-in effect (Gan et al, 2019). Numerous challenges need to be understood in order to succeed in PH, such as dealing with the lack of knowledge and expertise, higher capital costs, new technologies, low process efficiency, and so forth (Mao et al, 2015; Xue et al, 2018; Zhai et al, 2014). Due to the mismatch between the new PH supply chain and the conventional one, stakeholders bear additional risks for applying these various new technologies, and also in order to enforce the contracts. The additional processes (e.g., component design, manufacturing, component logistics) increase the complexity of the relationships among stakeholders (Liu et al, 2018). Higher communication costs are needed to ensure technology consistency. To achieve 30% PH of the new-built buildings by 2026 (GOSC, 2016), numerous challenges still need to be overcome. From the perspective of economics, the costs of overcoming these challenges,

stemming from the attributes of the transactions in terms of asset specificity, frequency, and uncertainty, are mostly transaction costs (TCs) (Williamson (1985).

TCs commonly appear in the traditional construction industry, while they are more noteworthy in the innovation industry because of their higher proportion of total costs. For instance, TCs of energy-efficient buildings have been estimated to be as high as 20% of the investment cost (Gooding & Gul, 2016). High TCs harm the enterprises' enthusiasm for adopting PH and disadvantage the efficiency of the PH projects. Although the TCs theory has been applied in many fields for improving production/management efficiency, the knowledge of TCs is still limited in the field of PH. Currently, the key stakeholders have limited knowledge on how to identify and control TCs in the project development process, and there are no strategies available to minimize TCs from a rational perspective. Accordingly, a relevant and essential research question needs urgently to be answered: **How to identify and reduce the TCs of PH projects**? To answer this question, this study aims: (1) to explore the TCs throughout the PH supply chain; and (2) identify the benefits to the key stakeholders by providing strategies for minimizing TCs.

Challenges such as high cost and low efficiency appear to be the common issues in the immature PH supply chain in developing countries like China. **Chapter 1** of this thesis analyzes these challenges from two aspects: the supply chain and the stakeholders. The TCs theory is adopted as a valuable lens that recognizes that the costs of spending on overcoming the challenges in PH are mostly TCs (Williamson, 1985). The efficient promotion of PH cannot be achieved without understanding and minimizing the TCs. Therefore, this study is designed to understanding the TCs with a deepening scope, from identifying TCs, to perceptions of TCs, causes of TCs, and choices of TCs. From the perspective of the stakeholders, a narrowing down of the target group is selected from key stakeholders to the developers to investigate the TCs. Meanwhile, the deep investigation of TCs is companied by a narrowing-down of the stakeholders' perspective - from key stakeholders to the developers. This contributes to solid research of TCs in China's PH market. In addition, the focus area of this study is designed starting from a representative city, and then to all the cities in mainland China, showing an expanding approach. Chongqing is selected as the representative city for identifying TCs. A deep investigation of the causes of TCs is based on the samples from all provinces in mainland China. Such a sample ensures the reliability of the collected data; simultaneously, data accessibility is considered.

The first step of studying TCs is identifying and defining them. **Chapter 2** of this thesis explores the TCs in the PH supply chain and regarding the stakeholders. Based on a comprehensive analysis of the PH supply chain and the barriers embedded, a TCs framework was developed by empirical study. Two projects in Chongqing were selected for the case studies. Social Network Analysis (SNA) was conducted to identify the critical stakeholders. The results indicate that stakeholders in the network of PH projects with a significant influence include: developers, general contractors, architects, local governments, supervisors, and component suppliers. Together with the questionnaire survey results, the interviews reveal the sources and nature of TCs in PH projects. By the nature of the TCs, due diligence is the most significant source of TCs in PH. The developers and general contractors bear more TCs compared with the other stakeholders. Throughout the PH supply chain, the *concept* and *construction* phases are where the majority of TCs appear, compared with the other phases. As one of the first research studies addressing the theory of TCs of PH, this section establishes the background knowledge for further investigation of the TCs in PH projects.

Further, the reduction of TCs requires a comprehensive understanding of stakeholders' perceptions of TCs. The objective of **Chapter 3** is to grasp practitioners' perceptions of TCs by considering the identification of the key stakeholder groups. Due to various interests, TCs tend to be specific to different stakeholders. Hence, perceptions of TCs were obtained from each stakeholder's perspective. The distribution of TCs related to the stages of the design and construction process and stakeholders is investigated by the literature study and validated by expert interviews. Questionnaire surveys and interviews in Chongqing demonstrate that assembly, detailed design, and design change are the most highlighted TCs by the key stakeholders. In particular, the component suppliers complained of TCs arising from the detailed design and hiring of skilled labor. The local government emphasized TCs on monitoring and enforcement in assembly, architectural design, and component transportation. Besides, group comparisons were conducted among stakeholders to uncover the similarity and variance of their perceptions of TCs. It is observed that TCs in PH by stakeholders are commonly highly-related to the prefabrication specificity. Moreover, the perception differences reveal that the private stakeholders tend to emphasize TCs from their production activities, while the authorities have an objective understanding of all TCs in the supply chain.

In **Chapter 4**, developers are selected as the representative of the private stakeholders to investigate the influencing factors of TCs. The survey scope for this part of the study was enlarged to the whole of China. The most influential factors are identified with their impacts on particular TCs, yielded from correlation analysis and logistic regression. It is indicated that the four most influential factors are: Qualification of the general contractor, Mandatory local policies, Owner type, and Competitiveness of the developer. Specifically, the higher qualification of a

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general contractor contributes to the lowering of the TCs for disputes, financing, land-bidding, and taxation. Improving the level of mandatory policies can reduce TCs arising from identifying experienced partners and signing sale contracts. As for the influence of owner type, developers' TCs for decision-making in public projects are more likely to be higher than in private projects. Additionally, it was unexpected to find that the developer's more potent capability related to even higher TCs for procuring the general contractor, a counter-intuitive finding. In general, through the analysis of the influencing factors, the effect of stakeholders' capability in determining TCs of PH has been emphasized. As a result, the corresponding recommendations for use by the developers are given for minimizing the TCs. Furthermore, according to the critical influence of mandatory local policies on the TCs, recommendations are provided for the policymakers. It is believed that popularizing the mandatory policies and setting up regional target prefabrication rates can effectively promote PH, leading to minimized TCs for private stakeholders.

As this study progressed, the occurrence of TCs and the reasons behind them become more apparent concerning Chinese PH. Thus these findings contribute to the final purpose of supporting the developers in making effective decisions to gain the maximized advantages of PH. For this purpose, in **Chapter 5**, a Bayesian Belief Network (BBN) model was developed based on the data collected from 31 provinces in China, identifying the developers' most influential choices. The single sensitive analysis identified developers' choices on three aspects that impose determining impacts on the TCs, including: (1) the Prefabrication rate; (2) PH experience; and (3) the Contract payment method. Simple strategies were recommended to developers on 1) Gradually improving the prefabrication rate to determine a best-matched prefabrication rate, instead of merely pursuing the highest rate; 2) Learning experience and hiring skilled employees, especially for the small-scale real estate companies; and 3) Choosing the appropriate contract payment methods to allocate the risks rationally for minimizing the TCs. Furthermore, the joint strategies were provided based on the multiple sensitivity analysis results for the developers facing different challenges. Indeed, TCs can be controlled by procuring high-certificated general contractors and adopting unit-price contracts in projects that require high prefabrication rates. For developers with limited PH experience, adopting the EPC delivery methods can vitally lower their TCs, thanks to the high-integrated contractual organization with low negotiation cost. The findings contribute to the current body of knowledge concerning the effect of stakeholders' decisions on TCs.

To sum up, this study explores the TCs in Chinese PH projects, highlighting the following significant conclusions:

- By nature, there are three types of TCs in Chinese PH projects: due diligence costs, negotiation costs, monitoring, and enforcement costs.
- Assembly, Detailed Design, and Design Change are the most critical sources of TCs in PH.
- Essentially, stakeholders in China's PH industry put more of their attention on TCs related to the specificity of prefabrication.
- Developers and general contractors are the most influential stakeholders that bear more TCs than the others.
- From the developers' perspective, Local mandatory policies, Owner type, Qualification of the general contractor, and Competitiveness of the developer are the most influential factors that determine the TCs in PH projects.

The findings in this study provide policy implications for China's PH. A key finding is that the governments' interventions are constructive for a favorable transaction environment, which aligns with the argument in other innovation industries (Qian et al, 2013). The value of the governmental TCs has been revealed for reducing the TCs of PH at both the project and the industry level. Hence, the establishment of certification regulations and a targeted education system for employees is the top priority of the most expected actions to meet market demands. Besides, according to the capacity of stakeholders' to influence TCs, the government is suggested to stimulate the inexperienced and the small-scale enterprises to participate in the PH market. Specific incentives, such as fund support, loan support, tax privilege, and convenient administration procedures, should be in place to lower the initial investment by the small companies. Furthermore, the mandatory policies are expected to be popularized among all Chinese provinces for PH promotion. For example, one key finding in this study is that the mandatory policy is a practical approach for educating and regulating practitioners. The uncertainties on the aspects of technique and management can be vastly reduced, contributing to the minimization of TCs.

Overall, this study contributes to a greater understanding of TCs of Chinese PH projects, benefiting the PH industry from scientific and societal aspects. To the author's knowledge, his thesis is the first study that creatively introduces the TCs theory in the field of PH. First, it develops an analytical TCs framework for identifying the hidden costs in the PH supply chain. It not only expands the application of the TCs theory, it also enriches the construction management theory. Second, this study adds the knowledge of the key factors influencing TCs. The investigation of the influencing factors of TCs uncovers the underlying mechanism of TCs. Furthermore, exploring the influence of stakeholders' choices on the TCs mirrors the relationships between actors' behavior and TCs. Third, by showing the Chinese cases, this thesis provides new insights into overcoming challenges of global PH development, especially for countries and regions with an immature PH market.

On the aspect of social relevance, this study provides the stakeholders with a lens for identifying the hidden costs of overcoming challenges in PH. Accordingly, corresponding measures can be taken to reduce these TCs to reap the benefits of PH. Practical suggestions are provided for each stakeholder and at specific phases of the supply chain. By reducing the TCs in the supply chain and the overall cost of PHs, the overall benefits of PH can be better compared to traditional construction methods, in which sustainability, high performance, and reduced construction time can be promoted. Last but not least, the policymakers can be inspired and supported by the findings of this study. The evidence of TCs and stakeholders' opinions of TCs from the surveys enable the policymakers to quickly grasp the market needs. The investigation of TCs determinants expounds on the function of local policies in the PH market, which derive reasonable policies to encourage the PH in all of China's local regions.

Samenvatting

Geprefabriceerde woningen (PH) werden in de jaren vijftig geïntroduceerd op de vastgoedmarkt in China en hebben vervolgens enkele decennia van exploratie en praktijk meegemaakt, zoals deze aangepast was aan de lokale omstandigheden. De Chinese autoriteit definieert momenteel PH als: “Residentiële gebouwen die ter plaatse worden gemonteerd met behulp van geprefabriceerde onderdelen” (MOHURD, 2018). Tegenwoordig is de invoering van prefabrikatie in de woningbouwsector een van de belangrijkste praktijken om duurzaamheid te bereiken en tegelijkertijd de groene bouw, innovatieve producten en een hogere kwaliteit te garanderen. Gezien deze beloofde voordelen is er sinds 2010 een massaal PH-programma dat door de Chinese autoriteiten wordt bepleit, vergezeld van de scherpste toename van het PH-beleid.

De recente promotie van PH in China door autoriteiten heeft geresulteerd in een welvarende periode. De omvang van de markt bereikte 13.4% van de nieuwgebouwde gebouwen in 2019 (STIDC, 2020). Aangezien China wereldwijd de grootste markt voor de bouw heeft, kan in China (PRC, 2019) een potentiële grote PH-markt worden verwacht. De volledige belofte van dergelijke voordelen wordt echter niet altijd gerealiseerd. Recente studies in China gaven aan dat de kapitaalkosten van prefabratie 10%-20% hoger waren dan in-situ bouwmethoden (Mao et al, 2016). Over het algemeen is de ontwikkeling van PH in China nog steeds in een onvolwassen staat.

Toch wordt de invoering van prefabrikatie technologieën beschouwd als het toevoegen van risico’s aan gevestigde praktijken in China. De soepele overgang van een arbeidsintensieve onsite methode naar een zeer geïntegreerde prefabrikatie methode vereist dat de Chinese bouwindustrie een sterke lock-in-effect (Gan et al, 2019) moet overwinnen. Talrijke uitdagingen moeten worden begrepen om in PH te slagen, zoals het omgaan met het gebrek aan kennis en expertise, hogere kapitaalkosten, nieuwe technologieën, lage procesefficiëntie, enzovoort (Mao et al, 2015; Xue et al, 2018; Zhai et al, 2014). Door de mismatch tussen de nieuwe PH-toeleveringsketen en de conventionele, dragen belanghebbenden extra risico’s voor de toepassing van deze verschillende nieuwe technologieën, en ook voor de uitvoering van de contracten. De aanvullende processen (bv. het ontwerp van onderdelen, de fabricage, de componentenlogistiek) vergroten de complexiteit van de relaties tussen belanghebbenden (Liu et al, 2018). Er zijn hogere communicatiekosten nodig om de technologische samenhang te waarborgen. Om 30% PH van de nieuwgebouwde gebouwen te bereiken met 2026 (GOSC, 2016), moeten er nog tal van uitdagingen worden overwonnen. Vanuit economisch oogpunt zijn de kosten van het overwinnen van deze uitdagingen, die voortvloeien uit de kenmerken van de transacties op het gebied van activakpecifiek, frequentie en onzekerheid, meestal transactiekosten (TCs) (Williamson (1985).

In de traditionele bouwsector komen TCs vaak voor, terwijl zij in de innovatie meer opmerkelijk zijn vanwege hun hogere aandeel in de totale kosten. Bijvoorbeeld, TCs van energie-efficiënte gebouwen zijn geschat zo hoog als 20% van de investeringskosten (Gooding &UL, 2016). Hoge TCs doen de bedrijven schade toe, enthousiasme voor het aannemen van PH en benadelen de efficiëntie van de PH-projecten. Hoewel de TCs-theorie op vele gebieden is toegepast voor de verbetering van de productie/management-efficiëntie, is de kennis van TCs nog steeds beperkt op het gebied van PH. Momenteel hebben de belangrijkste belanghebbenden beperkte kennis over het identificeren en controleren van TCs in het projectontwikkelingen proces, en er zijn geen strategieën beschikbaar om TCs uit een rationeel perspectief te minimaliseren. Daarom moet dringend een relevante en essentiële onderzoeksvraag worden beantwoord: Hoe kunnen de TCs van PH-projecten worden geïdentificeerd en verminderd? Om deze vraag te beantwoorden, is deze studie gericht op: (1) het verkennen van de TCs in de gehele toeleveringsketen van PH; en (2) identificeren van de voordelen voor de belangrijkste belanghebbenden door het verstrekken van strategieën voor het minimaliseren van TCs.

Uitdagingen zoals hoge kosten en lage efficiëntie lijken de gemeenschappelijke kwesties te zijn in de onvolwassen PH-toeleveringsketen in ontwikkelingslanden als China. **Hoofdstuk 1** van dit proefschrift analyseert deze uitdagingen vanuit twee aspecten: de toeleveringsketen en de belanghebbenden. De TCs-theorie wordt aangenomen als een waardevolle lens die erkent dat de kosten van uitgaven voor het overwinnen van de uitdagingen in PH voornamelijk TCs zijn (Williamson, 1985). De efficiënte promotie van PH kan niet worden bereikt zonder het begrijpen en minimaliseren van de TCs. Daarom is deze studie bedoeld om de TCs te begrijpen met een verdieping van de reikwijdte, van het identificeren van TCs, tot het waarnemen van TCs, de oorzaken van TCs en de keuze van TCs. Vanuit het perspectief van de belanghebbenden wordt een vernauwing van de doelgroep geselecteerd van de belangrijkste belanghebbenden naar de ontwikkelaars om de TCs te onderzoeken. Ondertussen wordt het diepgaand onderzoek naar TCs gepaard gegaan met een vernauwing van de belanghebbenden, het perspectief van belangrijke belanghebbenden tot de ontwikkelaars. Dit draagt bij tot een solide onderzoek van TCs in China rond PH-markt. Bovendien is het aandachtsgebied van deze studie ontworpen vanaf een representatieve stad, en vervolgens naar alle steden in het vasteland van China, met een groeiende aanpak. Chongqing is de representatieve stad voor het identificeren van TCs. Een diepgaand onderzoek naar de oorzaken van TCs is gebaseerd op de monsters van alle provincies in het vasteland van China. Een dergelijk monster garandeert de betrouwbaarheid van de verzamelde gegevens; tegelijkertijd wordt rekening gehouden met de toegankelijkheid van gegevens.

De eerste stap in het bestuderen van TCs is het identificeren en definiëren van deze systemen. **Hoofdstuk 2** van dit proefschrift onderzoekt de TCs in de toeleveringsketen van PH en de belanghebbenden. Op basis van een uitgebreide analyse van de PH-toeleveringsketen en de barrières die zijn ingesloten, werd een TCs-kader ontwikkeld door empirische studie. Voor de case studies werden twee projecten in Chongqing geselecteerd. De analyse van het sociaal netwerk (SNA) werd uitgevoerd om de kritische belanghebbenden te identificeren. De resultaten geven aan dat belanghebbenden in het netwerk van PH-projecten met een aanzienlijke invloed zijn: ontwikkelaars, algemene aannemers, architecten, lokale overheden, toezichthouders en leveranciers van componenten. Samen met de resultaten van de vragenlijst tonen de interviews de bronnen en de aard van TCs in PH-projecten aan. Door de aard van de TCs is due diligence de belangrijkste bron van TCs in PH. De ontwikkelaars en algemene contractanten hebben meer TCs in vergelijking met de andere belanghebbenden. In de hele PH-toeleveringsketen zijn de conceptfase en de bouwfase waar de meeste TCs verschijnen, vergeleken met de andere fasen. Als een van de eerste onderzoeks studies die betrekking hebben op de theorie van TCs van PH, wordt in dit deel de achtergrondinformatie gegeven voor nader onderzoek van de TCs in PH-projecten.

Verder vereist de vermindering van TCs een alomvattend begrip van belanghebbenden perceptie van TCs. Het doel van **hoofdstuk 3** is de perceptie van de beoefenaars van TCs te begrijpen door de identificatie van de belangrijkste groepen van belanghebbenden te overwegen. Door verschillende belangen zijn TCs vaak specifiek voor verschillende belanghebbenden. Daarom werden waarnemingen van TCs verkregen uit het perspectief van elke belanghebbende. De verspreiding van TCs met betrekking tot de stadia van het ontwerp- en bouwproces en belanghebbenden wordt onderzocht door de literatuurstudie en gevalideerd door deskundigeninterviews. Uit vragenlijsten en interviews in Chongqing blijkt dat assemblage, gedetailleerd ontwerp en ontwerpwijzigingen de meest geaccentueerde TCs zijn van de belangrijkste belanghebbenden. De toeleveranciers klaagden met name over TCs die voortvloeien uit het gedetailleerde ontwerp en het huren van geschoolde arbeidskrachten. De lokale overheid benadrukte TCs op het gebied van toezicht en handhaving in assemblage, architectonisch ontwerp en component transport. Bovendien werden groepsvergelijkingen uitgevoerd tussen belanghebbenden om de gelijkenis en de variantie van hun perceptie van TCs te ontdekken. Er wordt opgemerkt dat TCs in PH door belanghebbenden doorgaans sterk verband houden met de prefabrikatie specificiteit. Bovendien blijkt uit de perceptie verschillen dat de particuliere belanghebbenden de nadruk leggen op TCs van hun productieactiviteiten, terwijl de autoriteiten een objectief inzicht hebben in alle TCs in de toeleveringsketen.

In **hoofdstuk 4** worden ontwikkelaars geselecteerd als vertegenwoordiger van de particuliere belanghebbenden om de beïnvloedende factoren van TCs te onderzoeken. De onderzoeksruimte voor dit deel van de studie werd uitgebreid tot heel China. De meest invloedrijke factoren worden geïdentificeerd met hun effecten op specifieke TCs, die voortvloeien uit correlatieanalyse en logistieke regressie. Er wordt aangegeven dat de vier meest invloedrijke factoren zijn: kwalificatie van de algemene aannemer, verplicht lokaal beleid, eigenaar type, en concurrentievermogen van de ontwikkelaar. Met name draagt de hogere kwalificatie van een algemeen contractant bij tot de verlaging van de TCs voor geschillen, financiering, het bieden van land en belastingen. De verbetering van het niveau van het verplichte beleid kan TCs beperken die voortvloeien uit het identificeren van ervaren partners en het ondertekenen van verkoopcontracten. Wat betreft de invloed van het type eigenaar, ontwikkelaars; TCs voor besluitvorming in openbare projecten zijn waarschijnlijker hoger dan in particuliere projecten. Bovendien was het onverwacht om te ontdekken dat de ontwikkelaar's meer krachtige vermogen in verband met nog hogere TCs voor de aanschaf van de algemene aannemer, een contra-intuïtieve bevinding. In het algemeen wordt door de analyse van de beïnvloedende factoren het effect van stakeholders het vermogen om TCs van PH te bepalen, benadrukt. Als gevolg daarvan worden de overeenkomstige aanbevelingen voor het gebruik door de ontwikkelaars gegeven voor het minimaliseren van de TCs. Bovendien worden volgens de kritische invloed van verplicht lokaal beleid op de TCs aanbevelingen gegeven aan de beleidsmakers. Er wordt aangenomen dat het populariseren van het verplichte beleid en het opzetten van regionale streef prefabrikaten daadwerkelijk PH kan bevorderen, wat leidt tot geminimaliseerd TCs voor particuliere belanghebbenden.

Naarmate deze studie vorderde, werd het voorkomen van TCs en de redenen achter hen duidelijker ten aanzien van Chinese PH. Aldus dragen deze bevindingen bij tot het uiteindelijke doel van het ondersteunen van de ontwikkelaars bij het nemen van effectieve beslissingen om de maximale voordelen van PH te verkrijgen. een Bayesian Belief Network (BBN) model werd ontwikkeld op basis van de gegevens verzameld uit 31 provincies in China, waarbij de meest invloedrijke keuzes van de ontwikkelaars werden geïdentificeerd. De enkelvoudige gevoelige analyse identificeerde de keuzes van ontwikkelaars op drie aspecten die bepalend zijn voor de effecten op de TCs, waaronder: (1) de prefabrikatie snelheid; (2) PH-ervaring; en (3) de betalingsmethode van het contract. Eenvoudige strategieën werden aanbevolen aan ontwikkelaars op 1) Geleidelijk aan het verbeteren van de prefabrikatie snelheid om een het best-matching prefabriceringspercentage te bepalen, in plaats van alleen het volgen van het hoogste tarief; 2) Ervaring opdoen en gekwalificeerde werknemers inhuren, met name voor de kleine vastgoedbedrijven; en 3) Het kiezen van de juiste betalingsmethoden voor contracten om de risico's rationeel toe te wijzen voor het minimaliseren van de TCs. Bovendien werden de gezamenlijke strategieën verstrekt op basis van de resultaten van de gevoeligheidsanalyse voor de ontwikkelaars die met verschillende uitdagingen geconfronteerd worden. TCs kunnen immers worden gecontroleerd door het aanschaffen van hooggecertificeerde algemene contractanten en het aannemen van eenheidsprijscontracten in projecten die hoge prefabrikantentarieven vereisen. Voor ontwikkelaars met beperkte PH-ervaring, kan het aannemen van de EPC-leveringsmethoden van vitaal belang hun TCs verlagen, dankzij de hoge-geïntegreerde contractuele organisatie met lage onderhandelingskosten. De bevindingen dragen bij tot de huidige kennis over het effect van belanghebbenden; beslissingen over TCs.

Samenvattend wordt in deze studie ingegaan op de TCs in Chinese PH-projecten, met de volgende belangrijke conclusies:

- Van nature zijn er drie soorten TCs in Chinese PH-projecten: due diligence kosten, onderhandelingskosten, monitoring en handhavingskosten.
- Assemblée, Gedetailleerde Design en Design Change zijn de meest kritische bronnen van TCs in PH.
- In wezen hebben de belanghebbenden in de Chinese sector; de PH-industrie meer aandacht besteed aan TCs in verband met de specificiteit van prefabrikatie.
- Ontwikkelaars en contractanten zijn de meest invloedrijke belanghebbenden die meer TCs hebben dan de anderen.
- Vanuit het perspectief van de ontwikkelaars zijn lokale verplichte beleidsmaatregelen, eigenaar type, Kwalificatie van de algemene aannemer, en Concurrentievermogen van de ontwikkelaar de meest invloedrijke factoren die bepalen de TCs in PH-projecten.

De bevindingen in deze studie bieden beleidsimplicaties voor China; s PH. Een belangrijke bevinding is dat de interventies van de regeringen constructief zijn voor een gunstige transactie omgeving, die aansluit bij het argument in andere innovatie industrieën (Qian et al, 2013). De waarde van de overheids TCs is aangetoond voor de vermindering van de TCs van PH zowel op het project als op het niveau van de industrie. Daarom is de invoering van certificeringsvoorschriften en een doelgericht onderwijssysteem voor werknemers de hoogste prioriteit van de meest verwachte acties om aan de eisen van de markt te voldoen. Bovendien wordt de regering voorgesteld om de onervaren en de kleinschalige ondernemingen te stimuleren om deel te nemen aan de PH-markt om invloed uit te oefenen op TCs. Om de initiële investering van de kleine ondernemingen te verlagen, moeten specifieke prikkels worden ingevoerd, zoals steun voor fondsen, lening, fiscale privileges en administratieve procedures. Bovendien wordt verwacht dat het verplichte beleid onder alle Chinese provincies zal worden populariseerd voor PH-promotie. Een van de belangrijkste bevindingen in deze studie is bijvoorbeeld dat het verplichte beleid een praktische aanpak is voor het onderwijzen en reguleren van beoefenaars. De onzekerheden met betrekking tot de aspecten van techniek en beheer kunnen sterk worden verminderd, hetgeen bijdraagt tot de minimalisering van TCs.

Over het algemeen draagt deze studie bij tot een beter begrip van TCs van Chinese PH-projecten, die de PH-industrie ten goede komen van wetenschappelijke en maatschappelijke aspecten. Aan de auteur; de kennis, zijn the is de eerste studie die creatief introduceert de TCs theorie op het gebied van PH. Ten eerste, ontwikkelt het een analytische TCs kader voor het identificeren van de verborgen kosten in de PH toeleveringsketen. Het breidt niet alleen de toepassing van de TCs-theorie uit, het verrijkt ook de bouwmanagementtheorie. Ten tweede voegt deze studie de kennis toe van de belangrijkste factoren die TCs beïnvloeden. Het onderzoek naar de beïnvloedende factoren van TCs levert het onderliggende mechanisme van TCs op. Bovendien, het verkennen van de invloed van stakeholders pijlers; keuzes op de TCs weerspiegelt de relaties tussen actoren secto’s def. Ten derde, door de Chinese gevallen te tonen, biedt deze these nieuwe inzichten in het overwinnen van uitdagingen van wereldwijde PH-ontwikkeling, met name voor landen en regio’s met een onvolwassen PH-markt.

Wat het aspect van de sociale relevantie betreft, biedt deze studie de belanghebbenden een lens voor het identificeren van de verborgen kosten van het overwinnen van uitdagingen in PH. Bijgevolg kunnen overeenkomstige maatregelen worden genomen om deze TCs te verminderen om de voordelen van PH te halen. Voor elke belanghebbende en in specifieke fasen van de toeleveringsketen worden praktische suggesties gedaan. Door de TCs in de toeleveringsketen en de totale kosten van PH’s te verminderen, kunnen de algemene voordelen van PH beter worden vergeleken met traditionele bouwmethoden, waarbij duurzaamheid, hoge prestaties en verminderde bouwtijd kunnen worden bevorderd. Last but not least kunnen de beleidsmakers worden geïnspireerd en ondersteund door de bevindingen van deze studie. Het bewijs van TCs en belanghebbenden; adviezen van TCs uit de enquêtes stellen de beleidsmakers in staat snel inzicht te krijgen in de behoeften van de markt. Het onderzoek van de determinanten van TCs beschrijft de functie van het lokale beleid op de PH-markt, die een redelijk beleid uitstippelt om de PH in alle lokale regio’s van China te stimuleren.

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1 Introduction

1.1 Background

1.1.1 The application of prefabrication in housing construction

Globally, the housing construction sector is driven by the growing demands of housing and the new requirements of sustainability. Prefabrication has become one of the most promising solutions to approach efficient production and sustainability. The massive application of prefabrication in the housing sector is known as prefabricated housing (PH). Prefabricated housing generally refers to the practice of producing building components in a manufacturing factory, transporting complete components or semi-components to construction sites, and assembling the components to create residential buildings (Tam et al, 2007). Based on the degree of prefabrication implemented on the product, PH has been classified in the literature into four categories: 1) component manufacturing; 2) non-volumetric sub-assemblies; 3) volumetric sub-assemblies; and 4) modular buildings (Goodier & Gibb, 2007).

PH introduces an innovative business strategy, which entails benefits in construction duration, construction costs, product performance, onsite safety, productivity, customization, and environmental issues (Arif & Egbu, 2010). The literature revealed that the benefits of waste reduction from adopting prefabrication are up to 52%. It can achieve a 16% reduction in labor requirement (Jaillon & Poon, 2008). Timber formwork and concrete works can be reduced by between 74% - 87% and 51% - 60%, respectively (Pan et al, 2007). Li & Jiang (2017) indicated that modular PH could cut down the construction duration by about 40% compared with conventional construction. Hammad et al (2019) found that the PH can reduce the dust and noise onsite by about 9.5%, and with 68% less carbon dioxide generation. Generally, the development of PH projects can be regarded as a combination of manufacturing, transportation, and installation process, with fewer defects, higher quality, and a more reliable rate of production depended on less fluctuation. From the industrial revolution, prefabrication is the basis for modular construction, which will entail the benefits of industrialization on both technical and business aspects.

Given the benefits of PH, globally, there is a trend of diffusion on PH uptake. In Japan, the proportion of all new dwellings prefabricated has remained steady between 12% and 16% in the last decade (Steinhardt & Manley, 2016). In the Netherlands, 20% of all Dutch housing was offsite wood or concrete prefabricated in 2000 (Clarke & Wall, 2000). In Sweden, PH was used in 20% of production since the 1970s (Steinhardt & Manley, 2016). In the USA, new-built PH homes annually reached 95,000, with 22 million people living in PH until 2019 (MHI, 2020). Similar growing adoption of PH also appears in Australia, Germany, UK, etc. Generally, in developed countries, PH has become more reliable in the mature construction industries. For example, PH delivers outstanding quality and performance, being almost 50% cheaper than traditionally built houses in the USA (MHI, 2020). On the contrary, in developing countries, industrialization of the construction sector has just started. The primary purpose of a massive application of prefabrication is to supply more low-income housing. At this moment, the development of PH is facing numerous challenges in developing countries. Low efficient management appears to be a common issue in the immature PH supply chain (Liu et al, 2021). Bakhaty & Kaluarachchi (2020) pointed out the issues of workforce and productivity in the Egyptian PH industry. Hosseini et al (2018) indicate that the production cost of PH is relatively high in developing countries due to the lack of knowledge. Given this, more research studies on optimizing the supply chain, saving labor and cost, and increasing productivity are needed to improve the economic benefits of PH in developing countries.

In China, where the housing sector has always been an essential part of the economy, there has been a growing interest from the Chinese authorities to promote PH. In recent years, cities in China have experienced a rapid urbanization process, increasing the urbanization rate from 17.92% in 1978 to 56.1% in 2015 (Guan et al, 2018). Along with the urbanization process, the growing environmental problems, the rapid urbanization, and the disappearance of the demographic dividend in China have become genuine concerns for China. The issues of environment and labor shortage, when coupled with the expertise of China in manufacturing, are expected to take advantage of the benefits of the PH. Still, PH implementation in China is very limited. The market size of the PH projects accounted for 13.4 % of the new-built buildings in 2019, which is, however, even far less than that in the developed countries (STIDC, 2020). As a country with the largest construction market worldwide, there is still a great demand for construction. With a total output value reached 24.84 trillion Chinese YUAN (CYN) in 2019 (PRC, 2019), a vast potential PH market can be expected to explore in China.

1.1.2 Prefabricated housing in China

Prefabricated housing was introduced to China in the 1950s to meet the massive housing demand (Wu et al, 2019a). However, it had not been popularized because of immature techniques and quality issues. For a long time, the Chinese construction industry has been reluctant and conservative when exposed to technological emergence and usage. In 1998, the Ministry of Housing Industrialization Promotion Centre was established to provide construction companies with guidelines and technical supports. Since then, the promotion of PH in China had entered a normalization stage. In 2017, the China authority announced an official definition of Prefabricated Housing: “Residential buildings that are assembled on-site using prefabricated components” (MOHURD, 2018).

Technically, PH in China is still in its primary stage, with component manufacturing adopted as the typical (Wu et al, 2020). The most commonly adopted precast components in China’s PH market include precast laminated floor slabs, precast stairs, precast balcony slabs, and precast air-conditioning boards. Consideration has been given to extend prefabrication to entire kitchen assemblies and washrooms, as well as water tanks (Pan & Xiong, 2009). Unlike other developed areas (e.g., Europe and the United States), in Chinese densely populated regions, high-rise concrete residential building is the domain type of PH products (Li et al, 2020). It means high challenges on both the technical aspect and management aspects. As such, the uniqueness of Chinese PH implementation sets high barriers for its transition from a labor-intensive onsite method to a highly integrated prefabrication method

In the context of China, the government is taking the lead in PH development, for which a policy-oriented promotion is mainstream. To facilitate the application of PH in China, a large number of policy measures have been in place from the central governments to the local governments (Ji et al, 2017). Figure 1.1 illustrates a growing tendency of PH-related policies in China from 1956 to 2019, with a few fluctuations. As shown in the figure, although the first policy was announced in 1956 during the period of China’s First Five-Year Plan, only since 2010, the sharpest increase of policies has been seen for the development of PH (Wang et al, 2021). 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). In 2016, the authority announced that at least 30% of new construction has to adopt prefabrication by 2026 (GOSC, 2016). PH has been included in the latest three Chinese National Five-year Plans (from twelfth to fourteenth-five-year-plan) to meet the demand for increased quantity and quality levels. PH policies in China have worked with a top-down system, which combines legislative and executive powers (Gao & Tian, 2020). Under the leadership of the central government, more than 30 provinces have approved related policies and supportive measures to reach this goal (Wang et al, 2019). The primary policy measurements include the guiding policies, incentives policies, regulations, standards, mandatory policies, etc. (Jiang et al, 2019). Advocate policies are the most applied tools by the Chinese authorities. However, the rapid development of PH in China brings advanced requirements to the policy design and implementation. Catching up with the dynamic demands from PH practitioners are significant challenges to the Chinese policymakers (Wang et al, 2021).

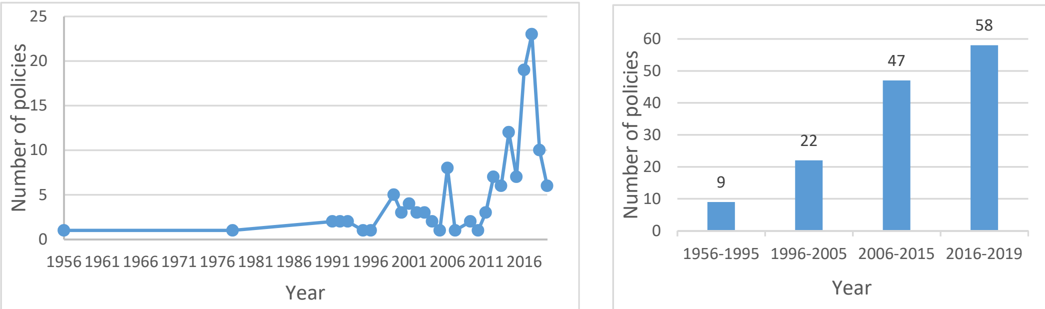

FIG. 1.1 PH related policies in China from 1956-2019 (Wang et al (2021))

Driven by the policies, there has been a growing interest from Chinese enterprises to develop PH projects (Ji et al, 2017). Nevertheless, the stakeholders do not receive the promised performance of applying the PH given that the promised benefits of PH have not been realized (Wu et al, 2019b). Recent studies in China indicated that the capital cost of prefabrication was 10%-20% higher compared with the in-situ (on-site) construction in China (Mao et al, 2016). Numerous challenges need to be understood to succeed in PH, such as higher capital costs (Xue et al, 2018a); low efficiency and rework (Shen et al, 2021); new technologies (Wu et al, 2019a); lack of knowledge and expertise (Mao et al, 2015), and so forth. Particularly, Shen et al (2021) stated that the combination of manufacturing and on-site construction causes additional risks and raises rework in the supply chain, which harms the success of PH projects. The enterprises, as profits-pursuers, have complaints about the high costs/effort for learning and adapting to prefabrication (Wu et al, 2019a). To sum up, as an innovative industry, the implementation of PH is faced with high uncertainties and risks in the supply chain and related to the stakeholders. To understand and overcome these challenges of PH in China, fundamental investigations must be carried out by considering the entire supply chain and influencing stakeholders.

1.2 Challenges of China's prefabricated housing

1.2.1 Challenges of the PH supply chain

A construction supply chain is a network of many organizations connected by information flow, materials flow, and contractual flow between stakeholders (Liu et al, 2018). The PH supply chain describes the entire development process of PH projects from the conceptual ideas to the final maintenance stage. Studies on PH have proposed that supply chain management is the key to the success of PH projects. In China's context, the current PH supply chain is developed on top of the well-established conventional construction supply chain. The application of prefabrication makes the supply chain an industrialized process, which contains additional tasks and processes that are not included in the cast-in-situ construction supply chain. The additional processes (e.g. component design, manufacturing, component logistics) increase both the complexity of the supply chain and the relationships among stakeholders (Liu et al, 2018). A body of research has discussed the challenges of PH development in China (Luo et al, 2019; Wang et al, 2018). Generally, the most severe challenges in the PH supply chain can be understood in two aspects: in **the process** and related to **the stakeholders**

Challenges in the transaction process primarily derive from risks and inefficiency. First, various risks exist in the Chinese PH supply chain due to the technical and organizational complexities. The application of prefabrication techniques entails risks to the conventional construction enterprises, which creates the possibility of design changes, disputes, and rework in the supply chain (Tam et al, 2015). In this circumstance, a lack of experienced professionals further results in significant technical risk, on-site management risk, and economic risk (Luo et al, 2015). Second, inefficient management has been a problem for the managers due to the conflicts between the well-established construction management and the fresh prefabrication production process. In China, the PH supply chain is still transitioning from conventional onsite construction to prefabricated offsite production. Dynamic development of the PH industry leads to the instability of the supply chain, which consumes more effort for learning and adopting (Jiang et al, 2018a).

In China's PH projects, poor coordination among the stakeholders is against addressing their different economic objectives (Zhang & Yu, 2020). For a PH supply chain, the client, general contractor, designer, manufacturer, transporter, and assembly subcontractors frequently interact in multiple flows throughout the whole development process. It requires a high degree of coordination among stakeholders to ensure smooth production in maintaining labor, materials, and equipment (Luo et al, 2019). The ineffective coordination easily leads to the failure of the PH projects. Additionally, along with developing the PH supply chain, stakeholders/suppliers are facing critical challenges to their survival in the volatile and dynamic market. Therefore, the timely understanding of stakeholders' demands is vital for supply chain management and PH promotion.

1.2.2 Challenges of stakeholders in PH

Stakeholders are practically promoting the development of PH. As a project-based industry, PH involves many stakeholders, with each party being an independent entity chasing its own interests and playing different functional roles in the innovative process (Xue et al, 2018b). Generally, there are two types of stakeholders in China's PH projects: public and private stakeholders. Public stakeholders are the organizations that play the role of governments in the PH projects, e.g., the central government, local urban planning department, local construction commission, etc. Private stakeholders are the non-governmental enterprises that aim to make profits in PH projects. Prefabrication introduces a new way of doing transactions for housing construction projects (Wu et al, 2020). Numerous difficulties, therefore, arise when the transaction process of the stakeholders is experiencing a reform. Quite an amount of literature has expounded on the challenges of the public and private stakeholders in developing PH.

The PH diffusion has brought additional responsibilities to the public stakeholders on both the industry level and the project level. To facilitate the immature PH industry, guiding policies are expected, which requires more effort from the government for policy-making (Gao & Tian, 2020). Besides, governmental departments are taking critical responsibility for issuing standards to regulate the production activities of PH. On the project level, local governments are highly involved in the manufacturing and construction work, and additional efforts are needed for manufacturing monitoring and component quality assessment (Jiang et al, 2019).

Private stakeholders expect to earn the promising benefits of adopting PH when struggling with new technologies and new project management processes. The implementation of PH has an even higher requirement on workers because of its innovative techniques and unique production process. Mao et al (2015) pointed out developers' particular barrier of lacking professional consultants, which leads to extra searching time and high consulting fees. The contractors complain about the rising cost from miscellaneous works from training labor (Jiang et al, 2018b) and transporting components (Hong et al, 2018). Tam et al (2015) emphasized architects' intensive coordination for the detailed design and manufacturing. If expected cooperation is not achieved for design, the ineffective assembly would be another burden for private stakeholders. These challenges limit the efficiency of production and diminish the stakeholders' enthusiasm for PH.

To overcome the challenges in PH, additional and redundant costs arise when extra efforts and time are consumed. These extra investments contribute to the increase in total construction costs, leading to disputes, delays, abandonment, and low efficiency of PH projects (Wu et al, 2019b). Nevertheless, these costs remain invisible in the traditional quantified cost system of the construction industry due to their obscured features in time, labor, and efforts. The stakeholders, especially the private stakeholders, lack knowledge of how these costs occur. To make the PH projects more financially attractive, the challenges of PH stakeholders must be well understood and eventually eliminated. However, the extant literature typically analyzes these challenges from the traditional construction management viewpoint (Gan et al, 2019), while the economic attributes of the challenges are ignored.

1.3 Transaction costs as a lens

The TCs theory was introduced by Coase (1937). The original formulation of TCs is that "the cost of using the price mechanism" and "the cost of carrying out a transaction by means of an exchange on the open market". Demsetz (1968) used a very narrow definition of TCs as the cost of exchanging ownership titles. A similar statement by Winch (1989) claims that in addition to the cost of production, there are also TCs between the parties arising from the economic exchange. Afterward, the concept of TCs has a broader range of definitions and empirical evidence. Buitelaar (2004) defined TCs as the costs for increasing the availability of information and reducing uncertainty brought by the institutions. Antinori & Sathaye (2007) defined the TCs are the costs beyond the direct costs of factor inputs into production but that are incurred in making a trade. The Transportation Research Board (TRB) termed TCs as soft costs (Schneck & Touran, 2010). Kiss (2016) stated that TCs are those unmeasured costs that prevent the adoption of new technologies. Although the numerous definitions of TCs seem inconsistent, commonly they agreed that TCs are the costs apart from the production costs and emphasized the hidden/unmeasured resources in the transaction process (define, establish, maintain, and transfer property rights).

From the perspective of TCs theory, in the context of PH, the costs spent on overcoming the challenges stemming from the attributes of the transactions in terms of asset specificity, frequency, and uncertainty are mostly transaction costs (TCs) (Williamson (1985). In the construction industry, Li et al (2015) defines the TCs are the costs of trade beyond the materials cost of the product, such as the costs of searching for projects, estimating, negotiation, monitoring, regulatory approval, and dealing with any deviations from contract conditions. This study adopts this concept specifically for the PH industry. In the PH project, a new development process and extra tasks require the support of new rules and institutions, and in turn, cause TCs to remain hidden. For example, transportation of the prefab components is a vital challenge that causes intensive coordination, therefore, high TCs of negotiation (Kamali & Hewage, 2016). The detailed design of PH would typically consume a longer time, high TCs from due diligence and negotiation, by taking the feasibility of assembly into account (O'Connor et al, 2015). In essence, challenges in PH can be understood as TCs by their nature. The TCs theory can provide a valuable lens for understanding the nature of the challenges, contributing to smooth the development process for PH.

The TCs theory is a mature theory that has been well developed and applied in different fields for advancing the efficiency of production and management. The New Institutional Economics (NIE) approach was propagated by Williamson (1985), which emphasizes the design of institutions and contracts to minimize unobservable transaction costs that are not directly quantified. Williamson (1985) believes that well-designed institutional structures lower TCs and provide net social benefits. The idea of Williamson's TCs economics has been widely applied to guide the practice in industries, such as stock, manufacturing, and construction (Rajeh et al, 2015). In the construction industry, it has been adopted to solve the problems of project management (Walker & Chau, 1999), institutional governance (Lai & Tang, 2016; Winch, 1989), procurement management (Carbonara et al, 2016), identification of TCs (Buitelaar, 2004), and policy management (Mundaca, 2007). In the innovation industries, TCs are often referred to as unmeasured costs that prevent new technologies (Kiss, 2016; Qian et al, 2016). TCs do not contribute directly to the output of a development process, like land, bricks, concrete, and trees, in other words, the production costs. It is assumed that the fewer the transaction costs, the more smooth and efficient the development process (Webster, 1998). Therefore,

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TCs can be seen as deadweight losses that have to be minimized in PH projects to improve production efficiency.

In investigating the determinants of TCs, three key constructs that reflect the fundamental representation of it: asset specificity, uncertainty, and frequency Williamson (1985). Asset specificity refers to the specific investment for a particular transaction (Williamson, 1981). In other words, they are the durable investments that are undertaken in support of particular transactions. These specific investments (e.g. capital, time, and labor) are sunk costs with a much lower value outside those particular transactions (Williamson, 1985). Uncertainty refers to economic uncertainty, market uncertainty, and policy uncertainty. The essence of uncertainty usually carries high risks. Frequency refers to how often the buyers make purchases in the market (Williamson, 1985).

To investigate the TCs of PH, the asset specificity is of high importance to be understood. According to Williamson (1991), asset specificity can be explained in four aspects: site-specificity, physical asset specificity, human asset specificity, and dedicated asset. In the context of China's PH, the location of a PH project particularly defines its site-specificity. Depending on the location of the PH project, the local policies, local market, and community environment vary, which results in diverse volume of TCs from administration, negotiation, and monitoring. Besides, the specific techniques and production activities for developing PH buildings indicate the physical asset specificity. For example, the assembly technologies in PH projects are the special investments for PH projects, consuming a lot of costs on coordinating and monitoring. The human asset specificity of PH is reflected by the professionalism and specialized knowledge of the employees. The dedicated asset is the discrete investment in general production for a particular transaction. In PH projects, it is reflected by the particularly designed modules for special components, logistics for large prefab modular, and the customized tower cranes, etc. Understanding the asset specificity of PH can contribute to explaining the causes of TCs in PH and explain the empirical findings.

1.4 Research approach

1.4.1 Problem statement

In recent years, there has been a strong motivation to apply PH in the Chinese market. However, the current realities of the implementation of PH have come along with many problems regarding cost control (Xue et al, 2018a), low process efficiency (Zhai et al, 2014), and the lack of regulations (Mao et al, 2015), etc. Driven by profits, attention is focused only on the capital costs, while the hidden costs are overlooked in both the industry practice and academic theories. Hidden costs, such as land acquisition costs, commissioning, and handover costs, are often excluded in recent studies Mao et al (2016); Xue et al (2018a). The new network, risks, mismatching between the existing governance system and the new PH supply chain are all causing extra effort, time, and costs, and through this, higher hidden costs. From the economic perspective, these ignored costs stemming from the attributes of the transactions in terms of asset specificity, frequency, and uncertainty are mostly transaction costs (TCs) (Williamson (1985). By their very nature, TCs are relatively obscure when compared with direct construction costs, but they do account for quite a large amount. TCs of energy-efficient buildings have been estimated to be as high as 20% of the investment cost (Gooding & Gul, 2016). The increase in TCs can negatively impact PH projects on the aspects of duration, cost, quality, and production efficiency.

In practice, high TCs do not only harm the popularization of PH but also prevent stakeholders from entering the sustainable market. Stakeholders are the main actors involved in the transactions and the payers of TCs in most cases. A high volume of TCs would limit production efficiency, thus shrink stakeholders' profits. However, stakeholders have minimal knowledge of TCs and are confused about where TCs arise in the PH project's supply chain. In academia, there have been very few attempts to investigate the TCs of PH from the stakeholders' perspective. In response to this research gap, the challenge of delivering a clear understanding of TCs for the stakeholders is of great necessity, which is also a key to smooth PH promotion in China.

In order to reduce the TCs, the causes of TCs are of high necessity to explore. As stated, both the public and private stakeholders are taking the burden from TCs. Nevertheless, private stakeholders are currently the prominent practitioners who

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are developing the PH projects. Therefore, to diffuse the adoption of PH, TCs of private stakeholders are more urgent to be investigated and reduced. However, to our knowledge, the previous studies seldom explored the causes of TCs in the construction industry. Even in the other fields, the available literature mostly focuses on studying the causes of TCs of governments, while the causes of private stakeholders' TCs seldom got attention.

The challenges in PH call for stakeholders' rational strategies for minimizing the TCs. However, as the primary payers of the TCs, private stakeholders in PH do not have an awareness of how their decisions can influence the TCs of PH. In the PH projects, many of the TCs are positively related to stakeholders' decisions. For example, choices about the characters of the projects defining particular transaction procedures that can essentially affect the TCs (Coggan et al, 2013), of developers' decisions on the project delivery methods determine the contractual relationships in PH projects' development. This results in different TCs for communication and coordination (Rajeh et al, 2015). However, under the constraints of the transaction environment and limited knowledge about the TCs, it is challenging for the private stakeholders to make rational choices for the minimized TCs.

1.4.2 Aim and research questions

This study aims to seek insights into TCs in Chinese PH projects and investigate strategies for minimizing the TCs and smooth the development process of PH projects. Accordingly, the core question to be answered in this thesis is as follow:

How do transaction costs occur in the PH projects' development process, and what strategies can be taken by the stakeholders to reduce the transaction costs?

To answer this main research question, the following key questions are to be addressed individually:

1 **What are the TCs in the PH supply chain, and how do they occur in the production activities?**

This fundamental question is answered by exploring the sources of TCs throughout the supply chain with the consideration of tasks and stakeholders involved in the whole process. Chapter 2 answers this key question by breaking it down into the following sub-questions:

- Who are the key stakeholders, and what are their TCs?
- How do TCs appear in the PH supply chain?
- How to understand the nature of TCs in PH?

2 **How do the key stakeholders perceive the TCs in the development of PH projects in China?**

Accordingly, three sub-questions need to be answered in Chapter 3:

- What are the critical TCs in PH projects?
- How do the stakeholders perceive TCs from the perspective of their roles?
- What are the similarities and differences of stakeholders' perceptions of TCs in PH?

3 **What are the influencing factors of TCs from the developer's perspective?**

The following sub-questions are answered in Chapter 4:

- What are the TCs of most concern in PH from the perspective of the developers?
- What are the influencing factors of developer-related TCs in PH?
- How do the influencing factors influence their correlated TCs?

4 **How can the developers minimize the TCs by making rational choices in different scenarios?**

Chapter 5 answers three sub-questions derived from this research question:

- How do the developers' choices relate to the TCs in PH projects?
- What are the most critical choices that can significantly influence the TCs in PH projects?
- What are the strategies for the developers to minimize TCs when facing various challenges?

1.4.3 Research scope

PH is a broad topic on the aspects of technology and management. The focus of this thesis is limited to a particular scope according to the current practical situation in China. Clarifications regarding the structure of PH, supply chain, and the TCs, are made as follows:

The structure of PH in China includes reinforced concrete (77.1% of the total gross floor area of PH) and steel structures, while wood construction is rarely applied (Ji et al, 2017). Therefore, the PH projects discussed in this study are mainly concrete structured. Concrete PH is a building technique whereby concrete components are cast either in a factory or at a fixed location on site, and completed elements are erected and assembled in situ to form complete building structures (Chiang et al, 2006). Moreover, component manufacturing and non-volumetric sub-assemblies are the mainly adopted PH type in China. Modular PH is not included in the discussion of this study because the development process would be different when it is at a high integration level.

The research object of this study is the supply chain of PH at the project level. Unlike the concept of the supply chain in logistics, the supply chain in this study defines the entire development processes of prefabricated buildings. Starting from the conceptual planning, the PH supply chain includes the stages of concept, planning and design, manufacturing, construction, and until the sale and delivery. Tasks in the maintenance period of operational use by owners/tenants of the PH buildings are not discussed in this thesis.

This thesis focuses on the TCs of PH projects without a comparison with the traditional housing construction. As stated, the supply chain PH is based on a transformation from the traditional one. Therefore, the TCs of PH include the TCs in traditional projects and the different/additional TCs because of prefabrication. Some TCs in PH are the same as those in traditional projects, for instance, Land surveying, Insurance, and contract signing. Other TCs' resources are also common in traditional projects, such as the Project Proposal, Feasibility Study, Decision-making, Land-bidding, Financing, etc. However, the content of these TCs may be somehow different from what is in the traditional projects, which is because of the adoption of prefabrication. Besides, there are also TCs particularly for PH projects, which are new to the practitioners from the conventional construction. Examples of these TCs include Identifying Partners with PH Experience, Prefabrication Technical Solutions, Communication for Prefabrication, Components Quality Test, Components Transportation, etc.

This study is based on an assumption that the TCs are specific to the current state of the PH industry in China. In other words, the further development of materials, plants, machinery, technologies, and education may change the occurrence of TCs in PH. As Choudhury & Sampler (1997) claimed, TCs are highly dependent on the time specificity of the transactions. Thus, this research is designed particularly for understanding the challenges of PH projects in the state of immature and underdevelopment. Moreover, the investigation of TCs in the current situation provides references and implications for the future PH industry.

1.4.4 Methodology

To achieve the aim of understanding and reducing TCs, this study employs a combination of qualitative and quantitative research methods. Figure 1.2 shows the overview of the research methodology design, including the sub-objective and methods. The four main chapters explore the TCs of PH from identification to the cause behinds TCs. Each chapter is built on top of previous chapters, which enables a deepening investigation process. Research methods, such as the literature study, interview, and questionnaire survey, are adopted to collect data. The analytical methods, including statistical analysis and Bayesian belief network analysis, are applied to achieve the sub-objectives of this research.

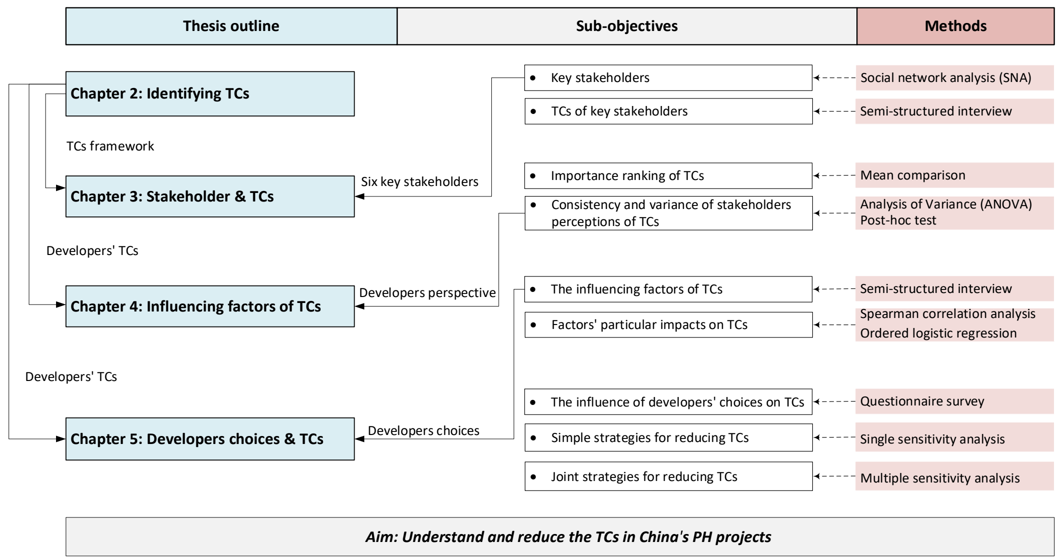

FIG. 1.2 Overview of the methodology design

The first objective of this study is to identify the TCs in the development process of China's PH. to achieve this, the methods of literature review, case study, questionnaire survey, and semi-structured interview were applied to collect data in Chongqing city. First, a questionnaire survey was conducted towards the employees in two cases to identify key stakeholders. Through Social Network Analysis (SNA), six key stakeholder groups in PH were identified by using the software of UCINET. Second, twenty-five semi-structured interviews with experts of the key stakeholders were held to validate the theoretical TCs framework. With a twofold purpose, the interviews also provide professional opinions for understanding the content and nature of TCs from different stakeholder perspectives. This is presented in Chapter 2.

The second sub-objective is to explore stakeholders' perceptions of TCs, which is achieved by using descriptive statistical analysis and the Analysis of Variance (ANOVA). Keeping Chongqing as the study area; twenty-five semi-structured interviews were conducted to understand how TCs appear at different phases and are related to various stakeholders. Overall, 154 of 400 questionnaires were returned as valid data for conduct the ANOVA to analyze the consistent perceptions among stakeholders. Furthermore, the Gabriel post hoc test is applied to grasp the variance of perceptions of TCs between pair of stakeholder groups. This is presented in Chapter 3.

The third part of this study (Chapter 4) uncovers the influencing factors of TCs. The first step is to perform the qualitative research, namely, semi-structured interviews, to improve the list of factors identified by an extensive literature review. Ten semi-structured interviews were conducted with the experts in China Prefabricated Building and Construction Technology Expo (2018). This was followed with a quantitative method, namely a questionnaire survey, to elicit the states of the factors and evaluate the importance of the TCs. Overall, 247 valid responses were collected from 31 of 34 provinces in China. The first section of the questionnaire captures the respondents' background, and the second section asks for information about the states of the factors. The third section was designed to evaluate the level of twenty sources of TCs using a five-point Likert-type scale. Analysis of the data from the questionnaire survey identifies the influencing factors of TCs, using the methods of Spearman correlation analysis and ordered logistic regression.

Finally, Chapter 5 develops a Bayesian Belief Network (BBN) model based on the results of previous chapters. A perception-based survey was conducted in China's PH market to obtain information about the choices of the developers and TCs. The questionnaires were developed and distributed through an online survey platform - wj.qq.com. The survey was successfully conducted with the assistance of the secretary from the website - precast.com.cn. Overall, 589 valid questionnaires were collected as the database input in the Netica 23.0 to conduct the automatic inference. The single contributor sensitivity analysis and multiple sensitivity analysis of the BBN model predict the influence of developers' choices on TCs and provide strategies for minimizing the TCs.

The study area of this study was designed starting from the representative city to all the cities in mainland China, showing an expanding approach. For identifying and understanding the TCs (in Chapters 2 and 3), Chongqing was selected as the representative city for case studying for three reasons. First, Chongqing is playing a vital economic and political role in China. Figure 1.3 shows the location of Chongqing in the southwest of China. As the newest one of the four municipalities under the direct governance of China Central Government, Chongqing plays an essential and strategic role in Western China. The urbanization rate of Chongqing is expected to rise from 60.9 percent in 2015 to above 75 percent by 2030, according to the Population Development Plan of Chongqing City (2016–2030) (Gan et al, 2019). Rapid urbanization and economic development have put Chongqing in a favorable situation to promote PH adoption. Second, there is a vast potential PH market in Chongqing. With over 33 million m^2 completed floor space of residential buildings in 2017, Chongqing plays a significant role in the housing construction market in China (Statistics, 2018). In a transforming stage from traditional on-site construction to off-site prefabrication, stakeholders in Chongqing will notice the problems and challenges to the construction market. Third, Chongqing reflects the average level of PH application in China cities. Dou et al (2019) scored the development level of PH in 31 provinces in China. Chongqing is the city with the closest prefabrication level to the average. Therefore, taking Chongqing as the study city helps to get an objective understanding of PH practices in China cities.

FIG. 1.3 Location of Chongqing in China

1.5 Structure of the thesis

This thesis contains six chapters that support its main goal to understand and reduce the TCs for stakeholders in China's prefabricated housing (PH). Figure 1.4 depicts the logical structure of the thesis. The chapters of the thesis have been compiled chronologically, in terms of analytical work as well as their publishing timeline. Chapter 1 opens this thesis by introducing the challenges of PH in China, defining the research questions, and designing the methodology. Consequently, Chapters 2 to 5 explore the TCs of PH from identification to the causes behind TCs. Each chapter is built on top of previous chapters, which enables a deepening investigation process. Chapters 2 to 5 are essentially journal articles, either published or in process. Chapter 6 is the final chapter of this thesis, which concludes the highlighted findings from the four articles, providing recommendations for both the private and public stakeholders.

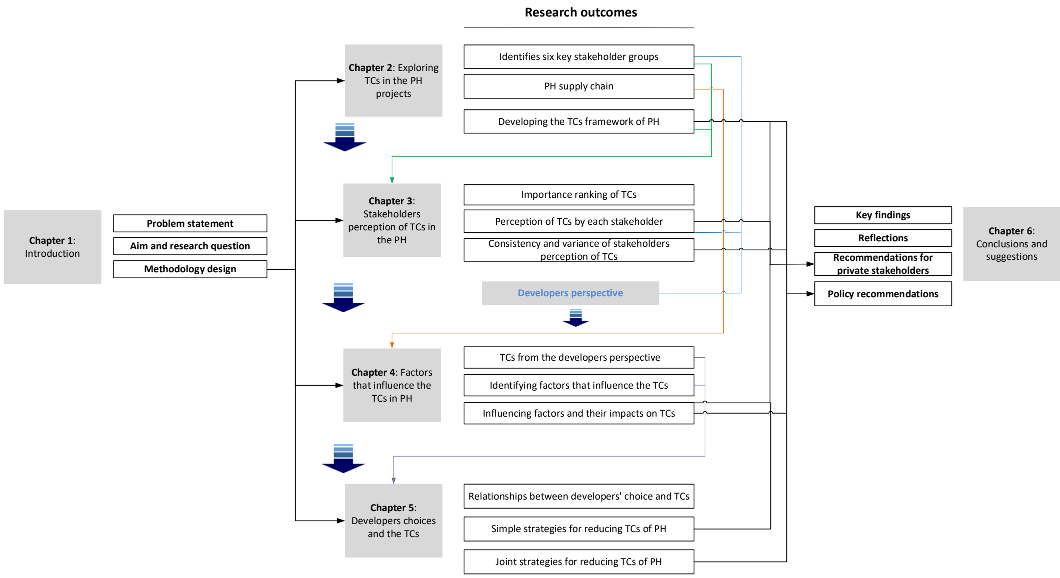

FIG. 1.4 The structure of this thesis

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Chapter 1 opens this thesis by introducing the challenges of China's PH from two angles: the supply chain and involved stakeholders. The TCs theory is adopted as a valuable lens that recognizes that the overcoming challenges in PH are mostly TCs. The core research question is defined as: How do transaction costs occur in the PH projects' development process, and what strategies can be taken by the stakeholders to reduce the transaction costs? Consequently, a four-step research is designed to understand the TCs with a deepening scope, from identifying TCs, to perceptions of TCs, causes of TCs, and developers' strategies influencing TCs. The deep investigation of TCs is companied by a narrowing-down the stakeholders' perspective - from key stakeholders to the developers. In general, the Introduction section identifies the problems and develops a complete methodology design, which contributes to a solid basis for the following research steps.

Chapter 2 presents our first exploration of introducing the concepts of TCs to the PH field. A TCs framework of the PH supply chain is developed and validated. The social network analysis identifies the key stakeholders of PH. The interviews, together with the questionnaire survey results, reveal the sources and nature of TCs in PH projects. Also, the primary payers and the main stages of TCs are discussed.

From the perspectives of the key stakeholders, Chapter 3 explores their perceptions towards TCs in the transaction process of PH in China and finds the potentials to lower the TCs. The findings revealed how TCs appear at different phases and are related to various stakeholders, while professionals' opinions from different stakeholders recognize their critical TCs. The questionnaire survey was conducted to find potential conflicts or areas of agreement among key stakeholder groups. Strategic implications are provided to both the public and the private stakeholders in PH.

In Chapter 4, developers are selected as the representative of the private stakeholders to investigate the influencing factors of TCs. The most influential factors are identified with their impacts on particular TCs, yielded from correlation analysis and logistic regression. Suggestions for developers are on the practical level to benefit the controlling of TCs in PH projects. To secure a favorable transaction environment, recommendations are also drawn for the policymakers.

Chapter 5 further investigates the strategies for developers to make rational choices for minimizing the TCs in PH. A Bayesian belief network (BBN) model was applied based on a questionnaire survey in China's PH market. The structure of the BBN model reflects the relationship between the developers' choices and TCs. Based on it, the single sensitive analysis identifies developers' most impactful choices on TCs. The joint strategies are recommended based on the multiple sensitivity analysis for the developers facing different challenges.

Chapter 6 is dedicated to the conclusions of this thesis. The findings from the previous chapters together answer the research questions of this programme. The main results also inspire deep reflections regarding the relationships between the PH supply chain, TCs, and stakeholders. Accordingly, recommendations are provided for the private stakeholders and policymakers to minimize their TCs in PH. Additionally, areas for future research are presented based on the findings of the study. Finally, attention is drawn to the possible limitations of the findings arising in this thesis.

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2 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.

KEYWORDS Transaction costs; Prefabricated housing; Construction supply chain; Stakeholders; Social Network Analysis; Sustainability

2.1 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 & 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 & Poon, 2008). Timber formwork and concrete works can be reduced by 74% - 87% and 51% - 60% respectively (Pan et al, 2007). Li & 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 & 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 & 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 & 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 & 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.

2.2 Literature Review

2.2.1 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 & Landin, 2005). Table 2. 1 gives definitions of 15 commonly involved stakeholders in PH projects. And there are links between stakeholders with different natures. Xing & 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 Figure 2.1.

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 Figure 2.1, 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 clients (developers) to the buyer after the sale. There are no logistics through the local government (Xing & 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). Figure 2.1 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).

TABLE 2.1 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).

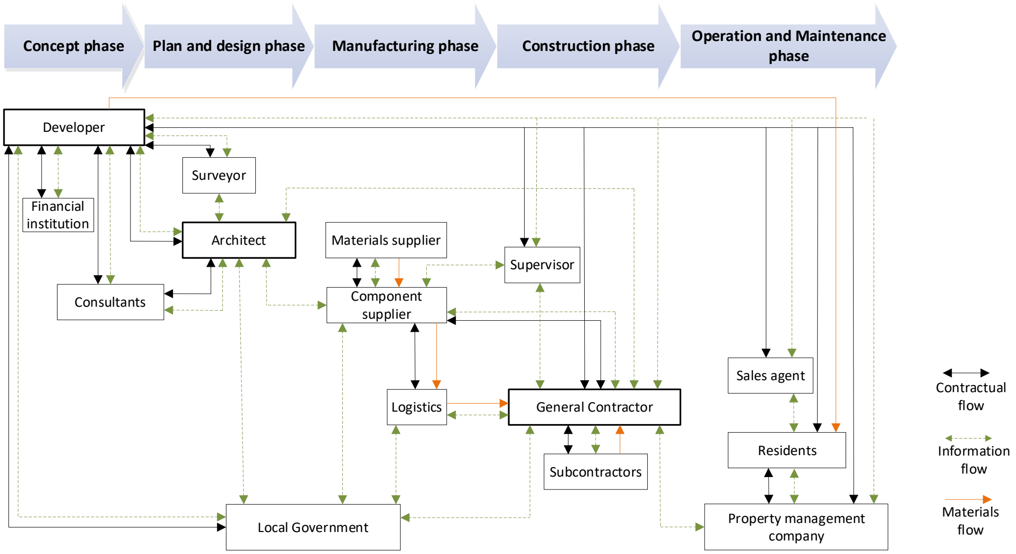

FIG. 2.1 DBB supply chain of PH in China (by the authors)

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 & 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 & 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 & 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 & Hewage, 2016). Larsson & 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).

2.2.2 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 & Chau, 1999), institutional governance (Lai & 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 & 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 2.2.

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).

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 & Sathaye, 2007).

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).

TABLE 2.2 TCs in the construction industry

Transaction Costs	References
1. Due diligence Costs	
Identifying the project	(Antinori & Sathaye, 2007)
Identifying project partners	(Kiss, 2016)
Consultations with stakeholders	(Rajeh et al, 2013)
Identification of customers	(Mundaca, 2007)
Prefeasibility study	(Antinori & 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 & Chau, 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.

2.2.3 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 2.3. Prefabrication represents a new mode of doing the transaction (Steinhardt & 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.

TABLE 2.3 Theoretical TCs framework in the PH supply chain

Phases		Sources of TCs	Content in PH projects	Sources	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 & Sathaye, 2007)		√
	2	Feasibility study	Solicit, review and select firms to work on the supplement, design, manufacture, construction, etc.	(Antinori & Sathaye, 2007)	√	
	3	Identify partners with PH experience	Costs for partners' identification are incurred by information searching and communication.	(Kamali & Hewage, 2016; Larsson & 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 & 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)	√	

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TABLE 2.3 Theoretical TCs framework in the PH supply chain

Phases		Sources of TCs	Content in PH projects	Sources	TCs in construction	Barriers
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 & 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 & 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 & Simonsson, 2012)		√

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TABLE 2.3 Theoretical TCs framework in the PH supply chain

Phases		Sources of TCs	Content in PH projects	Sources	TCs in construction	Barriers
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 & 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)		√

2.3 Methodology

The theoretical TCs framework formed the foundation for the empirical study. As shown in Figure 2.2, 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 understand the content and nature of TCs from different stakeholder perspective.

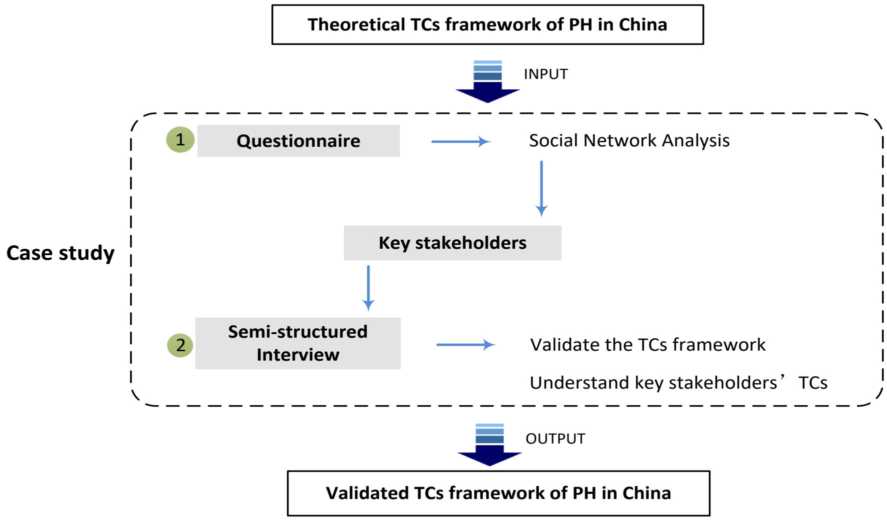

FIG. 2.2 Overview of the research design

2.3.1 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 & 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 Figure 2.3.

TOC

FIG. 2.3 Location of cases in Chongqing

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.

2.3.2 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.

2.3.3 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 2.4. 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.

TABLE 2.4 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

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?”

2.4 Data analysis and findings

2.4.1 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 inter-relationships 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 Figures 2.4 and 2.5. The network is non-directional and thus mutually symmetrical. The results of measures of degree centrality and betweenness centrality are displayed in Table 2.4.

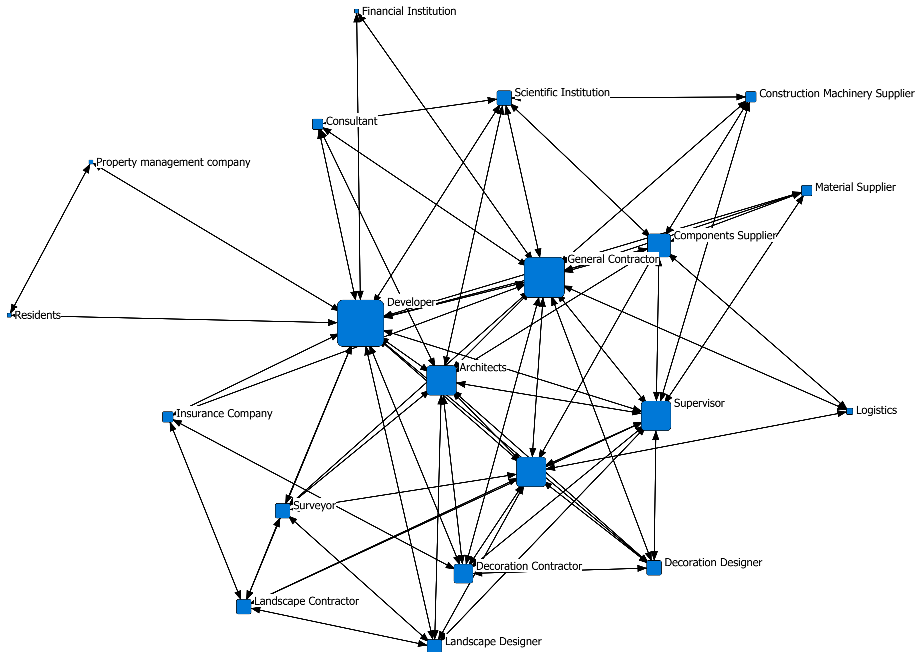

FIG. 2.4 Social Network (Centrality) of Stakeholders in Case A

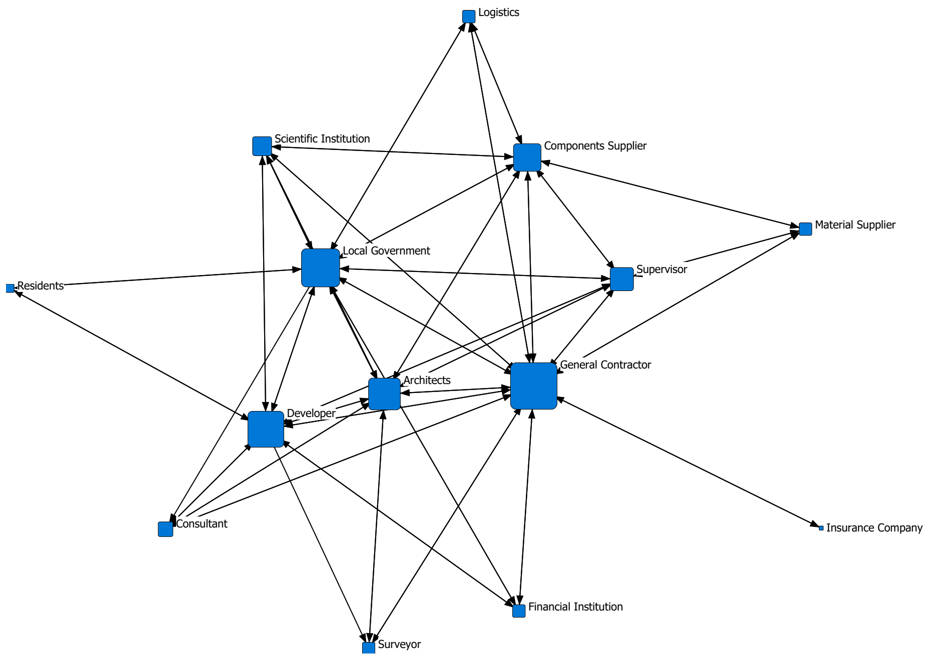

FIG. 2.5 Social Network (Centrality) of Stakeholders in Case B

TABLE 2.5 Results of Stakeholder Centrality Analysis

Case A			
No.	Stakeholders	Degree centrality	Betweenness centrality
1	Developer	17	58.95
2	General Contractor	15	30.02
3	Local Government	11	8.75
4	Architect	11	6.63
5	Supervisor	11	9.50
6	Components Supplier	9	6.12
7	Decoration Contractor	7	1.17
8	Scientific Institution	6	1.75
9	Decoration Designer	6	0.00
10	Landscape Designer	6	0.37
11	Landscape Contractor	6	1.50
12	Surveyor	6	0.60
13	Material Supplier	4	0.00
14	Construction Machinery Supplier	4	0.20
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

Case B			
No.	Stakeholders	Degree centrality	Betweenness centrality
1	General Contractor	12	56.43
2	Local Government	9	21.67
3	Developer	8	16.37
4	Architect	8	8.47
5	Components Supplier	7	6.13
6	Supervisor	6	3.53
7	Scientific Institution	5	0.40
8	Consultant	3	0.00
9	Financial Institution	4	0.00
10	Material Supplier	3	0.00
11	Logistics company	3	0.00
12	Surveyor	3	0.00
13	Residents	2	0.00
14	Insurance Company	1	0.00

As shown in Table 2.5, 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 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 government is so crucial in the stakeholder network.

2.4.2 Validated TCs framework for the PH supply chain

The validated TCs framework of PH projects in China is given in Table 2.6, with 33 items in total.

TABLE 2.6 Validated TCs Framework and Related Stakeholders

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

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

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.

2.4.3 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. 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 50-100 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

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).

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 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 sub-contractors 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 hours 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 mins 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 150km 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.

2.5 Discussion

2.5.1 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.

2.5.2 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 & 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 & 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.

2.5.3 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.

2.6 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 & 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 & 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.

2.7 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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3 Stakeholder perceptions of transaction costs (TCs) in prefabricated housing projects in China

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ABSTRACT Prefabrication promises to improve the efficiency and sustainability of housing production. However, there are various challenges in the realization of prefabricated housing (PH) from the stakeholders' perspective. Transaction cost (TCs) theory provides a particular angle that explains the invisible costs within transactions. This study aims to explore how perceptions of TCs vary for stakeholder groups and shows the potential to reduce TCs in China. The distribution of TCs related to stages and stakeholders was investigated by the literature study and validated by the expert interviews. Further, an existing framework of TCs was adopted to conduct a questionnaire survey for collecting perceptions of TCs from six stakeholder groups. The findings show that assembly, detailed design, and design change are the most highlighted TCs of PH. In particular, the component suppliers complained of TCs from the detailed design and hiring skilled labor. The local government emphasized TCs on monitoring and enforcement in assembly, architectural design, and component transportation. This research contributes to the construction management community by acknowledging stakeholders in understanding their TCs, which also inspires the policy-makers to reduce significant TCs to smooth transactions for the future of China's PH market.

KEYWORDS Prefabricated housing, Transaction costs, Stakeholder perceptions, Challenges, Construction

3.1 Introduction

From a social-economic perspective, the construction sector is one where energy and natural resources are primarily consumed (UNEP, 2003). Meanwhile, the construction sector in China continues to contribute a large percentage to the national gross domestic product. The focus of China's central government has been moved towards higher quality, innovative products, and established management processes (Wang & Yuan, 2011). Prefabrication is identified as a promising solution to achieve this target. Compared to traditional construction methods, prefabrication entails benefits such as accelerated construction, improved quality, decreased material waste, and reduced hazards (Arif & Egbu, 2010). Considering that prefabrication is nowadays mostly applied in the housing sector in China (Ji et al, 2017), this study specifically chose prefabricated housing (PH) as the research scope. PH generally refers to the practice of producing building components in a manufacturing factory, transporting complete components or semi-components to construction sites, and assembling the components to create residential buildings (Tam et al, 2007). This study adopts the latest definition of PH by the China authority: "Residential buildings that are assembled on-site using prefabricated components" (MOHURD, 2018). Based on the level of prefabrication, PH has been classified in the literature into four categories: 1) component manufacturing; 2) non-volumetric sub-assemblies; 3) volumetric sub-assemblies; and 4) modular buildings (Goodier & Gibb, 2007). Although the use of non-volumetric sub-assemblies is quite prevalent (Pan & Xiong, 2009), component manufacturing is still adopted as the mainstream in most projects in China.

PH has gained considerable attention and support from the Chinese government (Ji et al, 2017). Recently, the State Council of the People's Republic of China announced that the incentive policies for prefabrication would be enforced, such that prefabricated construction is expected to account for 30% of total construction within approximately ten years (GOSC, 2016). To achieve the expected diffusion of PH, numerous challenges need to be understood and to be overcome, such as higher capital costs (Xue et al, 2018a), new technologies, low process efficiency (Zhai et al, 2014), the lack of regulations (Mao et al, 2015), and so forth. The costs spending on overcoming challenges stemming from the attributes of the transactions in terms of asset specificity, frequency, and uncertainty are mostly transaction costs (TCs) (Williamson (1985).

TCs generally refer to costs of trade beyond the materials cost of the product, such as the costs of searching for projects, negotiation, monitoring, regulatory approval and dealing with any deviations from contract conditions (Antinori & Sathaye, 2007; Li et al, 2015). With a contribution to analyze and optimize the governance organization, TCs have gained considerable importance in research into the aspects of project management (Walker & Chau, 1999), institutional governance (Lai & Tang, 2016), procurement management (Carbonara et al, 2016), and policy management (Fan et al, 2018).

The occurrence of TCs contributes to the increase in total construction costs, which can also lead to disputes, delays, abandonment, and low efficiency in the supply chain. TCs commonly appear in the traditional construction industry (Li et al, 2015), while they are more noteworthy in the innovation industry because of the higher proportion. For instance, TCs of energy-efficient buildings have been estimated to be as high as 20% of the investment cost (Gooding & Gul, 2016). As an innovative industry in the construction sector, the implementation of PH is facing with high uncertainties, risks, and challenges, thus higher TCs. There are only a few studies available to understand the TCs of PH since TCs is a concept that has been newly applied in this context. According to Williamson (1985), the main founding father of TCs economic theory, actors involved in the transactions are one of the central determinants of TCs. Stakeholders are the main actors involved in the transactions, as well as the payers of TCs in most cases. High TCs do not only hinder the implementation of innovative technologies in the building sector but also prevent market stakeholders from entering the sustainable market (Qian et al, 2015). However, there have been very few attempts so far to investigate the TCs of PH. In response to this research gap, delivering a clear understanding of TCs for the stakeholders is of great necessity, which is also a key to implementing and promoting PH in China.

This study aims to articulate how key stakeholders perceive TCs in the practice of PH in China. The sub-research questions are 1) What are the important TCs in PH projects? 2) How do stakeholders perceive TCs from the perspective of their roles? And 3) What are the similarities and differences among key stakeholder groups about the perception of TCs in PH? It is so far unknown that the challenges in the PH process lie in the additional hidden costs, and these hidden costs have not been fully understood. The TCs theory can be provided with a unique lens to identify these hidden costs and how they relate to the stakeholders in the PH process. Once identified, it would help further investigate the potentials to reduce the TCs.

3.2 Literature review

3.2.1 Prefabricated Housing in China

PH was introduced to China in the 1950s to meet the massive housing demand (Wu et al, 2019a). In 1998, the Ministry of Housing Industrialization Promotion Centre was established to manage and implement the PH development in China (Ji et al., 2016). Recently, driven by sustainable development-a profound global challenge, there has been a growing interest from Chinese authority to promote PH. 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). However, even with strong motivation from the authority, the production of PH in China is still lagging far behind the developed countries and the local market demands. As of 2015, the prefabricated productivity in China can supply only 2% of the annual construction scale (Chang et al, 2018).

According to the four prefabrication levels defined by Goodier & Gibb (2007), component manufacturing is still adopted as the mainstream in most projects in China. The most commonly adopted precast components in China's PH market include precast laminated floor slabs, precast stairs, precast balcony slabs, and precast air-conditioning boards. Consideration has been given to extend prefabrication to entire kitchen assemblies and washrooms, as well as water tanks (Pan & Xiong, 2009). The structure of PH in China includes reinforced concrete (77.1% of the total gross floor area of PH) and steel structures, while wood construction is rarely applied (Ji et al, 2017). The development of a typical PH project in China mainly goes through five phases: 1) concept; 2) planning and design; 3) manufacturing; 4) construction and 5) operation and maintenance (Wu et al, 2019b).

Considering the new market and intense implementation pressure, stakeholders in China's PH industry are facing severe challenges. The new network, new cooperation, risks (Zhai et al, 2014), mismatching between the existing governance system and the new PH supply chain are all causing extra efforts, time, and costs and by this to higher TCs (Wu et al, 2019b). TCs contributes to the increase of the additional costs in PH. It was indicated that the cost of PH projects was 10%-20% higher compared to on-site construction in China (Mao et al, 2016).

3.2.2 Transaction costs in PH

According to Winch (1989), in an emerging field, where the environment is too complicated and uncertain, the ability to make rational decisions is limited or bounded, and TCs tend to be higher. TCs theory is helpful in that it provides a new lens to identify the hidden costs in the transaction process of PH.

In this study, TCs in the PH industry are defined explicitly as costs in terms of risks, time delay, information search, negotiation, contracting, organization set-up, monitoring, and enforcement (Wu et al, 2019b). TCs in China's construction market are even higher during its transformational period from traditional methods towards prefabrication (Sha, 2004). To understand the nature of TCs in PH, sources of TCs along the entire supply chain need to be thoroughly investigated. The current literature provides very little evidence on TCs in PH. Instead, knowledge of TCs in the general construction industry and challenges of PH were served as a pool to extract TCs for PH. This study adopted the TCs framework developed by Wu et al (2019b). Table 3.1 lists all sources of TCs in both traditional projects and PH projects, which shows the original 33 TCs along the entire process, split into the usual five phases of PH projects.

1 TCs that appear both in traditional projects and PH projects

As shown in Table 3.1, some sources of TCs in PH are the same as what they are in traditional projects, for instance, *Land surveying, Insurance, and contract signing.* Besides, some other TCs' resources are also common in traditional projects, such as the *Project Proposal*, *Feasibility Study*, *Decision-making*, *Land-bidding*, *Financing*, etc. However, the content of these TCs may be somehow different from what is in the traditional projects, which is because of the adoption of prefabrication. For instance, a feasibility study of PH is more complicated than it is in traditional projects, which is due to the different performance of PH on the aspects of technical, economic, and social influence. Therefore, to conduct a comprehensive feasibility study, costs arise for extra professional consultation. Besides, the land-bidding of PH projects consumes extra efforts of local governments by putting the requirement of adopting prefabrication in the bidding documents; and corresponding efforts have to be paid by tendering firms on considering prefabrication. Costs for permission and approval occur for the development of every regular project. At the same time, they appear to be more a burden in PH projects for both the firms and the authorities, because of the lengthy approval process and the professional requirements. Also, the detailed design of PH projects contains further considerations on components design. For example, incorporating different components together, in terms of lifting, transporting, placing on the foundation, and joining all parts together to form the building (O'Connor et al, 2015).

2 Special TCs for PH projects

Some sources of TCs are specific for PH projects, including Identifying Partners with PH Experience, Prefabrication Technical Solutions, Hiring Skilled Labor, Frequent Communication for Prefabrication, Components Quality Test, Components Transportation, etc. For example, the demand for machine-oriented skills, both on-site and in the factory, increases when adopting prefabrication. It will involve hiring skilled workers and local labor training (Chiang et al, 2006). Transportation of the prefab components is the task that connects the off-site manufacture and on-site construction, which is identified as a vital challenge that needs intensive coordination (Kamali & Hewage, 2016).

TABLE 3.1 Sources of TCs in conventional projects and PH projects

Code	Sources of TCs	TCs in conventional projects	TCs in PH projects	References for identifying TCs
TC_1	Project Proposal	Examine the project's financial, location, and environment reasonableness.	Extra consideration for the adoption of the prefabrication.	(Antinori & Sathaye, 2007; Kiss, 2016)
TC_2	Feasibility Study	Time, labor and effort spent on information collection and analysis.	More complicated due to the different performance of PH on the aspects of technical, economic, and social influence.	(Antinori & Sathaye, 2007)
TC_3	Identifying PH Experienced Partners	-	Looking for partners with experience in prefabrication.	(Kamali & Hewage, 2016; Larsson & Simonsson, 2012)
TC_4	Consultation	Looking for supports from the professionals.	Exploring special technical solutions for prefabrication.	(Mao et al, 2015)
TC_5	Learning	Time and efforts are devoted to collaboration with new partners, learning the new technology and digest new information.	Extra investment for learning knowledge about prefabrication.	(Wu et al, 2019b)
TC_6	Decision-making	Market analysis, discussion, and negotiation in the form of meetings.	Longer lead-in time for decision-making.	(Blismas et al, 2005)
TC_7	Land-bidding	Publishing the announcement for the bidding; Organizing the auction and the candidate evaluation.	Extra requirements about adopting prefabrication in the bidding documents; Corresponding efforts have to be paid by tendering firms on considering prefabrication.	(Buitelaar, 2004)
TC_8	Permission and Approval	Efforts to get the construction land-use planning permit and the land-use title certificate.	Efforts to meet the special requirements for prefabrication.	(Antinori & Sathaye, 2007; Qian et al, 2015)
TC_9	Financing	Filling out loan applications, discuss the project with lenders, review alternative loan terms, and respond to financial due diligence questions.	Evaluating the extra financial risk for the adoption of prefabrication.	(Antinori & Sathaye, 2007)
TC_{10}	Land Surveying	On-site surveying, information collection, and analysis	The same	(Buitelaar, 2004)
TC_{11}	Architectural Design	Labour and time spent on communication to conduct the design work.	More intensive pre-project planning and engineering are needed.	(Kamali & Hewage, 2016)
TC_{12}	Detailed Design	Time and effort on making the detailed construction scheme, including the optimization of the original design.	The complexity of modules' design; further considerations for incorporating different components.	(O'Connor et al, 2015)
TC_{13}	Design Consultation	Information searching and communication.	Extra consultation about the prefabrication.	(Mao et al, 2015)
TC_{14}	Procurement of the General Contractor	Calling for the bid, candidates evaluation, contract negotiating and signing.	More effort on identifying the general contractors who are able to implement assembly.	(Mao et al, 2015)

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TABLE 3.1 Sources of TCs in conventional projects and PH projects

Code	Sources of TCs	TCs in conventional projects	TCs in PH projects	References for identifying TCs
TC_{15}	Procurement of Subcon-tractors	Organizing the bidding, assessment of subcontractors, signing the contracts with subcontractors.	Additional efforts on looking for subcontractors with the ability for prefabrication.	(Kiss, 2016; Qian et al, 2015)
TC_{16}	Special Technical Solutions for Prefabrication	-	A particular technology scheme is needed when adopting prefabrication.	(Kiss, 2016; Qian et al, 2015)
TC_{17}	Setting up the Project Organization	Organization of project management, including hiring new workers, setting new institutions, and new offices.	Longer time to set up when people are not familiar with prefabrication.	(Qian et al, 2015)
TC_{18}	Hiring Skilled Labour	Time to searching and hiring skilled laborers.	Machine-oriented skills, both on-site and in the factory, increase when adopting prefabrication.	(Chiang et al, 2006)
TC_{19}	Frequent Communi-cation for Component Production	-	The effort on communication and cooperation is needed from all involved stakeholders to ensure product consistency.	(Kamali & Hewage, 2016)
TC_{20}	Production Supervision	-	Monitoring the manufacture in the factory.	(Mundaca, 2007)
TC_{21}	Component Quality test	-	Investment of time and labor to check the quality of prefab products.	(Mundaca, 2007)
TC_{22}	Components Transporta-tion	-	A task that connects the off-site manufacture and on-site construction, which needs intensive coordination among stakeholders.	(Kamali & Hewage, 2016)
TC_{23}	Risk of Delivery Early or Delay	-	The early components delivery causes extra costs from on-site protection. And the delay of components causes the delay of the construction period.	(Larsson & Simonsson, 2012)
TC_{24}	Labour Education	Training includes techniques skills, safety, management rules, etc.	Extra training about the techniques and management for prefabrication.	(Zhai et al, 2014)
TC_{25}	Insurance	Insurance associated with project risk, accident, and natural disaster.	The same	(Antinori & Sathaye, 2007)
TC_{26}	Monitoring Construction Activities	Including safety supervision, time control, and quality supervision for construction.	More attention needs to be paid on works about assembly in the whole construction.	(Kiss, 2016; Li et al, 2012; Mundaca T et al, 2013)
TC_{27}	Design Change	Workloads regarding redesign, negotiation, the arrangement of new construction.	Extra workloads may result from the reproduction of the components or molds.	(Tam et al, 2015)
TC_{28}	Dispute Solution	Mainly communication and labor costs arising from the dispute.	There are more chances that more stakeholders would be involved in the dispute in PH projects.	(Lu et al, 2015)

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TABLE 3.1 Sources of TCs in conventional projects and PH projects

Code	Sources of TCs	TCs in conventional projects	TCs in PH projects	References for identifying TCs
TC_{29}	Assembly	-	The assembly has higher requirements for the skills of on-site workers, which generates extra training costs and longer lead-in time.	(Wu et al, 2019b)
TC_{30}	Permission and Approval	Efforts to get the housing sale permit or Pre-sale permit.	It appears to be more burden in PH projects for both the firms and the authorities, because of the lengthy approval process and the professional requirements.	(Kiss, 2016; Mundaca T et al, 2013)
TC_{31}	Advertising	Efforts for advertising the new projects to the public, the authorities, and potential partners.	Advertising and promotion for prefabricated housings bring an additional burden on stakeholders.	(Wu et al, 2019b)
TC_{32}	Contract Signing	Prepare the contract; negotiate on the terms.	The same	(Mundaca, 2007)
TC_{33}	Taxation	Business Tax, City Maintenance and Construction Tax, Educational Surtax, Land Added Value Tax, Property Tax, Income tax, etc.	Sometimes can be less if there are economic support policies for PH	(Xue et al, 2018a)

3.2.3 Transaction costs of key stakeholders in PH

Prefabrication introduces a new way of doing transactions for construction projects, which poses several challenges to the involved stakeholders. As a project-based industry, PH involves many stakeholders, with each party being an independent entity chasing its own interests and playing different functional roles in the innovative process (Xue et al, 2018c). However, not all stakeholders can significantly influence the process efficiency of PH (Mettepenningen et al, 2011). A valuable perspective from which to understand the process of PH is that of the key stakeholders. Wu et al (2019b) identified six stakeholders in PH projects as the key stakeholders: developer, general contractor, local government, supervisor, architect, and components supplier. The definitions of key stakeholders in China's PH are given in Table 3.2.

Stakeholders are designated to perform different tasks throughout the PH supply chain. As such, they are facing particular challenges when they perform their tasks. In China, in which PH is still in its infancy, there are relatively more issues. After an analysis of the literature, Figure 3.1 summarizes how the key stakeholders are related to TCs in the PH development process.

TABLE 3.2 Definitions of key stakeholders in China's PH

Stakeholder	Definition
Developer	Who 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	Who is responsible for arranging the project timeline, the assembly, construction, and working with other stakeholders, including providing the adjusted technology proposal for architects.
Local Government	Who approves permits for new developments and monitors the production.
Architect	Who is responsible for preliminary design, final brief, and detailed design.
Supervision Company	Who guarantees the schedule, quality, and cost of the project on behalf of the client.
Components Supplier	Who produces prefab components or units according to the detailed design from the architect.

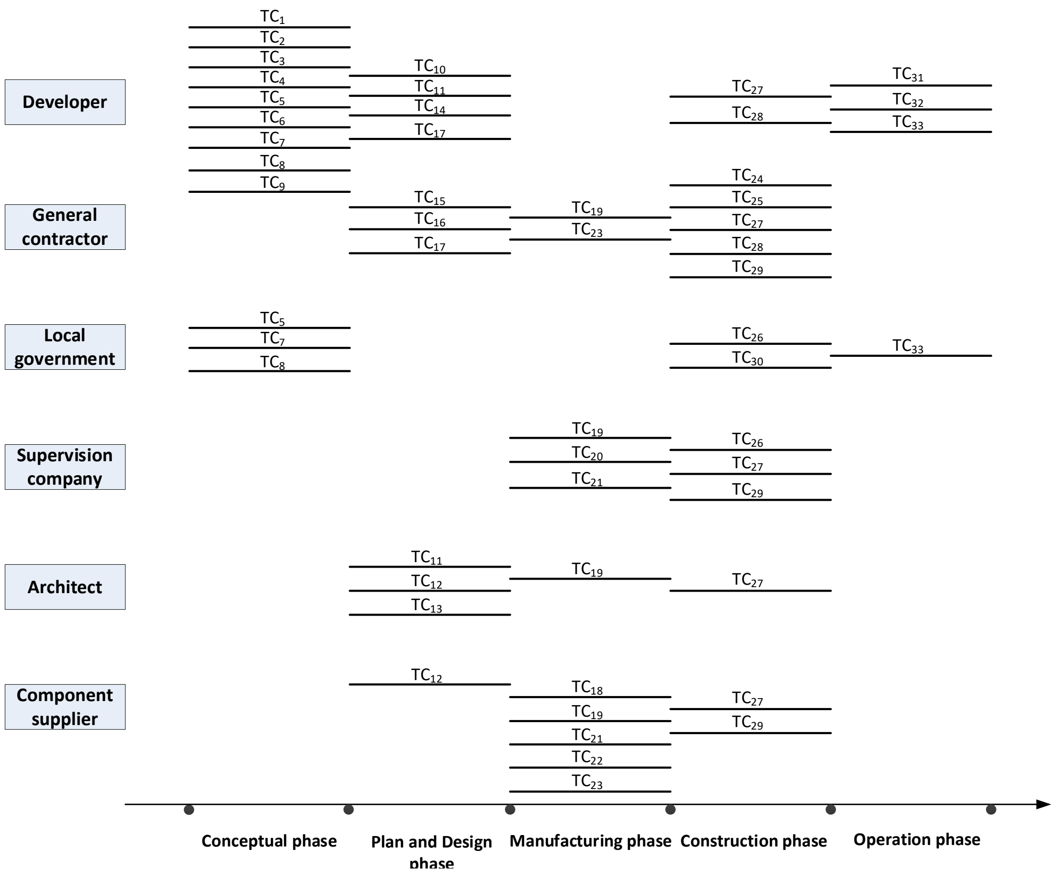

FIG. 3.1 TCs of key stakeholders in the supply chain of PH

TOC

For developers, most of their TCs arise at the early stage of the supply chain ((TC_1)- (TC_9)) according to their role of imitating projects. Specifically, the lack of availability of knowledgeable and experienced experts is a challenge, such as engineers and designers who have enough experience for prefabrication (TC_3) (Larsson & Simonsson, 2012). The long lead-in time for decision making (TC_6) is also recognized as a hindrance (Blismas et al, 2005; Goodier & Gibb, 2007). In the plan and design phase, developers are responsible for TCs such as the land bidding (TC_7), general contractor procurement (TC_{14}), permission application (TC_8), etc. (Wu et al, 2019b). TCs related to the developers also appear in the construction phase, arising from the design change (TC_{27}) (Tam et al, 2015) and dispute (TC_{28}) (Lu et al, 2015). In the operation phase, as the sponsor and owner in many cases in China, developers are responsible for TCs from advertising (TC_{31}) (Wu et al, 2019b), contract signing (TC_{32}) (Mundaca, 2007), and taxation (TC_{33}) (Xue et al, 2018b)

TCs related to general contractors are typically occurring in the construction phase. Qian et al (2015) identified procuring professional sub-contractors (TC_{15}) and setting up the project organization (TC_{17}) as the sources of TCs. Hong et al (2018) pointed out that additional miscellaneous works such as hiring highly-skilled workers (TC_{24}), design changes (TC_{27}), and logistic processes (TC_{23}) are significant contributors to the rising cost in PH. Besides, general contractors are the main stakeholder for executing the assembly (TC_{29}) (Wu et al, 2019b). Extra time and costs may arising from the disputes (TC_{28}) in the construction process (Lu et al, 2015).

The most common TCs for the local governments are the costs of permits and monitoring. In the concept phase, Buitelaar (2004) expounded that TCs from land-bidding (TC_7) are generated by publishing the announcement, organizing the auction, and evaluating the candidate. Kiss (2016) stated that some TCs are from monitoring and enforcement in the field of technology change. In PH projects, the local governments are highly involved in the manufacturing and construction work (TC_{26}), while there are permits approvals (TC_{30}), production monitoring, quality assessment, etc. (Jiang et al, 2019).

The responsibilities of the supervision companies in PH projects mainly include factory supervision (TC_{20}) and site supervision (TC_{26}) (Wu et al, 2019b). To ensure strict quality control on prefabrication, they do quality detection for both the raw materials and prefabricated components (TC_{21}). Their responsibilities also include monitoring the assembly process (TC_{29}) and supervising the final building acceptance (Tam et al, 2007).

For the architects, intensive pre-project planning and engineering are believed as significant challenges for the architectural design (TC_{11}), (TC_{13}) (Kamali & Hewage, 2016). The detailed design (TC_{12}) of PH considers the feasibility, which should be convincing for the following work, such as manufacturing, transportation, lift, and assembly. Additionally, architects can also be severely affected by the design change (TC_{27}). As stated by Tam et al (2015), the inflexibility for design changes is one of the most severe hindrances in PH projects.

Component suppliers, in their new role in a construction project, mostly participate in the manufacturing phase. To enlarge the market scale, they pay much effort into understanding the design plan (TC_{12}), training their labor (TC_{18}), and technology exploration on the quality test. Besides, there is intensive communication in the component manufacturing stage (TC_{19}) due to the high requirements for consistency in PH projects (Tam et al, 2015). Apart from this, transportation is also a vital challenge (TC_{22}). In addition to their knowledge of general transportation regulations, they also need to liaise for special traffic control for heavy and bulky modules, so that additional labor training is also an extra burden (Chiang et al, 2006; Kamali & Hewage, 2016).

Although the previous studies have tried to analyze the challenges of PH, none of them attempted to explore the perceptual consensus or differences of stakeholders about TCs. TCs are generated in the transaction process and originate from the behavior of stakeholders (Williamson, 1985). Stakeholder perceptions of TCs, therefore, have a tremendous determinate effect on project efficiency. The use of perceptions is also theoretically consistent with the concept of bounded rationality in the TCs theory, which refers to human behavior that is intentionally rational but only to a limited extent (Simon, 1978). Because of the importance of perceptions regarding TCs, some studies use this instead of real TCs measurements (see, e.g. (Badstue, 2004; Brockhoff, 1992)).

3.3 Methodology

In order to elicit the opinion of professionals about TCs in PH projects, both qualitative and quantitative approaches are employed. Semi-structured interviews are conducted to validate Figure 3.2 for understanding how TCs appear at different phases and are related to different stakeholders. It also obtained professional opinions from different stakeholders on recognizing their critical TCs, which provides practical evidence on explaining the results of the subsequent questionnaire survey. The questionnaire survey is then adopted to evaluate the importance level of TCs and to understand stakeholders' perceptions of TCs. The overview of the methodology is given in Figure 3.2.

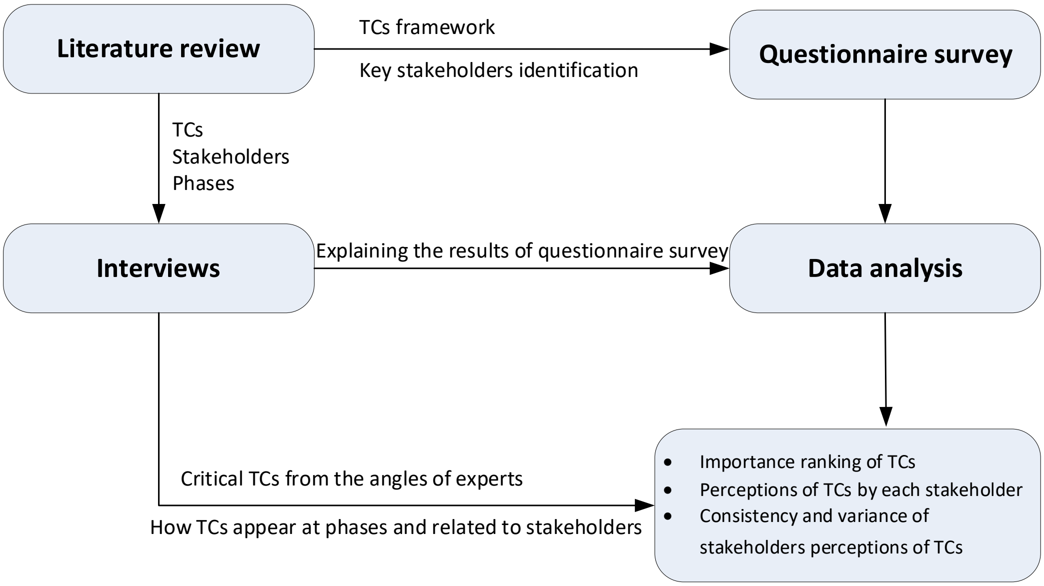

FIG. 3.2 Overview of the research process

Chongqing was selected as the study area. Chongqing is a representative city to show the present situation of PH in most Chinese cities. First, Chongqing is playing a vital economic and political role in China. As the newest one of the four municipalities under the direct governance of China Central Government, Chongqing plays an essential and strategic role in Western China. The urbanization rate of Chongqing is expected to rise from 60.9 percent in 2015 to above 75 percent by 2030, according to the Population Development Plan of Chongqing City (2016–2030) (Gan et al, 2019). Rapid urbanization and economic development have put Chongqing in a favorable situation to promote PH adoption. Second, there is a vase potential PH market in Chongqing. With over 33 million m^2 completed floor space of residential buildings in 2017, Chongqing plays a significant role in the housing construction market in China (Statistics, 2018). In a transforming stage from traditional on-site construction to off-site prefabrication, stakeholders in Chongqing will notice the problems and challenges to the construction market. Third, Chongqing reflects the average level of PH application in China cities. Dou et al (2019) scored the development level of PH in 31 provinces in China; Chongqing was scored at 3.2, which is the closest to the average level (3.1). Therefore, studies about PH in Chongqing help to give a relatively objective understanding of PH practice in China.

3.3.1 Semi-structured interviews

Semi-structured interviews were used to understand how TCs appear at different phases and related to different stakeholders, while professionals' opinions from different stakeholders are given to recognize their critical TCs. The respondents selected have a management-level position and extensive practical experience with PH. Their senior profile ensures that they have a sophisticated understanding of the whole supply chain. In total, twenty-five respondents were interviewed as representatives of key stakeholders in PH. The profiles of the interviewees are shown in Table 3.3. The interview was conducted separately, to reflect on the respondents' perceptions of the TCs impact from their past experiences.

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TABLE 3.3 Profiles of Interviewees

Stakeholder	Position	Profile
Local Government	Section Director	Municipal Commission of Urban-Rural Development
	Director	Construction Technology Development Center
	Technical engineer	Construction Industry Modernization Department
	Section manager	Municipal Commission of Urban-Rural Development
Developer	Senior engineer	Real Estate Company
	Operation Manager	Real Estate Company
	Manager	Department of investment and development, Real Estate Company
	Quantity Surveyor	Real Estate Company
	Architect	Local District Development Group
	Quantity Surveyor	Local District Development Group
	Quantity Surveyor	Local District Development Group
	Engineer	Local District Development Group
General contractor	Construction engineer	Construction Engineering Company
	Project Manager	Construction Engineering Company
	Project Manager	Construction Engineering Company
	Quantity Surveyor	Construction Engineering Company
Component supplier	Manufacturing Manager	Precast concrete Components Company
	Senior manager	Precast concrete Components Company
	Architect	Construction High-tech Building Material Company
	Production manager	Construction High-tech Building Material Company
Architect	Design director	Design Company
	Researcher	Design Company
	Designer	Design and Research Institute of Construction Engineering Group
Supervisor	Chief supervision engineer	Engineering Supervision Company
	Supervision engineer	Engineering Construction Supervision Company

3.3.2 Questionnaire survey

The purpose of the questionnaire survey was to determine the importance of TCs items and to find potential conflicts or areas of agreement among key stakeholder groups. The questionnaire survey was conducted in Chongqing, China, from September 28 to November 20, 2017. Accordingly, 400 questionnaires were distributed via hard copy, email, and through the professional online questionnaire platform www.sojump.com. A process of “snowball” or referral sampling was used, which was particularly useful in surveying on-site managers who were generally more difficult to identify and contact. A valid response rate of 25% was determined from the 154 questionnaires returned. After data checking, 110 completed-questionnaires were believed as valid and trustable to support the data analysis. The Cronbach's Alpha was 0.895, indicating that the questionnaire adopted has a high level of internal consistency and thus very reliable.

1 Questionnaire design

The questionnaire included two sections. In the first section, we asked the respondents to provide their professional backgrounds, including their education, position, years of working experience, and the enterprise type. The second section constituted the main body of the questionnaire. It required each respondent to choose his/her perceived importance ratings of the 33 variables from 1 (extremely unimportant) to 5 (extremely important), based on their experience.

2 Data descriptions

Table 3.4 provides details of the respondents who participated in this survey, including their gender, age, education, year of experience in construction, and PH. It also shows the sample distribution among the six stakeholder groups. Most of the respondents were male (85.45%), which is reasonable due to the unique characteristics of the construction industry. Besides, the respondents' age between 21-40 years-old account for 96.36% of the whole. Overall, 80.91% of the respondents were with educational attainment at a Bachelor's degree or higher level, which explains the credibility of the data. It is interesting to notice that 75.45% of the respondents had experience in the construction industry for more than three years, while 12.73% of them even had experience longer than ten years. However, at the same time, few of the respondents (3.64%) had experience in PH for longer than three years. It reflected that the PH market in Chongqing is still in a quite initial stage of development.

TABLE 3.4 Sample characteristics

		De	GC	LG	Ar	SC	CS	Frequency	Percentage (%)
Gender	Male	25	21	11	11	15	11	94	85.45
	female	5	4	3	2	1	1	16	14.55
Age	21-30	21	15	10	8	10	4	68	61.82
	31-40	8	8	5	5	5	7	38	34.55
	41-50	1	2	0	0	0	1	4	3.64
Education	Junior college	3	7	0	0	8	3	21	19.09
	Bachelor	18	17	6	1	7	6	55	50.00
	Master	9	1	9	11	0	3	33	30.00
	Doctor	0	0	0	1	0	0	1	0.91
Year in construction	0-3	8	4	5	6	3	0	27	24.55
	3-5	12	9	7	2	5	6	39	35.45
	5-10	8	6	3	4	5	3	29	36.36
	>10	2	6	0	1	2	3	14	12.73
Year in PH	0-1	17	14	6	3	8	3	50	45.45
	1-3	13	11	9	10	7	5	56	50.91
	3-5	0	0	0	0	0	1	1	0.91
	>5	0	0	0	0	0	3	3	2.73
Total		30	25	15	13	15	12	110	
		27.27%	22.73%	13.64%	11.81%	13.64%	10.91%		100%

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

3.4 Results and findings

3.4.1 Results from the interviews

By reviewing Figure 3.1, the interviewees gave their opinions on the TCs and related stakeholders in the transaction process of PH. Generally, they agree with the proposed mapping of TCs. It is worth noticing that the learning costs (TC5) were confirmed mostly in the conceptual phase by the interviewees. Firms with less experience have high learning costs because they need to switch their work to adapt to the prefabrication mode. A director from the Local Municipal Commission of Urban-Rural Development pointed out that all most all stakeholders have to pay for learning, while some of these costs are calculated in the projects, and some are invisible and ignored. In addition, *Assembly* (TC_{29}) got great attention from the industry in the construction phase. TCs from the assembly are known by the interviewed stakeholders as needed high initial investments, extra training costs of workers, longer lead-in times, risks of mistakes and reworks, etc. The on-site assembly is a challenging task mainly to the general contractors, while the other key stakeholders have all mentioned their extra effort in it as well.

The second purpose of interviews was to collect opinions from the experienced experts about how they perceive high TCs from the role of their firms. In the interviews with developers, managers highlighted their extra efforts on learning and permission application. The quantity surveyors emphasized their learning costs in doing a feasibility study, for instance, costs related to professional training sessions and learning new regulations. General contractors expounded their challenges in the procurement of subcontractors, design change, and assembly. The architect complained about the invisible efforts on communication from cooperation and negotiation. It was not surprising that the participants from the local government emphasized the costs for monitoring and promotion, while the supervision company mentioned extra costs on manufacturing supervision.

3.4.2 General importance ranking of TCs from the questionnaire survey

With the data acquired from the questionnaire, we performed a ranking analysis to identify the important TCs. Several descriptive statistical analyses were applied, such as average and standard deviation. The Statistical Package for Social Sciences (SPSS) version 24.0 was used to perform statistical analysis.

As presented in Table 3.5, *Assembly* (TC_{29}), *Detailed Design* (TC_{12}), and *Design Change* (TC_{27}) are the top three significant sources of TCs in PH. *Assembly* (TC_{29}) is a procedure that does not exist in traditional construction projects. Being identified as the second most important source of TCs, *Detailed Design* (TC_{12}) for PH projects is more complicated than it is in traditional projects. In addition to the complexity of the component design itself, further considerations are needed when incorporating different components together, for example, when they are lifted, transported, placed on the foundation, and joined to form the building (O'Connor et al, 2015). Additionally, another primary source of TCs is *Design Changes* (TC_{27}), which may lead to the redesign, reconstruction, or even changing the molds for components. In most cases, design changes could bring damage to the interests of all parties (Section manager of the Municipal Commission of Urban-Rural Development).

TABLE 3.5 General importance ranking of TCs

	Sources of TCs	Mean	SD	Rank
TC_1	Project Proposal	2.54	1.18	23
TC_2	Feasibility Study	2.73	1.07	22
TC_3	Identifying Experienced Partners	3.13	1.03	13
TC_4	Consultation	2.83	1.15	19
TC_5	Learning	3.18	0.98	12
TC_6	Decision-making	2.79	0.95	20
TC_7	Land-bidding	2.49	1.21	26
TC_8	Permission and Approval	2.53	1.18	25
TC_9	Finanacing	2.42	1.14	29
TC_{10}	Land Surveying	1.83	0.89	33
TC_{11}	Architectural Design	3.13	1.14	14
TC_{12}	Detailed Design	3.51	0.94	3
TC_{13}	Design Consultation	2.91	1.04	17
TC_{14}	Procurement of the General Contractor	2.37	1.08	30
TC_{15}	Procurement of Subcontractors	3.00	0.85	15
TC_{16}	Special Technical Solution for Prefabrication	3.26	0.95	9
TC_{17}	Setting up the Project Organization	2.79	1.00	21
TC_{18}	Hiring Skilled Labour	3.38	0.87	5
TC_{19}	Frequent Communication for Component Production	3.38	0.95	6
TC_{20}	Production Supervision	3.28	0.90	8
TC_{21}	Component Quality Test	3.24	0.88	11
TC_{22}	Components Transportation	3.44	1.05	4
TC_{23}	Risk of Delivery Early or Delay	3.25	0.99	10
TC_{24}	Labour Education	2.97	1.01	16
TC_{25}	Insurance	2.45	0.98	27
TC_{26}	Monitoring of Construction Activities	2.86	1.07	18
TC_{27}	Design Change	3.54	0.91	2
TC_{28}	Dispute Solution	3.30	1.02	7
TC_{29}	Assembly	3.74	0.97	1
TC_{30}	Permission and Approval	2.54	0.97	24
TC_{31}	Advertising	2.24	1.02	31
TC_{32}	Contract Signing	2.17	1.00	32
TC_{33}	Taxation	2.45	1.08	28

3.4.3 Perceptions of TCs for the Six Stakeholder groups

We calculated the mean and standard deviation of each variable to represent its level of importance to each of the six different stakeholder groups. Table 3.6 shows the ranking results of the 33 variables.

TABLE 3.6 Mean Scores of TCs of stakeholder groups in PH

Source of TCs		Developer		General contractor	
		Mean	Rank	Mean	Rank
TC_{1}	Project Proposal	2.70	26	2.67	20
TC_{2}	Feasibility Study	2.63	28	2.00	27
TC_{3}	Identifying Experienced Partners	3.48	6	3.00	6
TC_{4}	Consultation	2.78	23	2.33	24
TC_{5}	Learning	3.07	16	3.00	6
TC_{6}	Decision-making	2.85	20	2.00	27
TC_{7}	Land-bidding	2.85	20	3.00	6
TC_{8}	Permission and Approval	2.85	20	2.67	20
TC_{9}	Financing	2.74	25	3.00	6
TC_{10}	Land Surveying	2.03	34	1.67	31
TC_{11}	Architectural Design	2.90	18	2.75	18
TC_{12}	Detailed Design	3.31	10	3.11	5
TC_{13}	Design Consultation	2.69	27	2.17	26
TC_{14}	Procurement of General Contractor	2.48	31	2.00	27
TC_{15}	Procurement of Subcontractors	3.24	12	3.17	4
TC_{16}	Special Technical Solution for Prefabrication	3.17	14	3.00	6
TC_{17}	Setting up the project organization	2.97	17	2.90	14
TC_{18}	Hiring Skilled Labour	3.37	8	3.41	2
TC_{19}	Frequent Communication for Component Production	3.53	4	3.00	6
TC_{20}	Production Supervision	3.27	11	2.94	13
TC_{21}	Component Quality Test	3.43	7	2.78	17
TC_{22}	Components Transportation	3.67	3	3.00	6
TC_{23}	Risk of Delivery Early or Delay	3.50	5	2.82	16
TC_{24}	Labour Education	3.20	13	2.83	15
TC_{25}	Insurance	2.57	29	2.18	25
TC_{26}	Monitoring Construction Activities	3.14	15	2.40	22
TC_{27}	Design Change	3.69	2	3.22	3
TC_{28}	Dispute Solution	3.34	9	2.71	19
TC_{29}	Assembly	3.72	1	3.48	1
TC_{30}	Permission and Approval	2.86	19	2.00	27
TC_{31}	Advertising	2.37	33	1.60	32
TC_{32}	Contract Signing	2.41	32	1.60	32
TC_{33}	Taxation	2.52	30	2.40	22

Local government		Architect		Supervision company		Component supplier	
Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
1.79	28	3.00	19	1.40	26	3.25	15
2.62	21	3.69	8	1.43	25	3.00	23
3.00	15	3.46	14	1.71	22	2.88	29
2.46	24	3.62	13	1.60	23	3.25	15
2.77	19	3.92	5	2.67	13	3.50	5
2.77	19	3.38	16	1.50	24	3.00	23
1.93	27	2.54	28	1.00	29	2.75	32
1.71	29	2.77	23	1.00	29	3.38	10
1.42	31	2.92	20	1.00	29	2.71	34
1.36	34	1.62	34	1.00	29	2.75	32
3.80	2	3.23	18	2.50	14	3.17	20
3.67	4	3.92	5	3.00	7	4.17	1
3.00	15	3.69	8	2.17	19	3.38	10
2.00	26	2.62	27	1.00	29	3.13	21
3.00	15	2.38	31	2.50	14	3.38	10
3.13	14	3.69	8	3.14	6	3.50	5
2.43	25	2.77	23	2.00	21	3.25	15
3.23	12	3.46	14	3.00	7	3.83	2
3.57	5	4.08	3	2.69	12	3.33	13
3.29	7	3.69	8	3.40	2	3.13	21
3.21	13	3.69	8	3.27	3	3.00	23
3.71	3	3.77	7	2.93	9	3.42	8
3.57	5	3.38	17	2.86	11	3.33	13
3.25	10	2.69	25	2.27	18	3.58	4
2.56	22	2.23	33	2.45	16	3.00	23
3.29	7	2.54	28	2.87	10	2.82	31
3.25	10	4.23	2	3.20	4	3.75	3
3.27	9	4.00	4	3.20	4	3.50	5
4.00	1	4.38	1	3.67	1	3.42	8
2.55	23	2.85	21	2.15	20	2.88	29
1.44	30	2.46	30	1.25	27	3.25	15
1.38	32	2.31	32	1.00	29	3.00	23
1.38	32	2.85	21	1.25	27	3.25	15

As shown in Table 3.6, the developers scored highest on *Assembly* (TC_{29}) and *Design Change* (TC_{27}). *Assembly* is identified as a significant cause of additional costs by developers; Transforming from traditional work to manufacturing and assembly poses immense pressure on developers' initial investment. Besides, developers believe that *Design Changes* (TC_{27}) give rise to hidden losses, which are mainly reflected in decline in the reputation of developers and the reduced willingness of other stakeholders to cooperate with them subsequently. It was told that even in total fixed-price contracts, design changes sometimes might bring more losses to the contractors than to the developer. However, the reputation damage to developers is irreversible.

Assembly (TC_{29}), *Hiring Skilled Labor* (TC_{18}), and *Design Change* (TC_{27}) are the top three crucial TCs to general contractors. Technically, the assembly of components has higher requirements for workers' skills than traditional on-site work. It, therefore, generates extra training costs for workers and lead-in times. *Hiring Skilled Labor* (TC_{18}) for manufacturing ranks second. It may because general contractors are mostly responsible for supplying components in China. Besides, the impact of *Design Changes* (TC_{27}) is more severe than in PH projects than in traditional construction projects. Sometimes, the molds for components are even needed to be changed due to the changes in the original design.

From the perspective of the local governments, *Assembly* (TC_{29}), *Architectural Design* (TC_{11}), and *Component Transportation* (TC_{22}) are the top 3 critical sources of TCs. The local government does not directly participate in the *Assembly* (TC_{29}). They are responsible for monitoring the assembly, including the tower crane work, safety, quality inspection, and spot checks of environmental protection measures. Besides, the local governments perceive *Architectural Design* (TC_{11}) is a difficult task based on the experience of approval for a PH design scheme. *Component Transportation* (TC_{22}) is ranked in third place for the local government, whereas extra staff and time are devoted to regulation-making, application approval, and regulation enforcement.

For the architects, *Assembly* (TC_{29}), *Design Change* (TC_{27}), and *Communication During Component Manufacturing* (TC_{19}) are the most important TCs. Following the opinions of the interviewees, architects are more involved in the production and construction process in PH, compared with traditional projects. Yet their experience is usually in design, which explains why architects have great difficulty with the activities in the production rather than in the design phase.

It is not surprising that supervision companies also gave the greatest concern on *Assembly* (TC_{29}) because it is a task that they are not familiar with the process.

Components Production Supervision (TC_{20}) and *Components Quality Test* (TC_{21}) are also perceived as the most massive extra workloads by supervision companies.

As a new stakeholder role in construction projects, component suppliers evaluate the difficulty of the activities without comparing with traditional projects but based their views on their perceptions of production activities. Although *Detailed Design* (TC_{12}) is initially the responsibility of the architects, component suppliers have to participate in it because the design of components in China is not mature yet and so they need to complete this work together. Additionally, *Hiring Skilled Labor* (TC_{18}) and *Design Changes* (TC_{27}) are also identified as high TCs sources by the component suppliers.

3.4.4 Consistency and variance of stakeholder perceptions of TCs

Scores on TCs were treated as continuous data, and Analysis of Variance (ANOVA) was used to ascertain if various respondent groups had consistent opinions or not. ANOVA is a collection of statistical models, pioneered by Fisher, which can be used to analyze the differences between group means and their associated procedures (Fisher, 1992). If a probability value P from an ANOVA test is below 0.05, it suggests that there is a high degree of difference in the opinion among groups. ANOVA has been applied as an effective method to understand TCs. Adhikari & Lovett (2006) analyzed the variation of TCs for different income groups in natural resource management. Chomchaiya & Esichaikul (2016) developed a framework for government e-procurement performance measurement by using ANOVA.

In this study, three steps pre-checking were prepared before the ANOVA analysis. Firstly, the data distribution has been tested for each stakeholder group. ANOVA is valid to apply, although, within six groups, not all variables are normally distributed (Blanca et al, 2017). Secondly, we did the power check of the sample size. According to the widely used rule (Lan & Lian, 2010), the required sample of each group should be above 10, which is met in this survey. Thirdly, we checked the homogeneity of the data to consider the variables in one-way ANOVA.

The results of the Homogeneity Test reveal that there are three variables with p-values below 0.05 - TC_9, TC_{14}, and TC_{32}. They cannot be included in one-way ANOVA because the variances of these three items are unequal. Then, one-way ANOVA and the post-hoc test for the remaining 30 sources of TCs was conducted, considering the stakeholders' group identity (Table 3.7).

TABLE 3.7 Analysis result of ANOVA and Post-hoc test

Source of TCs		Between Groups		Within Groups		F	Sig.	Post-hoc Gabriel test
		Sum of Squares	df.	Sum of Squares	df			P<0.05
TC_{1}	Project Proposal	22.018	5	73.353	64	3.842	0.004	CS>LG; CS>SC
TC_{2}	Feasibility Study	26.664	5	55.857	67	6.397	0.000	Ar>De; Ar>SC; GC>Ar; CS>SC
TC_{3}	Identifying Experienced partners	19.584	5	54.275	65	4.691	0.001	De>SC; Ar>SC; LG>SC
TC_{4}	Consultation	19.572	5	70.341	63	3.506	0.007	Ar>SC
TC_{5}	Learning	12.204	5	54.416	65	2.915	0.020	Ar>LG
TC_{6}	Decision-making	17.539	5	46.292	65	4.925	0.001	De>SC; Ar>SC; LG>SC; CS>SC
TC_{7}	Land-bidding	18.180	5	81.067	63	2.826	0.023	De>SC
TC_{8}	Permission and Approval	30.329	5	65.114	64	5.962	0.000	De>LG; De>SC ; CS>LG; Ar>CS CS>SC
TC_{10}	Land Surveying	14.548	5	41.423	65	4.566	0.001	CS>LG; CS>Ar; CS>SC
TC_{11}	Architectural Design	11.420	5	89.314	73	1.867	0.111*	
TC_{12}	Detailed Design	13.340	5	69.908	87	3.320	0.009	CS>GC
TC_{13}	Design Consultation	17.837	5	62.518	70	3.994	0.003	Ar>De; Ar>LG; Ar>SC
TC_{15}	Procurement of Subcontractors	9.404	5	44.596	70	2.952	0.018	De>Ar
TC_{16}	Special Technical Solution for Prefabrication	4.124	5	69.498	76	0.902	0.484*	
TC_{17}	Setting up the Project Organization	8.286	5	71.102	74	1.725	0.139*	
TC_{18}	Hiring Skilled Labour	4.741	5	68.289	92	1.277	0.280*	
TC_{19}	Frequent Communication for Component Production	16.449	5	73.254	95	4.266	0.002	Ar>GC; Ar>SC
TC_{20}	Production Supervision	4.501	5	72.906	90	1.111	0.360*	
TC_{21}	Component Quality Test	8.349	5	70.004	96	2.290	0.052*	
TC_{22}	Components Transportation	10.963	5	97.677	94	2.110	0.071*	
TC_{23}	Risk of Delivery Early or Delay	9.903	5	91.659	99	2.139	0.067*	
TC_{24}	Labour Education	15.941	5	90.974	99	3.469	0.006	De>SC; CS>SC
TC_{25}	Insurance	5.136	5	83.897	87	1.065	0.385*	
TC_{26}	Monitoring Construction Activities	10.373	5	105.706	96	1.884	0.104*	
TC_{27}	Design Change	12.519	5	73.328	98	3.346	0.008	Ar>GC; Ar>SC
TC_{28}	Dispute Solution	14.137	5	88.953	95	3.020	0.014	Ar>GC

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TABLE 3.7 Analysis result of ANOVA and Post-hoc test

Source of TCs		Between Groups		Within Groups		F	Sig.	Post-hoc Gabriel test
		Sum of Squares	df.	Sum of Squares	df			P<0.05
TC_{29}	Assembly	9.244	5	89.360	100	2.069	0.076*	
TC_{30}	Permission and Approval	12.895	5	74.435	88	3.049	0.014	De>GC
TC_{31}	Advertising	20.922	5	47.199	60	5.319	0.000	CS>GC; CS>LG; CS>SC
TC_{33}	Taxation	22.303	5	51.758	59	5.085	0.001	De>LG; Ar>LG; Ar>SC; CS>LG; CS>SC

**= p>0.05*
- = Statistical non-significant

The ANOVA test results indicated that there were statistically non-significant differences (P>=0.05) between stakeholder groups for twelve of the thirty-three TCs. Among them, the mean scores of *Propose Special Technical Solutions for Prefabrication* (TC_{16}), *Insurance* (TC_{25}), and *Production Supervision* (TC_{20}) have the lowest F values. It means they received the most consistent opinions among all stakeholder groups. Besides, it is noticeable that consistent perceptions are appeared about six out of the nine of stakeholders' crucial TCs (P<0.05): *Architectural Design* (TC_{11}), *Hiring Skilled Labor* (TC_{18}), *Components Production Supervision* (TC_{20}) and *Components Quality Test* (TC_{21}), *Component Transportation* (TC_{22}) and *Assembly* (TC_{29}). Generally, stakeholders all believe that new tasks bring challenges to them while they are all directly or indirectly involved in them. For instance, the perceptions of *Assembly* (TC_{29}) among stakeholders are rather consistent. Moreover, although *Architectural Design* (TC_{11}) is performed by the architects, the other stakeholders also believe that the addition of innovative prefabrication technology brings extra difficulties to this task.

In addition to pointing to a consensus in the ranking of TCs in PH, there are differences between the mean perceptions of respondents from different stakeholder groups. The remaining 18 variables are analyzed by the post-hoc multiple comparisons. The Gabriel post hoc test is applied due to the unequal sample sizes of the six stakeholder groups in this study (Field, 2018). Table 3.7 gives the results of the Gabriel Post Hoc test, showing that the 18 variables with at least one pair of stakeholder groups differ significantly from each other (P<0.05). Three key TCs identified by stakeholders are on the list of these 18 variables.

Detailed Design (TC_{12}) CS>GC

The results show that the perceptions of TCs from the detailed design stage are significantly different between the component supplier and the general contractor. The component suppliers remarked it as the most critical source of TCs (mean=4.17). Interviewees from the component suppliers pointed out that they have to be actively involved in the work of detailed design, not only because it could be a way to improve their reputation and to promote their business but also due to the lack of experienced architects.

Frequent Communication for Component Production (TC_{19}) Ar>GC Ar>SC

TC_{19} received considerable attention from all key stakeholders (mean>3.0). The pair-comparison reflects that there are differences in the perceptions between the architects and general contractors, architects, and the supervision company. Compared to the general contractors and the supervision companies, more effort on communication and cooperation has been needed from the side of the architects. Interviewees also claimed that intensive meetings for the production of the components had become a burden to the architects.

Design Change (TC_{27}) Ar>GC Ar>SC

Although it is commonly identified as a critical TCs resource, design change received greater attention from architects than general contractors and supervision companies. The design change is one of the most significant risks for architects, and it brings additional workload and costs. Prefabrication requires high technical consistency, for which quite an amount or costs can occur on communication when there are design changes.

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3.5 Discussion

The results of the data analysis show similarities as well as a diversity of stakeholders' perceptions of TCs, which stimulated a necessity to further exploring the consistencies and differences of stakeholders' perceptions about TCs in PH projects. Firstly, by analyzing the consistency of stakeholders' most concerned TCs, this study can help to build a thorough understanding of TCs from their nature. Our goal is not only to identify the critical TCs from the eye of each stakeholder but eventually to investigate the hinders along the supply chain that incur common TCs to the relevant stakeholders. Secondly, for private stakeholders, exploring the consistencies of stakeholders' perceptions about TCs can contribute to finding better strategies for the governance of the whole supply chain. Understand the differences in stakeholders' perception is helpful to understand the differences in their roles and interests in the PH. Knowing the difficulties and interests of other stakeholders is beneficial for enterprises in the PH industry to adjust their measures and strategies. Moreover, exploring the consistencies and differences of perceptions of TCs among stakeholders provides the policy-makers with a better understanding of needs from the market, which will contribute to making more effective policies.

3.5.1 Consistency of the perceptions of TCs between stakeholders

According to data analysis results of TCs ranking for each stakeholder group, nine items are commonly recognized by six key stakeholders groups as significant sources of TCs in PH: *Architectural Design* (TC_{11}), *Detailed Design* (TC_{12}), *Hiring Skilled Labor* (TC_{18}), *Communication During Component Manufacturing* (TC_{19}), *Components Production Supervision* (TC_{20}) and *Components Quality Test* (TC_{21}), *Component Transportation* (TC_{22}), *Design Changes* (TC_{27}) and *Assembly* (TC_{29}). From the nature of TCs, it is observed that stakeholders in the PH industry in China are putting more of their attention on TCs related to the asset specificity of PH. Asset specificity refers to the specific investment for a particular transaction (Williamson, 1981). It is observed that the three most important TCs – Assembly, Detailed Design, and Design Change – are highly related to the specificity of prefabrication. For instance, *Assembly* requires new construction techniques for the workers, more intensive coordination among stakeholders, as well as extra supervision and monitoring work for the authorities.

Another common point on stakeholder perceptions of TCs is that they emphasized activities involving innovation works where high uncertainties and risks may arise (Mettepenningen et al, 2011). For example, being more complicated than found in the traditional construction projects, Design Changes in PH projects not only cause remanufacturing or reassembly but could even lead to changing the molds for producing components. In most cases, design changes may damage the interests of all related stakeholders.

3.5.2 Differences between the perceptions of TCs from public stakeholders and private stakeholders

Playing different roles in PH projects, stakeholders have various interests. Due to their different interests, stakeholders could encounter different impediments leading to divergent perceptions on the TCs (Gan et al, 2019). The phases that stakeholders participate in and the activities that different roles are involved in determining that the TCs that they experienced are different. Based on the data analysis findings, further discussions about the differences in the perceptions of TCs between public and private stakeholders are carried out.

1 Private stakeholders tend to emphasize TCs from their production, while the authorities have an overview of all sources of TCs in the whole supply chain. For example, the interviews with general contractors and supervision companies reflect that they prefer to highlight the challenges that come from the innovation of PH compared with traditional projects. Four of the five private key stakeholders identified the *Assembly* as the task where high TCs occur, which is due to the changes in their regular production activities. However, different from private stakeholders, the aim of the local government is not to make profits but to promote PH in China (Zhai et al, 2014). The view of the government is more objective and comprehensive compared with the private stakeholders. It is interesting to notice that the most important TCs evaluated by the local government are *Assembly*, *Architectural Design*, and *Component Transportation*, which are not directly carried out by the local governments. In addition, during the interviews, government experts have expressed a clear understanding of TCs by explaining academic and economic meaning.

2 The burden of TCs from PH is allocated diversely to private and public stakeholders, which leads to different intentions to reduce TCs. It is known from the interviews that private stakeholders are bearing most of the TCs in a PH project because of their direct involvement in the development process. Specifically, developers pay

for most of the TCs in the concept and design phase, whereas general contractors are bearing most TCs in the construction phase (Wu et al, 2019b). The interviewees delivered a firm intention from the perspective of private stakeholders to lower their TCs. On the contrary, the interviewees showed that public stakeholders believe that the existence of TCs is inevitable. To the governments, maximizing social benefits, rather than minimizing TCs is the goal. Some additional TCs are favorable for the projects and the industry as a whole – for example, the formulation of industry norms (Lu et al, 2015). For example, the questionnaire survey results did not show that approval and monitoring costs as the most critical TCs from the perspective of local government. It somehow implies that they believe the TCs spending on promotion of PH would contribute to the improvement of the social benefits in the long run.

3.5.3 Strategic implications to stakeholders in PH projects

It is assumed that the fewer the TCs, the more smooth and efficient the development process is (Webster, 1998). From a perspective of cost efficiency, some of the TCs are deadweight losses that have to be minimized.

Suggestions for private stakeholders

First, by identifying the commonly emphasized nine TCs sources by key stakeholders, there are some general suggestions to the private stakeholders according to their perceptions' consistency. 1) Partner cooperation is a solution to eliminate redundant TCs and improve the efficiency of the organization's operation. Ensuring the efficiency of projects is not a single party's affair, but it is instead a collective effort from all interested parties in the partnership arrangement (Osei-Kyei & Chan, 2017). 2) This study has made it clear that communication and coordination are among the most concerned sources of TCs in PH by key stakeholders. Therefore, developing long-term cooperative relationships between stakeholders, (e.g., between architect companies and developers), is one of the solutions to smooth the coordination and to save costs from information searching. 3) Furthermore, private stakeholders could reduce their internal TCs on the firm level by upgrading the firm organization. As shown from the survey results, the *Detailed Design* is partly taken by the architects, while there was no team available in their initial organization. Then extra costs have to be paid on hiring new staff or adjust the task distribution among staff. To reduce TCs arising from the internal organization, they must adjust the structure of their organization to adapt to the new transaction and administration process (Ketokivi & Mahoney, 2016).

Second, considering the differences in stakeholders' roles and perceptions of TCs, specific measures implications are also given to each private stakeholder. For the developers, learning costs (e.g., in the form of meetings, project investigations) are worth paying to reduce the TCs from the mistakes and low efficiency in the *Assembly* (Kiss, 2016). For the general contractors, reducing uncertainty in the early phases is a solution to decrease TCs from *Assembly and Design Change*. A practical solution is employing mature design technologies for assembly simulations, such as having pipeline interferences by using BIM, which results in very few design changes. The architects perceived TCs from *Communication During Component Manufacturing* as a great challenge. Corresponding management measures, such as ensuring the completeness of plans and specifications, can decrease the number of disagreements and disputes in the manufacturing, therefore reduce the TCs in the manufacturing stage (Li et al, 2012). The supervision companies have recognized their massive extra workloads on *Components Production Supervision* and *Components Quality Test*. Possible measures for them to minimize TCs could be experience-learning. Supervision lessons learned from completed PH projects should be kept in the organizational memory and being used in future projects (Mettepenningen et al, 2011). Additionally, as reflected in the interview, component suppliers believe that their early involvement in the *Detailed Design* can benefit the efficiency of their manufacturing activities. Therefore, the TCs from the *Detailed Design* are not necessary to be reduced from the side of the component supplier even though it is recognized as a vital source of TCs by them.

Suggestions for public stakeholders

Public stakeholders have a function and ability to take actions that can reduce TCs for both the public and private stakeholders. 1) On the one hand, they can reduce TCs for private stakeholders by improving the knowledge level of the public. In our survey, many stakeholders have mentioned about the costs of hiring skilled labor and educating staff. The shortage of skilled and competent labor in the PH industry has become an obstacle to stakeholders in China. Improving the economic awareness of the TCs among private stakeholders is one of the essential points to reduce TCs practically. Therefore, it is suggested that, apart from training for the employed person, it would be more efficient to start with putting prefabrication in the education system in the college. 2) On the other hand, developing a straightforward legal environment could play a significant role in decreasing the TCs burden (McCann, 2013). The results of the interview reveal that, for public stakeholders, TCs are more likely to arise from permission approval, monitoring, and publicity. The unclear regulations brought additional TCs to the private stakeholders; for instance, the supervision companies identified components quality test as a difficulty when the official quality standards were absent. Therefore, the local government action is the key point of TCs related to the policy environment. Providing clear regulations, in terms of component design, assembly, and quality assessment would significantly reduce TCs for both the public and private stakeholders.

3.6 Conclusions

The low-efficiency problem of PH is a commonly-identified reality. TCs are identified to help reduce dead-loss costs through the construction process of prefabrication. This study explores the major stakeholder perceptions towards TCs in the transaction process of PH in China and finds the potentials to lower TCs for stakeholders.

The findings of the questionnaire survey show that assembly, detailed design, and design change are the most critical sources of TCs in PH in China. In particular, the component suppliers complained of TCs from the detailed design and hiring skilled labor. For the architects, assembly is the most critical TCs, although they do not practically participate. The local government emphasized TCs on monitoring and enforcement in assembly, architectural design, and component transportation.
In addition, in exploring the consistent perceptions of TCs between stakeholders, twelve of thirty-three TCs received consistent agreement between key stakeholder groups. It is observed that the commonly highlighted TCs in PH are highly-related to the asset specificity and uncertainties from innovation. Besides, the analysis results also revealed the perceptions' differences of TCs between stakeholders due to their different roles and interests. Generally, private stakeholders tend to emphasize TCs from their production, while the authorities have an overview of all TCs in the supply chain. It is interesting to notice that the most critical TCs evaluated by the local government are *Assembly*, *Architectural Design*, and *Component Transportation*, which are not directly carried out by the local governments. Moreover, the information from the interviews and the survey delivered a firm intention from the perspective of private stakeholders to lower their TCs, whereas the public stakeholders believe that the existence of TCs is inevitable. It can be explained by the fact the private stakeholders are essentially profit-driven, the goal of the government is to promote the development of PH.

The practical implications from the findings of this study suggest that building strong cooperative relationships between partners is a long-term strategy for private enterprises to minimize their TCs. Educating the public can improve the knowledge level on PH and would further reduce the investment from private stakeholders for labor education. Moreover, public stakeholders are suggested to develop a straightforward legal environment for decreasing the TCs burden to both the public and private stakeholders. For instance, making clear regulations, in terms of component design, assembly, and quality assessment can significantly reduce TCs for private stakeholders, which would also lower the monitoring TCs for the local governments.

The findings of this study are very impactful to both academia and practice for the construction engineering and management. This study contributes to theory by uncovering the TCs of PH projects from the perspectives of stakeholders. Compared with previous TCs-related researches in other fields that only focused on TCs of a single stakeholder (Kiss, 2016; Mundaca T et al, 2013; Qian et al, 2015), this study has a broader scope investigating the perceptions of key stakeholders on TCs. In practice, this research has allowed stakeholders to look beyond difficulties in production and have a complete view of the TCs. It guides a direction for the private stakeholders to strategically lower TCs at specific phases of the process and improve the project efficiency. Furthermore, the findings inspire policy-makers in reducing TCs for both the private and public stakeholders, which will contribute to smooth transactions for future China's PH market. For cities and countries where the development of PH is in the early stage, findings from this study can provide implications on the aspect of TCs control in the development process of PH projects. Chongqing reflects the average level of PH application in China cities. Studies about PH in Chongqing give a relatively objective understanding of PH practice in China. It also provides a base for studies in other regions of China to investigate TCs in the local market by having Chongqing as a comparison case. Moreover, this study is expected to provide inspiration for understanding the states of TCs and investigating stakeholders' perceptions of TCs in other countries where the development of PH is in different stages. A limitation associated with this study is the comparatively small size of the sample. Perhaps future research can focus on the exploration of stakeholders' attitudes towards TCs in China with a broader research region and a more significant number of responses, according to the type of PH project, and procurement methods.

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4 Factors Influencing Transaction Costs of Prefabricated Housing Projects in China

Developers Perspectives

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ABSTRACT

Purpose – The recent promotion of prefabricated housing (PH) in China has resulted in a prosperous period for its implementation. However, transaction costs (TCs) cause low economic efficiency to stakeholders and hinder the further promotion of PH. No relevant study has yet been made to investigate the TCs and their causes in the PH field. This paper identifies critical TCs and explores the influencing factors from the developers' perspective.

Design/methodology/approach – Semi-structured interviews and a questionnaire survey were used to collect data about TCs and influencing factors. The most influential factors are identified with their impacts on particular TCs, yielded from correlation analysis and logistic regression.

Findings – From the developers' perspective in China's PH market, this study identified that the most concerning sources of TCs are: hidden costs arising from Disputes, extra workloads from Design Changes, Learning costs, intensive communication and coordination in Assembly, and unexpected information costs in Decision-making. The use of an ordered logistic regression approach indicates that the four most influential factors are: Qualification of the general contractor; Mandatory local policies; Owner type; and Competitiveness of the developer.

Practical implications – To reduce the TCs, experiencing learning, and ensuring the design scheme's complicity are recommended to save information searching and exchanging costs. The implications for the PH developers are for them to: (1) professionalize their own organization; and (2) procure high-qualified general contractors. For the policy-makers, this means they should improve the clarity of the mandatory local policies for PH step-by-step.

Originality/value – By applying the transaction costs economic theory, this study explores factors that influence transaction costs in the PH industry. It sheds light on the influencing mechanism behind the transaction costs in the context of prefabricated housing.

KEYWORDS Transaction cost; Prefabricated housing; Developers; Stakeholders, Ordered logistic regression

4.1 Introduction

Prefabrication has entailed considerable benefits to the construction industry, such as enhanced quality, shorter construction period, decreased materials cost, and improved onsite working environment (Arif & Egbu, 2010). The housebuilding sector can benefit greatly (Arashpour et al, 2015). Typically, prefabricated housing (PH) projects include manufacturing components/modular in a factory, transporting, and completing assembly onsite (Tam et al, 2007). In China, where the housing sector has always been an essential part of the economy, the government has introduced stringent measures to facilitate PH (Ji et al, 2017). In 2016, the authority announced that at least 30% of new construction has to adopt prefabrication by 2026 (GOSC, 2016). Under the leadership of the central government, more than 30 provinces have approved related policies and supportive measures to reach the goal. A total of 152 PH supporting policies were announced in 57 prefecture-level cities by August 2017 (Wang et al, 2019). For example, the Henan provincial government would subsidize 50 RMB/m^2 for qualified PH projects (prefabrication rate > 30% or assembly rate > 50 %) by 2025. Generally, the market size of the

TOC

PH projects accounted for 13.4 % of the new-built buildings in 2019, which is, however, still far less than that in the developed countries (STIDC, 2020). The unique features of China's construction have formed a widely-used mechanism for projects' development. Yet, the adoption of prefabrication technologies is considered as adding risks to well-established practice (Luo et al, 2015). Therefore, the smooth transition from a labor-intensive onsite method to a highly-integrated prefabrication method requires the China construction industry to overcome this lock-in effect (Gan et al, 2019). Numerous challenges need to be understood to succeed in PH, such as dealing with the lack of knowledge and expertise (Mao et al, 2015); higher capital costs (Xue et al, 2018a); new technologies (Wu et al, 2019a); low process efficiency (Zhai et al, 2014); and so forth. The costs spending on overcoming these challenges stemming from the attributes of the transactions in terms of asset specificity, frequency, and uncertainty are mostly transaction costs (TCs) (Williamson (1985). In the PH industry, TCs are defined explicitly as costs in terms of risks, time delay, information search, negotiation, contracting, organization set-up, monitoring, and enforcement (Wu et al, 2019b).

Common sense dictates that TCs bring both burdens and losses to the stakeholders, especially private stakeholders, because they are profit-pursuers. TCs account for quite a percentage of cost and shrink their profits (Whittington, 2008). For instance, TCs of energy-efficient buildings have been estimated to be as high as 20% of the investment cost (Gooding & Gul, 2016). In the cases where the public organization plays a developer's role, TCs are also an extra burden to them. However, they are less profit-motivated, therefore make fewer complaints about TCs compared to the private stakeholders. In the PH industry, TCs are usually unidentified or unrealized by the private enterprises. For example, additional efforts are consumed by the developers for seeking the experienced engineers and designers in PH projects (Larsson & Simonsson, 2012). The contractors complain about the rising cost from miscellaneous works such as hiring highly-skilled workers and components transportation (Hong et al, 2018). The architects need to coordinate intensively for components manufacturing and assembly (Tam et al, 2015). These obscure TCs limit stakeholders' production efficiency and hamper the progression of the whole industry (Qian et al, 2015). To make projects more financially attractive and to smooth the PH promotion process, TCs for private stakeholders must be well understood and minimized.

The core for effectively controlling the TCs for private stakeholders is to uncover the influencing mechanism behind them. A body of research efforts has already been able to identify the factors that influence the TCs. McCann (2013) categorized and analyzed factors affecting TCs for improving environmental policy design. Coggan et al (2013) built a framework for identifying factors influencing TCs for policy instruments. Phan et al (2017) identified the key drivers of TCs in forestry carbon projects. Shahab et al (2019) focused on what determines the amount of TCs in transferable development rights programs and how these specific effects worked. To our knowledge, the investigation of TCs is still quite a new topic in the PH industry. In particular, the factors that influence the TCs of PH are unclear and have not been studied.

This study investigates the influencing factors of TCs for private stakeholders, particularly from the developer's perspective. In the PH industry, the developer is recognized as one of the most influential stakeholders in China's context (Wu et al, 2019b). By taking the role of the clients in most PH cases, developers are participating in many transactions and bearing a large part of TCs in the project development process. The added burden from TCs has harmed developer enthusiasm to enter the market (Jiang et al, 2019). Being motivated by the fact that the frictions in PH projects cannot be released without comprehensive knowledge about TCs, the study aims to seek insights into TCs and the influencing factors. It is expected to give a better understanding and control of TCs in the PH. The following questions are answered in this paper:

1. **What are the TCs of most concern in PH from the perspective of the developers?**

2. **What are the influencing factors of developer-related TCs in PH?**

3. **How do the influencing factors influence their correlated TCs?**

The findings from this study can benefit both academia and industrial practitioners through a better understanding of the TCs and production efficiency of PH. They provide insights into the private stakeholders' perceptions when identifying the ignored TCs and lay a foundation for further studies into the occurring mechanisms behind TCs.

TOC

4.2 Literature review

4.2.1 Transaction costs of PH projects in China

Prefabrication was introduced to China in the 1950s to meet the massive housing demand (Wu et al, 2019a). Recently, driven by the global trend in sustainable development, PH has been a broadly advancing sustainable method in China's market. China's authorities define prefabricated housing as: "*Residential buildings that are assembled onsite using prefabricated components*" (MOHURD, 2018). The transformation of the construction industry from conventional methods to prefabrication is facing significant challenges in China. The new network, new cooperation, risks, mismatching between the existing governance system and the new PH supply chain are all causing extra effort, time, and costs, and through this, higher TCs (Wu et al, 2019b; Zhai et al, 2014).

Transaction costs generally refer to costs of transactions beyond the materials cost of the product, including the costs of searching for information, communication between stakeholders, negotiation, monitoring, and dealing with deviations from contracts (Antinori & Sathaye, 2007). With a contribution to analyze and optimize the governance organization, TCs have gained considerable importance in research into the fields of project procurement (Carbonara et al, 2016), new technology implementation (Kiss, 2016), policy management (Shahab et al, 2018), regulation improvement (Qian et al, 2016), and institutional governance (Lai & Tang, 2016). However, the concept of TCs is not universally accepted by all practitioners in the construction industry (Li et al, 2014b). Knowledge and evidence of TCs are still limited in the field of PH. In this study, TCs in the PH industry are defined explicitly as costs in terms of risks, time delay, information search, negotiation, contracting, organization set-up, monitoring, and enforcement (Wu et al, 2019b).

Transaction costs are unique in a particular transaction environment. It is hard to give a justification for the level of TCs between PH and traditional projects. Two arguments can be made for investigating them:-

1. Some of the TCs in PH are commonly-seen in conventional construction projects; however, the content and scale of these TCs are different compared with the traditional projects. For example, TCs for the feasibility study of PH projects are different from conventional projects due to the extra performance of

prefabrication on the aspects of technical, economic, and social influence (Antinori & Sathaye, 2007). Besides, the detailed design of PH projects contain further TCs on components design, for example, more negotiation to ensure the transporting (Mundaca, 2007), lifting and incorporating of different components together (O'Connor et al. 2015);

2 Apart from the commonly-seen TCs in conventional construction projects, there are some TCs specific for PH projects, including identifying partners with PH experience (Kiss, 2016), establishing the technical scheme, hiring skilled labor, and tests on components quality (Mundaca, 2007), etc.. For conducting the prefabrication construction, local laborers' extra training to get machine-oriented skills needs to be accomplished (Chiang et al, 2006). Components transportation is a new task that connects the offsite manufacturing and the onsite assembly, which is identified as a vital challenge that needs intensive coordination (Kamali & Hewage, 2016). It can be derived from the literature that TCs in the current China PH market are higher than expected. TCs are perceived to be too high due to the uncertainties from adopting the renovation technologies and production process (Winch, 1989). In this sense, there is considerable potential for TCs in China's PH to be reduced (Wu et al, 2019b).

4.2.2 Developer-related TCs in PH

Stakeholders involved in the PH project should realize the existence and importance of TCs. In the context of China, the developers are generally acknowledged as taking the leading role in promoting PH (Xue et al, 2018b); hence the developers' perspective is a valuable view to take. In the typical PH projects, developers initiate and organize the whole development process; therefore having more contractual relationships and information exchanges. Through taking the role of the clients in most PH cases, developers are participating in many transactions and bearing more TCs than other stakeholders in PH projects (Wu et al, 2020). Therefore, for exploring the TCs in PH, the first step is to overview TCs from the developers' perspective. Considering the limited research about TCs of developers in the PH field, TCs related to developers are identified by reviewing the literature about barriers in the PH, TCs in the construction industry, and the application of TCs theory in other fields. Table 4.1 has concluded the developers-related TCs in the development process of PH projects.

Taking the role of initiator in many PH projects, most of the developers' TCs arise at the early stage of the projects' development process. Apart from the similar TCs from project brief and feasibility study in conventional projects, efforts on looking for potentials partners with PH Experience (TC_3) are identified as a significant source of TCs. Larsson & Simonsson (2012) stated the challenge of the lack of knowledgeable professionals for PH, especially experienced architects and engineers. Besides, Learning activities (TC_5), such as digesting new information, mastering new technologies, and adapting the organization to the prefabrication mode, can lead to additional costs (Wu et al, 2019b). For the Decision-making in PH projects (TC_6), the long lead-in time, more work from information collection and analysis are also recognized as hindrances (Goodier & Gibb, 2007). In the plan and design phase, developers are responsible for TCs such as Land-bidding (TC_7), Permission Application (TC_8), General Contractor Procurement (TC_{13}), etc. (Wu et al, 2019b). Notably, the Detailed Design (TC_{12}) in a PH project would typically consume a longer time of professionals taking the feasibility of assembly into account (O'Connor et al, 2015). TCs related to the developers also appear in the construction phase, arising from the Design Changes (TC_{15}) (Tam et al, 2015) and Disputes (TC_{16}) (Lu et al, 2015). Furthermore, to ensure the efficiency of implementing the construction contracts, enforcement measures, such as construction monitoring and quality inspection for the assembly, are also taken from the developers' side (Rajeh et al, 2015). In the operation phase, as the client and owner in many cases in China, developers are responsible for TCs from Advertising (TC_{18}) (Wu et al, 2019b), Contract Signing (TC_{19}) (Mundaca, 2007), and Taxation (TC_{20}) (Xue et al, 2018b).

TABLE 4.1 Sources of developer's Transaction Costs (TCs)

	Code	Sources of TCs
Conceptual phase	TC_1	Preparation of a project brief.
	TC_2	Evaluating the project's feasibility.
	TC_3	Identifying experienced partners.
	TC_4	Consultation about prefabrication in the conceptual and design phase.
	TC_5	Learning new technologies, digesting new information, and adapting the organization to the prefabrication mode.
	TC_6	Decision-making for adopting prefabrication technologies and the prefabrication rate.
	TC_7	Preparing and participating in the land-bidding.
Planning and design phase	TC_8	Obtaining approvals and permits in the conceptual and design phases
	TC_9	Preparing and negotiating for the financing.
	TC_{10}	Land-surveying.
	TC_{11}	Information searching, learning, and communication for architectural design.
	TC_{12}	Information collection, communication, and coordination to complete the detailed design.
Construction phase	TC_{13}	Procuring the general contractor.
	TC_{14}	Setting up the project organization.
	TC_{15}	Communication, negotiation, time delay, and rework from the design change.
	TC_{16}	Dispute costs.
	TC_{17}	Communication, monitoring, and quality inspection for the assembly.
Operation phase	TC_{18}	Advertising, popularization, and promotion of PH projects.
	TC_{19}	Drafting, negotiating, and signing the sale contracts.
	TC_{20}	Taxation paid by the developer in the project development process.

4.2.3 Factors that influence TCs in PH

Williamson (1996) defines the determinants of TCs as specificity, uncertainty, frequency, bounded rationality, and opportunism. Mettepenningen et al (2011) classify the determinants of TCs into factors relating to the actors, characteristics of the schemes, institutional environment, and natural environment. McCann (2013) classifies factors affecting TCs into physical, cultural, and institutional environment factors for improving environmental policy design. Coggan et al (2013) also develop a framework for identifying factors influencing TCs for environmental policy instruments based on characteristics of the transaction, characteristics of the transactors, the nature of the institutional environment, and the nature of the institutional arrangements. In the Chinese construction industry, factors affecting TCs are categorized into the predictability of the owner's behavior, predictability of the contractor's behavior, project management efficiency, and uncertainties in the environment (Li et al, 2012).

Based on previous studies, this study developed a framework as a basis for identifying the factors influencing TCs in PH, as outlined in Table 4.2. We argue that the factors that influence TCs in the PH industry are comprised of three categories:

1. The attributes of transactions: the asset specificity of the transacted items, the frequency of the transaction, and the level of uncertainties in the transaction process;
2. The characteristics of stakeholders: factors regarding bounded rationality, opportunism, and information asymmetry;
3. The institutional environment: the context where the economic activities take place, with its particular features of formal and informal legal, social, and political rules.

TABLE 4.2 Factors that influence the TCs of PH projects

Categories	Factors	Explanation	References
Attributes of transactions	Project Location	Location and scale, are the project factors that impact TCs.	(Phan et al, 2017)
	Project Size	Larger projects require more effort in monitoring, which increases TCs.	(Torres & Pina, 2001)
	Owner Type	The owner type largely determines the pre and post-contract TCs.	(Li et al, 2014b)
	Prefabrication Rate	High technical complexity raises uncertainties in the transaction process, hence increasing the cost of procurement and execution.	(Farajian, 2010; Li et al, 2012)
	Procurement Method	Fragmented design and construction is typical in the design-bid-build procurement system and contributes to the uncertainties, hence increasing TCs.	(Li et al, 2014b; Rajeh et al, 2015)
	Contract Type	The contract type of projects determines the frequency of the payment and therefore has a direct impact on TCs.	(Chen et al, 2013; Li et al, 2014b)
Characteristics of Stakeholders	Collaboration Experience	The interaction among partners necessitates communication and governance, and familiarity improves transactions.	(De Schepper et al, 2015)
	Experience	Lessons learned from previous experience can be applied in future projects, and stability in the owner's behavior greatly reduces TCs.	(Fan et al, 2018; Mettepenningen et al, 2011)
	Qualification of the General Contractor	Contractors with outstanding operation capability help build an efficient transaction environment, and stability lowers TCs.	(Li et al, 2014b)
Institutional environment	Social Climate and Attitudes	When systems work well, people don't like change. Once people have adapted to an institutional structure, changing will be quite costly.	(Mettepenningen et al, 2011).
	Local Policies	Policies impact TCs by directing how the exchanges take place.	(Wu et al, 2019b)

1 The attributes of transactions

Conforming to Williamson (1985), the characteristics of a transaction can be defined concerning its asset specificity, uncertainty, and frequency. Accordingly, the attributes of the transaction in PH that affect the TCs can be summarized, including the project location, project size, owner type, prefabrication rate, procurement method, and contract type.

The location of projects in different regions can influence the TCs because the development of PH between cities is different. According to the market situation of different cities, China central government set particular goals for PH promotion by categorizing cities into three types: The newly-built prefabricated buildings are expected to reach 20% of total construction for the primary promotion region; 15% for the positive promotion region; and 10% for the encouraging promotion region (GOSC, 2016; MOHURD, 2018). Besides, plenty of studies have shown that the size of construction projects has a significant influence on the scale of TCs (Torres & Pina, 2001). Ho & Tsui (2009) assert that the project scale and project complexity will primarily affect contracting costs. Similarly, Carbonara et al (2016) found that TCs increase when the project size grows due to a more considerable effort to monitor and negotiate. Additionally, the owner type of project is an essential determinant of TCs. The owner type indicates the type of ownership (public or private) of PH buildings. The owner type determines the developers' decision-making flexibility in pre-contract management, determining access to alternative dispute resolutions (Li et al, 2014b).

The prefabrication rate reflects the technical uncertainties in a PH project, which is believed as an essential factor of TCs (Farajian, 2010). The target prefabrication rate of the project defines the technical complexity of the projects. It can be connected to Williamson's argument of asset specificity, which positively correlates with TCs (Shahab et al, 2018). The higher the prefabrication rate, the more challenges arise in techniques, workers' training, cooperation, communication, etc.

The procurement method and contract type of a PH project determine the frequency of transactions in its development process. Particular procedures and routines tailored to a particular transaction (Coggan et al, 2013), the procurement method is, therefore, a vital effect factor of TCs in a project's development. TCs related to the different procurement situations vary on the volume of information to be processed. The higher the specificity (i.e., uniqueness and uncertainty) of the procurement, the more need to exchange and share fresh information (Carbonara et al, 2016). Besides, the effect of contract type on TCs is a typical reflection of the influence of transaction frequency. The main construction contract is a single transaction and can be viewed as a series of transactions, implying high transaction frequency (Chen et al, 2013). The contract type of PH projects, including Lump-sum, Unit-price, Cost-plus-fee, etc., determines the payment frequency and, therefore, directly impacts TCs.

2 The characteristics of the stakeholders

The characteristics of the stakeholders are identified according to the concept of information asymmetry, bounded rationality, and opportunism. Factors in this category include collaboration experience, experience on PH, and the qualification of contractors.

The theory of information asymmetry and knowledge specificity all pointed out that previous collaboration experience within a group of stakeholders is a critical influencing factor of TCs (Jobin, 2008). Particular skills, knowledge, and expertise of staff are specific to a transaction. The challenges of communication, negotiation, coordination, and governance could be better addressed if stakeholders have had previous dealings with each other (Coggan et al, 2013).

Bounded rationality acknowledges that rational people's decision and behavior are bounded by the information available, time, cognition, and ability to foresee all contingencies (Simon, 1950). Experience learning is valid if the lessons learned from completed projects are kept in the organizational memory and used in future projects. The more experience the actor has, the lower TCs will be, indicating a learning effect (Mettepenningen et al, 2011).

TCs occur from developing complete contracts and monitoring to manage risks from opportunistic behaviors. Trust and confidence in the stakeholders' information flow can reduce TCs associated with opportunism (Li et al, 2014b). Contractors with a high level of qualification, meaning relatively strong capability, provide the basis for building trust and stability in cooperation. In China, the qualification of housing construction general contractors is divided into four levels: special grade, first level, second level, and third level. According to the Standard of qualification for construction enterprises in China's construction industry, the special grade is the top level of the construction contractors (MOHURD, 2014). The higher level of enterprises' qualification represents the high capability of creditworthiness, management capability, and experience. For instance, the requirements about the registered capital for four levels of certification are above 300 million CNY, 50 million CNY, 20 million CNY, and 6 million CNY (from special grade to the third level), respectively. Additionally, for the special grade certification, there are additional requirements for scientific progress.

3 The institutional environment

The institutional environment has a significant influence on the TCs, ranging from political settings such as legal regulations and organizations to social climate and attitudes (Coggan et al, 2013). The factors, namely the social environment and the policies, are summarized here from the literature with evidence showing their impacts on the TCs.

Social climate and public attitudes are identified as relevant TCs influencing factors for agri-environmental schemes by Mettepenningen et al (2011). It is claimed that significant changes to the technology and the management system are unlikely to be encouraged in a short time because of path dependency. PH is leading the upgrading of the construction industry, while public knowledge and attitude toward PH are of considerable significance to the advancement of construction transformation (Wang et al, 2019).

Policies impact TCs through directing how exchange takes place, which, in turn, imposes influence on TCs to both public and private parties (Coggan et al, 2013). For instance, policy design and briefing generate TCs to the public stakeholders, while the private stakeholders are also bearing TCs from learning and adapting to the policy. The government could influence the application of new technology by policies, for example, tax incentives (Wu et al, 2019a). Thus, a market with supportive policies can lower the information-searching costs for private stakeholders.

4.3 Methodology

The methodology of this study consisted of four steps, as presented in Figure 4.1. The first step was to perform the qualitative research, namely, semi-structured interviews, to improve the list of factors identified by an extensive literature review. We followed this with a quantitative method, namely a questionnaire survey, to elicit the states of the factors and evaluate the importance of the TCs. The third and fourth steps are data analysis to identify the influencing factors of TCs, using the methods of correlation analysis and ordered logistic regression. Details of the semi-structured interviews and the questionnaire survey are described in the following subsections.

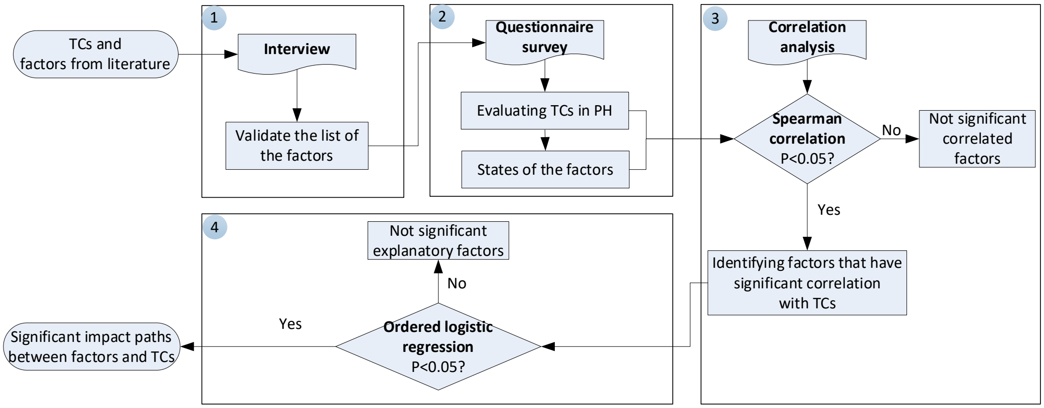

FIG. 4.1 Methodology design

4.3.1 Semi-structured Interviews

The semi-structured interviews were designed to validate the accuracy and completeness of the theoretical factors. To get in touch with experts with a wealth of experience in PH, we visited the Prefabricated Building and Construction Technology Expo, 22 - 24 November 2018, in Changsha, China. Ten experts participating in the Expo agreed to participate in our research. All of the interviews were conducted on a face-to-face basis in the location of the Expo. Each interview lasted for around 30 minutes. The selected interviewees are from the developer and include professionals from the government, construction companies, consultants, component suppliers, and architects. Profiles of the ten interviewees can be seen in Table 4.3

TABLE 4.3 Profiles of the interviewees

Code	Role of the company	Position	Experience in PH (year)
1	General contractor	Technology director	6
2	Developer + General contractor	Marketing manager	1.5
3	General contractor + component supplier + Consultant	Marketing manager	3
4	Consultant + General contractor	Architect	2.5
5	Developer + General contractor + consultant	Deputy general manager	7
6	General contractor + component supplier	Architect	3
7	General contractor + component supplier	Architect	2
8	Architects	Senior engineer	4.5
9	Developer	Head engineer	4
10	Local government	Director	6.5

During the interview, the interviewees were asked: (1) to verify and adjust the list of factors that influence TCs in PH projects from their perspectives; (2) to share more views about the causes of TCs beyond the framework; and (3) to explain how each factor influence TCs of developer based on their experience in PH. Note-taking and recording were done by the agreement of the interviewees. Then, a code-based content analysis was carried out, which helped to organize data in the identified factors to enable the analysis and interpretations. The authors also reviewed related policy documents, reports, and literature to provide theoretical supports for the experts' input.

As suggested by the interviewees, the factor – *Social climate and attitude* – has been removed from the list. Feedback from the participants said that it was not easily-understandable for them to evaluate an item with many explanatory variables behind each. The social attitude includes the attitudes of the authorities, co-operators, workers, and the end-users, all of which are quite complex and cannot be qualified by using one variable.

The *Competitiveness of the developer* has been added, as suggested by the interviewed experts. The rank of a developer in the Top 100 Chinese real estate enterprises is a direct reflection of its competitiveness. This annually-released official list indicates the competitiveness of the developers based on 52 business indices, such as profitability, solvency, sustainable development, and operational capacity. Haan et al (2002) claimed that the developers' competitiveness mirrors their capability to respond to the changes and risks in the environment where most TCs incur promptly. In China's housing developing market, the developers with different competitiveness have different sources to guarantee production.

Compared with small enterprises, competitive real estate developers naturally have advantages in learning new technologies, identifying partners, financing, etc. (Statista, 2020).

The policy environment has been divided into two factors: *Mandatory local policy* and *Local incentives*. The interviewees believed that mandatory local policies have an essential influence on PH in the Chinese market. For example, when the government of Tianjin city announced that five types of projects must adopt prefabrication from 2018, the local real estate developers had to raise their investment to meet the increasing demands on technical supports, skilled labor, and upgrading management system for PH. It can be explained that adapting to new regulations and facing risks in new production activities generate unexpected costs (Qian et al, 2013) because mandatory policies change the rules or the consequence of the new norm. Considering the different policy environments in different regions in China, the local compulsory policy's status has been defined at three levels: 1) No mandatory requirements; 2) Must use prefabrication; 3) Has a specific requirement on the prefabrication rate. As for the incentive policies, they have been published mainly in three types according to the research of Jiang et al (2019): 1) Only non-economic incentives: Including reputation incentives (e.g., qualification promotion, priority awards), pre-sale policy, priority in the approval, traffic support; 2) Only economic incentives: including fund support, loan support, tax privilege, floor area reward, and priority land supply, etc.; 3) Combination of economic and non-economic incentives.

After the validation by the semi-structured interviews, a full list of factors potentially affecting developer-related TCs for PH projects was identified (Table 4.4).

TABLE 4.4 Validated list of factors affecting TCs for PH projects

	Factors	Description	States
1	Project Location	38 cites in Beijing-Tianjin-Hebei Urban Agglomeration Region, Yangtze River Delta Urban Agglomeration and Pearl River Delta Urban Agglomeration	Primary promotion region
		27 cities with permanent population > 3 million	Positive promotion region
		Other cities in mainland China	Encouraged promotion region
2	Project Size	Floor area <100,000m^2	Small
		100,000 – 200,000 m^2	Medium
		>200,000m^2	Large
3	Owner Type	Private housing: the sponsor is the developer Public housing: the owner and the sponsor is the government	Private
			Public
4	Prefabrication Rate(by volume)	<25%	Low
		25%-50%	Medium
		>50%	High
5	Procurement Method	Design-bid-build	DBB
		Design-build	DB
		Engineering Procurement Construction	EPC
		Construction Management, turnkey, partnering, etc.	Others
6	Contract Type	The type of the main construction contract	Lump-sum
			Unit-price
			Cost-plus-fee
			Others
7	Collaboration Experience	Have the team members worked together before, on another project, before this one?	Yes
			No
8	Experience of PH	How many PH projects have been developed by your company in the past 3 years?	<3
			3-10
			>10
9	Competitiveness of the Developer	The ranking of your current company among the Top 100 Chinese Real Estate Enterprises?	TOP 10
			10-50
			50-100
			Not on the list
10	Qualification of the General Contractor	Construction enterprise qualification standards, 2015	Special grade
			First-level
			Second-level
			Third-level
11	Mandatory Local Policies	(Province level)	No Mandatory Policies
			Must use prefabrication
			Has a specific requirement on the prefabrication rate

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TABLE 4.4 Validated list of factors affecting TCs for PH projects

	Factors	Description	States
12	Local Incentives		No incentives
		Including Reputation incentive, pre-sale policy, optimize the approval process, bidding policy, traffic support, etc.	Only Non-economic incentives
		Including fund support, loan support, tax privilege, floor area reward, and priority land supply, etc.	Only Economic incentives
			Economic + Non-economic incentives

4.3.2 Questionnaire survey

Based on the validated factors list, a questionnaire survey was conducted. The obtained information about TCs and the states of factors provides evidence on how the TCs are influenced in PH projects. It was a perception-based survey for developers in China, carried out from 20th December 2019 to 8th March 2020. The questionnaires were developed and distributed through an online survey platform - wj.qq.com. The questionnaire survey was conducted with the assistance of the secretary from the website - precast. com.cn. It is an organization established in 2010 by several provincial Building Industrialization Associations in China. The questionnaires were distributed to around 1500 of their members. There were 401 responses. Respondents were asked to verify that they were currently working for PH developers before continuing to fill out the questionnaire. Consequently, 249 among 401 respondents were verified to complete the questionnaire (247 valid responses). The valid samples were collected from 31 of 34 provinces in China (no sample from Tibet, Hong Kong, and Taiwan).

The first section of the questionnaire captured the respondents' background information, such as education, year of experience in construction and PH. The second section asked for information about the states of the factors (with the explanation of the states given). The third section was designed to evaluate the level of 20 sources of TCs using a five-point Likert-type scale from 1 (extremely low) to 5 (extremely high). Reliability testing was conducted for the pilot study before the final questionnaire survey. The most popular Cronbach's alpha was used, which is commonly-accepted for testing the internal consistency reliability. The Cronbach's Alpha for the TCs evaluation section was 0.95 (threshold=0.8), indicating that the questionnaire adopted has a high internal consistency (Taber, 2018).

Table 4.5 shows the characteristics of the samples. Overall, the majority of the respondents have either an education degree in Junior college or Bachelor's (27.94% and 60.73%). It implies that the respondents are well-educated. Having enough knowledge of the current PH market, their opinions are valuable for exploring the TCs of China's PH industry. As for the respondents' experience, it is interesting to notice that 38.06% of the respondents had longer than five-year experience in construction. In comparison, only 3.64% of the respondents had experience in PH for longer than five years. This is reasonable considering the stage of development of PH in China. A massive application of PH in China's construction market had only been started after 2010 since the publishing of a milestone policy – Plan on Green Building (MOHURD, 2013). With such a short history of implementation, it was almost impossible to find respondents with more extensive experience (e.g., >10 years) in China's PH market. Moreover, there was an open question in the first section asking for the respondents' position in their company. Fifty-three among the 247 respondents stated their positions at a manager level, such as director, section chief, department manager, technical manager, project manager, or even shareholder. It indicated that the information collected by this survey was primarily based on the points of view from the managers who have an overall view of the project development process, thus being quite reliable.

TABLE 4.5 Sample characteristics

		Frequency	Percentage (%)
Educational Attainment	Junior college	69	27.94
	Bachelor	150	60.73
	Master	27	10.93
	Doctor	1	0.40
Years in construction	0-5	153	61.94
	5-10	67	27.13
	10-20	20	8.10
	>20	7	2.83
Years in PH	<1	112	45.34
	1-3	97	39.27
	3-5	29	11.74
	5-10	5	2.02
	>10	4	1.62

4.4 Data analysis results

4.4.1 Developers' perception of TCs

The information from the first section of the questionnaire was analyzed to capture the importance ranking of TCs in the PH (Table 4.6). Statistical analysis was performed using IBM SPSS 25.0. The method of Mean Comparison has identified the five most important sources of TCs in PH from the opinion of the developers in China: Disputes (TC_{16}), Design Changes (TC_{15}), Learning (TC_5), Assembly (TC_{17}), and Decision-making (TC_6).

TABLE 4.6 Rank of the importance of TCs by developer

Code	Sources of TCs	Mean	N	Std. Deviation
TC_{16}	Dispute costs.	3,47	247	1,096
TC_{15}	Communication, negotiation, time delay, and rework from the design change.	3,42	247	1,130
TC_5	Learning new technologies, digesting new information, and adapting the organization to the prefabrication mode.	3,38	247	1,000
TC_{17}	Communication, monitoring, and quality inspection for the assembly.	3,34	247	1,074
TC_6	Decision-making for adopting prefabrication technologies and the prefabrication rate.	3,33	247	1,033
TC_3	Identifying experienced partners.	3,29	247	1,041
TC_9	Preparing and negotiating for the financing.	3,28	247	1,090
TC_{13}	Procuring the general contractor.	3,27	247	1,110
TC_{12}	Communication, coordination, and information collecting and adapting to complete the detailed design.	3,26	247	1,097
TC_7	Preparing and participating in the land-bidding.	3,24	247	1,150
TC_8	Obtaining approvals and permits in the conceptual and design phases	3,23	247	1,094
TC_{18}	Advertising, popularization, and promotion of PH projects.	3,20	247	1,137
TC_4	Consultation about prefabrication in the conceptual and design phase.	3,19	247	1,029
TC_2	Evaluating the project's feasibility.	3,19	247	,988
TC_1	Preparation of a project brief.	3,15	247	1,087
TC_{11}	Information searching, learning, and communication for architectural design.	3,14	247	1,082
TC_{20}	Taxation paid by the developer in the whole project development process.	3,14	247	1,104
TC_{19}	Drafting, negotiating, and signing the sale contracts.	3,06	247	1,114
TC_{14}	Setting up the project organization.	3,02	247	1,121
TC_{10}	Land-surveying.	2,96	247	1,173

4.4.2 Identifying the influencing factors

The second section of the questionnaire provided information about the states of twelve factors, shown in Table 4.7. The data set was then subjected to multiple ordered logistic regression to identify the correlated factors for TCs and estimate the power and direction of the influences. Before the logistic regression analysis, two statistical methods were employed to guarantee that the regression assumptions are valid: 1) Collinearity test among factors (independent variables); and 2) Correlation analysis to identify the factors that statistically have a significant correlation with TCs.

TABLE 4.7 Descriptive statistics of the factors

	Factors	Code	States	Frequency	Percent %
F1	Project Location	1	Primary promotion region	78	31,6
		2	Positive promotion region	88	35,6
		3	Encouraged promotion region	81	32,8
F2	Project Scale	1	Small	143	57,9
		2	Medium	77	31,2
		3	Large	27	10,9
F3	Owner Type	1	Private	178	72,1
		2	Public	69	27,9
F4	Prefabrication Rate	1	Low	109	44,1
		2	Medium	111	44,9
		3	High	27	10,9
F5	Procurement Method	1	DBB	88	35,6
		2	DB	69	27,9
		3	EPC	44	17,8
		4	Others	46	18,6
F6	Contract Type	1	Lump-sum	121	49,0
		2	Unit-price	58	23,5
		3	Cost-plus-fee	43	17,4
		4	Others	25	10,1
F7	Collaboration Experience	1	Yes	180	72,9
		2	No	67	27,1
F8	Experience of PH	1	<3	107	43,3
		2	3-10	101	40,9
		3	>10	39	15,8
F9	Competitiveness of the Developer	1	TOP 10	48	19,4
		2	10-50	51	20,6
		3	50-100	46	18,6
		4	Lower than 100	102	41,3
F10	Qualification of the General Contractor	1	Special grade	74	30,0
		2	First-level	99	40,1
		3	Second-level	44	17,8
		4	Third-level	30	12,1
F11	Mandatory Local Policies	1	No Mandatory Policies	75	30,4
		2	Mandatory for adopting prefabrication	106	42,9
		3	Has a specific requirement on the prefabrication rate	66	26,7
F12	Local Incentives	1	No incentives	51	20,6
		2	Only Non-economic incentives	91	36,8
		3	Only Economic incentives	44	17,8
		4	Economic + Non-economic incentives	59	23,9

First, the pre-condition before correlation analysis is to find variables statistically with non-multicollinear (for meaningful inference). In this study, variance inflation factors (VIF) were used to detect the severity of multicollinearity. A maximum VIF greater than ten is thought to signal harmful collinearity (Marquaridt, 1970). A correlation matrix was developed to see if any correlation exists among the independent variables selected from the previous procedures. As shown in Table 4.8, correlations among variables included in this model are low (VIF<10), suggesting that the potential problem of multicollinearity is not severe in this study. Therefore, all these twelve factors were allowed to be included in the subsequent correlation analysis.

TABLE 4.8 Collinearity statistics among twelve factors

Factors	Tolerance	VIF
F1	0.871	1.148
F2	0.761	1.315
F3	0.939	1.065
F4	0.730	1.369
F5	0.861	1.161
F6	0.828	1.207
F7	0.887	1.127
F8	0.867	1.153
F9	0.606	1.650
F10	0.636	1.573
F11	0.814	1.532
F12	0.858	1.166

Second, the Spearman correlation was calculated to filter the factors that have correlations with the TCs. As the results show, in Table 4.9, eight of twenty TCs have at least one factor showing a significant correlation. It means that although all these factors are theoretically useful in explaining the occurrence or the size of TCs in PH, it does not mean that all factors are significant.

TABLE 4.9 Spearman Correlation

Rank	Source of TCs	Correlated factors (Sig.<0.05)
TC_{16}	Dispute costs.	F4
		F10
		F11
TC_{15}	Communication, negotiation, time delay, and rework from the design change.	-
TC_{5}	Learning new technologies, digesting new information, and adapting the organization to the prefabrication mode.	-
TC_{17}	Communication, monitoring, and quality inspection for the assembly.	-
TC_{6}	Decision-making for adopting prefabrication technologies and the prefabrication rate.	F3
TC_{3}	Identifying experienced partners.	F11
TC_{9}	Preparing and negotiating for the financing.	F10
TC_{13}	Procuring the general contractor.	F9
TC_{12}	Communication, coordination, and information collecting and adapting to complete the detailed design.	-
TC_{7}	Preparing and participating in the land-bidding.	F9
		F10
TC_{8}	Obtaining approvals and permits in the conceptual and design phases	-
TC_{18}	Advertising, popularization, and promotion of PH projects.	-
TC_{4}	Consultation about prefabrication in the conceptual and design phase.	-
TC_{2}	Evaluating the project's feasibility.	-
TC_{1}	Preparation of a project brief.	-
TC_{11}	Information searching, learning, and communication for architectural design.	-
TC_{20}	Taxation paid by the developer in the project development process.	F10
TC_{19}	Drafting, negotiating, and signing the sale contracts.	F10
		F11
TC_{14}	Setting up the project organization.	-
TC_{10}	Land-surveying.	-

Third, multiple ordered logistic regression analysis was performed to judge how these eight TCs are impacted by their correlated factors.

The reasonability and the effectiveness of the ordered logistic regression models were tested. First, there is an essential assumption that parameters should not change for different categories (levels) of the dependent variable in ordered logistic regression models. In other words, the correlation between independent variables and the dependent variable does not change for dependent variable's levels; also, parameter estimations do not change for different levels in the regression equation.

TOC

The test of Parallel Lines examines whether the assumption holds or not. In this study, Parallel Lines' tests indicated that the parameters are the same for all levels of TC (P >0.05), meaning that the adoption of the ordered logistic regression model is reasonable. Second, the Model Fitting test results met the statistical significance at the level of P< 0.05, which indicates the effective meaning of the ordered logistics regression models for each TC and correlated factors. Considering a significance level of 5%, Table 4.10 depicts the results from the multiple ordered logistic regression models and the odds ratios for each model considered.

TABLE 4.10 Results of ordered logistic regression and the odds ratios

TCs	Correlated factors	Parameter Estimate β	Std. Error	Wald	Sig.	Odds Ratio Exp (β)	OR 95% Confidence Interval	
							Lower Bound	Upper Bound
TC_{16}	[F4=1]	0.679	0.414	2.687	0.101	1.972	0.876	4.442
	[F4=2]	0.515	0.396	1.687	0.194	1.673	0.770	3.637
	[F4=3]	0^a				1		
	[F10=1]	-0.971	0.407	5.687	**0.017***	0.379	0.170	0.841
	[F10=2]	-0.542	0.396	1.875	0.171	0.581	0.268	1.264
	[F10=3]	-0.266	0.440	0.365	0.546	0.767	0.324	1.815
	[F10=4]	0^a				1		
	[F11=1]	0.492	0.326	2.278	0.131	1.636	0.863	3.101
	[F11=2]	-0.035	0.291	0.014	0.904	0.966	0.545	1.709
	[F11=3]	0^a				1		
TC_6	[F3=1]	-0.532	0.260	4.180	**0.041***	0.587	0.352	0.978
	[F3=2]	0^a				1		
TC_3	[F11=1]	0.617	0.309	3.988	**0.046***	1.853	1.011	3.393
	[F11=2]	0.121	0.284	0.182	0.670	1.129	0.647	1.971
	[F11=3]	0^a				1		
TC_9	[F10=1]	-0.951	0.395	5.792	**0.016***	0.386	0.178	0.838
	[F10=2]	-0.483	0.378	1.636	0.201	0.617	0.294	1.293
	[F10=3]	-0.326	0.428	0.579	0.447	0.722	0.312	1.671
	[F10=4]	0^a				1		
TC_{13}	[F9=1]	0.449	0.316	2.019	0.155	1.567	0.843	2.913
	[F9=2]	0.685	0.311	4.844	**0.028***	1.985	1.078	3.654
	[F9=3]	0.106	0.320	0.110	0.741	1.112	0.594	2.081
	[F9=4]	0^a				1		

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TABLE 4.10 Results of ordered logistic regression and the odds ratios

TCs	Correlated factors	Parameter Estimate β	Std. Error	Wald	Sig.	Odds Ratio Exp (β)	OR 95% Confidence Interval	
							Lower Bound	Upper Bound
TC_7	[F9=1]	-0.350	0.370	0.891	0.345	0.705	0.341	1.457
	[F9=2]	0.350	0.358	0.957	0.328	1.419	0.704	2.860
	[F9=3]	0.230	0.340	0.457	0.499	1.258	0.646	2.449
	[F9=4]	0[a]				1		
	[F10=1]	-1.709	0.469	13.264	**0.000****	0.181	0.072	0.454
	[F10=2]	-1.016	0.421	5.811	**0.016***	0.362	0.159	0.827
	[F10=3]	-1.009	0.437	5.332	**0.021***	0.364	0.155	0.858
	[F10=4]	0[a]				1		
TC_{20}	[F10=1]	-1.135	0.398	8.148	**0.004****	0.321	0.147	0.701
	[F10=2]	-0.614	0.379	2.623	0.105	0.541	0.257	1.138
	[F10=3]	-0.767	0.431	3.165	0.075	0.464	0.199	1.081
	[F10=4]	0[a]				1		
TC_{19}	[F10=1]	-0.625	0.398	2.469	0.116	0.535	0.246	1.167
	[F10=2]	0.034	0.384	0.008	0.930	1.034	0.487	2.196
	[F10=3]	0.185	0.432	0.183	0.669	1.203	0.516	2.804
	[F10=4]	0[a]				1		
	[F11=1]	0.712	0.313	5.174	0.**023***	2.038	1.104	3.765
	[F11=2]	-0.015	0.285	0.003	0.959	0.985	0.564	1.721
	[F11=3]	0[a]				1		

1 The **Qualification of the General Contractor** (F10) is a significant explanatory parameter to four sources of TCs in PH: Dispute Cost (TC_{16}), Financing (TC_9), Land-bidding (TC_7), and Taxation (TC_{20}). As highlighted in Table 4.10, the negative coefficients for these models reveal that the higher value of the F10 is assigned to higher ratings in TCs. The ordered logistic regression analysis for TC_{16} and its three related factors show that only F10 is the significant impact factor. The odds of general contractors with third-level qualifications (code 4) that contribute to high dispute costs are 2.641 (=1/0.379) times more than the odds of special-grade general contractors (code 1). The results of analysis show that TC9 - Preparing and negotiating for the financing- can be significantly influenced by the factor F10 ($p<0.05$). The decrease in general contractors' qualifications from the special grade to the third level will correspondingly increase the odds of higher TCs for financing at 2.591 (=1/0.386) times. Similarly, for Taxation (TC20), high TCs are less likely to be incurred by the special-grade general contractors (code 1), referring to the third-level qualification. Additionally, it is worth noticing that for TC_7 -

Preparing and participating in the land-bidding, significant differences are shown between group 4 and the other three groups. The likelihood of general contractors with third-level qualifications experiencing higher TCs is higher than that for the other groups (code 1, code 2, code 3) at 5.523, 2.762, and 2.743 times respectively.

2 **Owner type** (F3) of a PH project emerges as having a noteworthy influence on TCs from Decision-making (TC_6). The estimated β value at -0.532 means that private PH projects (code 1) are less likely to raise higher TCs than public projects (code 2). Public projects increase the odds of higher decision-making costs at 1.730 (=1/0.578) times of private projects.

3 The **mandatory local policies** (F11) show a significant influence on TCs for Identifying experienced partners (TC_3) and Signing the sale contracts (TC_{19}). The calculation shows that with a decline of the mandatory policies from level 3 to level 1 (no mandatory policies), the odds of high TCs for identifying experienced partners will increase at 1.853 (= exp(0.617)) times. Besides, different levels of the mandatory local policies also impose a significant influence on TCs for signing the sale contracts of PH assets. Referring to level 3, **mandatory local policies** on level 1 (odds ratios 2.038, CI 1.104-3.765) are more likely to incur high TCs.

4 The positive coefficients reveal that the developer's higher capability (F9) brings about higher TCs for procuring the general contractor (TC_{13}). The odds of the developers in group 2 cause TCs for procuring are 1.985 times higher than that of developers in group 4 (ranking lower than 100), holding all other factors constant. It implies that developers ranking at 10-50 are the ones who are bearing higher TCs for procuring the general contractor. The first group (top ten) and the third group (50-100) reveal no significant difference.

4.5 Findings and Discussion

4.5.1 TCs of most concern to Developers

It has been identified that the five sources of TCs of most concern in PH from the opinion of the developers in China are: Disputes (TC_{16}), Design Changes (TC_{15}), Learning (TC_5), Assembly (TC_{17}), and Decision-making (TC_6).

Developers perceive the additional costs from Disputes (TC_{16}) on a high importance level in this study. Similarly, Lu et al (2015) recognized the critical influence of hidden TCs from dispute settlement in conventional projects. In China's context, developers' great concern on TCs from disputes reflected that the chance of dispute is even higher in an immature PH market. Besides, it is not surprising that Design Change (TC_{15}) got great attention from the developers. The extra workloads, regarding redesign, negotiation, the arrangement of new components production, or even the new construction plan, from the design change, have been stated in previous studies (Tam et al, 2015). Another significant TCs resource is Learning (TC_5). When switching from familiar traditional production methods to those using prefabrication, practitioners noticed the additional inputs for digesting new information, mastering new technologies, and collaborating with new stakeholders (Wu et al, 2019b). However, most of the time, the learning costs are kept invisible in PH because of the difficulty of measuring them at the project level. Additionally, developers believed that the Assembly (TC_{17}) is a challenging task that is incurring an added burden (Wu et al, 2020). Decision-making (TC_6) for a PH project also confronts developers with unexpected costs regarding information searching in the housing construction market, financial analysis, and risk assessment, etc. (Goodier & Gibb, 2007).

If one is seeking the underlying TCs of most concern in PH, the primary sources of the top five TCs are mostly information costs. Hobbs (1997) defined the information costs as costs arising ex-ante to exchange and include obtaining information on price, product, and identifying suitable trading partners. The information costs stem from two aspects: **information searching** and **information exchange**. These are explained as follows:

1. **Information searching** and analysis are activities in Learning and Decision-making. Stakeholders are motivated to learn in a situation when there is limited or asymmetric information. As the initiator of most PH projects in China, developers are responsible for collecting and assessing information from the prefabrication market about the market size, competitors, and the new prefab techniques. In this process, they invest capital, time, labor, and effort to make rational decisions; and

2. TCs from the Design Change and Assembly are mainly linked with the **information exchange**. For example, when design changes happen, the contractor delivers the information to the architects and the developers. The resulting intensive negotiations in meetings, emails, and documents will cause additional costs.

The reason developers identified TCs as being highly related to information costs can be explained by the developer's profit-driven characteristics and the hard-to-measure nature of TCs. In our survey, 72.1% of the PH projects were developed by private enterprises, naturally pursuing profits. TCs high-related to the information costs are emphasized as additional burdens because they do not directly contribute to profits. The invisibility and immeasurability of the information cost make it a focus of attention from developers.

4.5.2 Influencing factors and their impacts on TCs

The data analysis reveals four influencing factors of TCs: *Qualification of the general contractor* (F10), *Local mandatory policies* (F11), *Owner type* (F3), and *Competitiveness of the developer* (F9).

1 Qualification of the general contractor (F10)

The *Qualification of the general contractor* (F10) is a significant explanatory parameter to four sources of TCs in PH: Dispute costs (TC_{16}); Preparing and negotiating for the financing (TC_9); Preparing and participating in the land-bidding (TC_7); and Taxation paid by the developer (TC_{20}). The survey revealed that the chosen general contractors for PH mostly have high qualifications: 30% with a special grade (highest level) and 40.1% with a first-level. In general, the higher qualification of general contractors contributes to lower TCs on these four aspects, which is in line with the argument of Li et al (2014b), who believe that capable contractors could operate efficiently and contribute to a more stable environment with lower TCs. Specifically, the higher contract management ability for dispute resolution means fewer costs and time lost on negotiation, mediation, arbitration, and litigation. On the other hand, as expounded by Lu et al (2015), good contractors pay more attention to maintaining their reputation, which means fewer disputes by implementing sound contract management. Moreover, TCs for the financing and the land-bidding are influenced by the qualification of general contractors. The early involvement of a general contractor with strong capability will create a collaborative and supportive climate for project implementation (Wuni & Shen, 2020). It contributes to lowering the risk for financing and increasing the chance of winning the tender, thus reducing TCs.

2 Local mandatory policies (F11)

As plenty of studies have emphasized the influence of policies for PH development, it is no surprise that the *Mandatory local policies* (F11) show a significant effect on two sources of TCs in this study. In PH, more precise and restrictive mandatory policies may reduce TCs for identifying experienced partners (TC_3) and signing sale contracts (TC_{19}). Particularly, when there are no mandatory policies on using prefabrication, TCs for identifying professional partners are higher than in the mandatory cases. In many of China's metropolitan cities, adopting prefabrication has become mandatory (Gan et al, 2018). Consequently, enterprises in the industry have to adjust to the new market, which means there will be more candidates in the PH's supply chain to choose. This also means that there will be a shorter time for developers to search and to identify partners. Additionally, the quantitative analysis results also indicate that the stronger the promotion from the authority, the less effort is needed from the developers to sign the sale contracts. The mandatory policy is an approach of popularization of PH, by which, robust understanding and acceptance of PH among the public can be developed. Minimizing the information asymmetry between the developer and the potential buyers thus saves time on negotiation. Still, 30% of the respondents stated that there were no mandatory policies in their cities.

3 Owner type (F3)

The TCs for decision-making (TC_6) can be significantly influenced by the *Owner type* (F3) of a PH project, which is consistent with a previous study by Li et al (2014b). Adopting private real estate developers to develop PH projects is one of the most frequently applied ways in China for building public housing (Li et al, 2014a). Developers' opinions in this study reflected that TCs for public projects are more likely to be higher than those for private projects. For developers, public projects consume more of their efforts for deciding on adopting prefabrication, since the real client of public projects is mostly the local government, who usually holds great power in a project. It means that the pre-contract management is inefficient with less flexibility of decision for developers. In that sense, developers have to meet the real client's requirements and, at the same time, also need to have excellent communication skills to deliver the information to the contractors.

4 Competitiveness of the developer (F9)

The ordered logistic regression analysis shows that developers with higher competitiveness spend higher TCs for procuring general contractors. This can be understood in practice. For example, a developer with excellent operational capacity is always prudent in selecting a general contractor, which is a measure taken beforehand to reduce the uncertainty in the contract execution stage. TCs, especially time costs, are spent on activities, such as attending meetings, preliminary design, transition observation, training, and site visits to ensure the quality of the procurement (Rajeh et al, 2015). Besides, rather than the low-bid principle in conventional projects, the best-value method is more reasonable when procuring contractors for PH projects. Developers with excellent sustainable development capability pursue the quality of projects rather than only the benefits. However, the efforts invested in considering the contractor's experience, reputation, and ability means that they pay higher TCs and contract costs compared with merely choosing the lowest-price bidders.

There may be a number of reasons why only four of the twelve factors showed significant influences on developer-related TCs. A prominent explanation is because of the unique functions of critical stakeholders in the promotion stage of PH in China. Essentially, the four influencing factors revealed the power of the key stakeholders in PH, namely: developers, general contractors, and the local governments (who decide the owner type and the level of mandatory policies). This finding is in line with other studies in the field of PH, which affirms the remarkable role of these three key stakeholders in the developing stage in promoting PH (Wu et al, 2019b). The roles of the developers and contractors were also shown to have substantial influences on TCs, compared to their conventional counterparts (Li et al, 2012). Additionally, regarding the original principal of TCs economic theory, Williamson (1985) had claimed the fundamental determining effects of actors in the transactions.

4.5.3 Recommendations for minimizing the developer-related TCs

1 Recommendation for the developers

In a PH project, not all the identified influencing factors are amenable to change by the developers. Developers in China's PH industry are suggested to take measures according to the critical TCs and the factors that they can decide or influence in PH - Qualification of the general contractor and the Competitiveness of the developer.

- Reducing costs from **information searching**: For the developers, Learning activities (e.g., in the form of meetings, project investigations, etc.) are encouraged to minimize the TCs from the mistakes and low efficiency in the Assembly stage (Kiss, 2016). Besides, from real estate company management, experiential learning can save time on Decision-Making (Coggan et al, 2013).

- Reducing costs from **information exchange**: Having a complete design scheme helps to decrease the TCs from information exchange by reducing the subsequent number of Design Changes and Disputes in PH projects. A well-defined project scope and technical illustration reduce the uncertainties in the subsequent transactions, hence lowering the TCs (Li et al, 2015). The potential difficult issues in the manufacture, the components transportation, and the assembly onsite can be identified and solved in the design stage (Zhang & Yu, 2020).

- Even though the data analysis showed that the higher competitiveness of the developer related to higher TCs for procuring the general contractor, it is not reasonable that the developers should keep their competitiveness at a low level; On the contrary, improving the capability of the developer is always a rational option to reduce the TCs for the development process, although it may result in higher TCs in some of the tasks. The enhancement of developers' competitiveness can be achieved in many aspects; for instance, building good relationships with other parties to improve the predictability of their behavior (Li et al, 2012). A practical aspect for developers to enhance their competitiveness is to update the firm's organizations to adapt to the prefabrication production mode. A high institutional efficiency allows a smooth operation, and a more stable environment, reducing TCs.

- Another influencing factor that can be decided by the developers is the qualification of the general contractor. Our findings conclude that a general contractor with a high qualification contributes to reducing TCs arising from Disputes, Financing, Land-bidding, and Taxation. As Li et al (2014b) stated, contractors with high capabilities would efficiently contribute to the operation and promote a problem-free environment, contributing to a more stable environment with lower TCs. A rational developer should choose the highly-qualified general contractors, as long as the budget allows.

2 Recommendation for the policy-makers

This study has presented the critical influence of mandatory local policies on the transaction efficiency of PH projects. This is in line with the argument of Gao & Tian (2020), who stated that the supportive industrial policies by Chinese local governments to promote PH are necessary and effective. From the perspective of the TCs theory, governments' interventions to secure a favorable transaction environment are essential in an innovation industry like PH (Qian et al, 2013). According to our study results, and considering the actual situation of PH in China, some policy implications are recommended for Chinese local authorities:

- To popularize the mandatory local policies in Chinese provinces. The mandatory policy is a practical approach for educating stakeholders, by which the uncertainties on the aspects of the technique can be vastly reduced, contributing to the minimization of TCs. However, there were still 30% of the respondents who stated that there were no mandatory policies in their regions. A recent study by Gao &

Tian (2020) also indicated that only 10/34 provinces in China have supportive regulations for PH. It is, therefore, necessary to enforce the implementation of a mandatory generalised policy for PH in Chinese provinces.

- The mandatory policy needs to suit the PH level of the local market. Lu et al (2018) argued that the optimal level of prefabrication is produced by bounded-up forces from the aspects of political, economic, social, and technological. Although the findings from this study indicated that a higher level of the mandatory policy contributes to reducing TCs, the target prefabrication rate should be set considering the practical situation of the applied region. For example, in the primary promotion region, particular requirements on the prefab rate can be set for projects that apply prefabrication. Simultaneously, the focus of mandatory policies in the encouraged promotion region should focus on qualifying the quality of PH projects instead of only pursuing a high prefabrication rate. It is necessary for the local governments to formulate mandatory punitive regulations for ensuring the quality of PH projects.

- The mandatory local policy should be specific, with detailed implementation measures. Greenstone & Hanna (2014) stated that policies and action plans with detailed measures are more effective in their study of India's environmental regulation. The Chinese central government has issued a series of national technical standards that can meet the needs of current mainstream PH projects (Luo et al, 2020). However, the effectiveness of the issued national standards is constrained because of the lack of local supportive regulations in terms of the training, education, or skill certification of construction workers. TCs from learning can be effectively reduced when the economic scale of PH be attained with the support of systemic education and certification regulation by the local governments.

4.6 Conclusions

Under the conditions that Transaction Costs (TCs) are bringing additional burdens to the private stakeholders in PH, this study explored the factors influencing TCs in China's market from the developers' perspective. The statistical analysis showed that the developers perceived *Disputes* as the most critical source of TCs in PH in China's PH market. **Design changes, Learning, Assembly**, and **Decision-making** are also identified as relevant sources of TCs. Besides, the correlation analyses and ordered logistic regression indicated that the most influential factors for developer-related TCs in PH projects are: **Qualification of the general contractor; Local mandatory policies; Owner type***;* and **Competitiveness of the developer**.

In line with similar arguments from the conventional construction management and the TCs economic theory, this result highlights stakeholders' determining effects on TCs in the PH field. The ordered logistic regression also explained the directions of impacts from the influencing factors to particular TCs. The higher Qualification of a general contractor contributes to lowering the TCs for Dispute, Financing, Land-bidding, and Taxation. Improving the level of mandatory policies can reduce TCs arising from Identifying experienced partners and Signing sale contracts. Moreover, for the developers, TCs for decision-making in public projects are more likely to be higher than in private projects. Additionally, it was unexpected to find that the developer's more potent capability related to even higher TCs for procuring the general contractor, a finding which is counter-intuitive.

The results of critical TCs and influencing factors have provided substantial evidence on the mechanism of TCs in PH, which, in turn, inspires their application to minimize TCs for developers. Thus, there are three aspects to consider in these results:

First, in order to understand the essence of the identified critical TCs, corresponding measures are suggested to reduce developer TCs of most concern from the aspects of information searching and exchange. The activities of learning, such as project visits, educating, and meetings, are encouraged in order to reduce those high TCs arising from information searching in the subsequent tasks of Assembly and Decision-Making. Besides, developers are suggested to ensure the completeness of the design, in order to decrease the risks from subsequent Design Changes and Disputes, thus saving potential hidden costs from information exchange.

Second, suggestions are given to the developers regarding the influencing factors and the influencing mechanism. It is proposed that developers reduce TCs by enhancing their competitiveness, building good relationships with other parties, and upscaling the organization to improve their institution's efficiency. Moreover, developers are recommended to procure general contractors with high qualifications as long as their budget allows.

Third, policy recommendations are provided for the local governments to reduce TCs. The mandatory policies are expected to be popularized in Chinese provinces, while the level of the mandatory policies should be set considering the practical situation of different regions. TCs from learning can be effectively reduced when the economic scale of PH be obtained with the support of building systemic education and certification regulation by the local governments.

The contribution of this paper is to extend the theory by exploring factors that influence TCs in the PH and shedding light on the influencing mechanism of TCs. Practically, this study helps the developers investigate the nature of their TCs of most concern and further analyze the underlying reasons. Providing the enterprises understand how the influences are imposed, suggestions for developers are on the practical level to benefit the controlling of TCs in PH projects. Using a focus on the TCs of developers, the findings and methods in this study can be further applied to analyze the TCs of other PH stakeholders. Furthermore, taking China's market as an example, the conclusions of this study also provide useful references to PH in other developing countries and transitional construction markets.

There are some limitations to this study. One of them is that, when validating the list of the factors, an important factor – "social climate and attitude"– was suggested to be removed due to the difficulty of quantifying it in the model. Another limitation of this study is that the results are based on the market conditions current at the time of the survey, which may not be used to explain TCs and their influencing factors when the maturity of the PH industry is different. Therefore, the factors could be adjusted according to actual conditions when applied to other countries or to different PH development periods.

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5 A Bayesian Belief Network Model of Developers' Choices for Minimizing Transaction Costs in China's Prefabricated Housing

Submitted for review.

ABSTRACT

The implementation of prefabricated housing (PH) has become prevalent in China recently because of its advantages in saving energy, shortening the construction period, and improving production efficiency. However, the benefits of adopting PH cannot always be accrued by the stakeholders because of the arising of transaction costs (TCs). Developers in China play the leading role in most PH projects. Their choices can significantly influence TCs in the projects' development process. This study investigates the strategies for developers to make rational choices for minimizing the TCs of the PH project. A Bayesian belief network (BBN) model was applied as the analytical method, based on a questionnaire survey in China's PH market. The single sensitive analysis indicated that developers' three most impactful decisions influencing TCs are the Prefabrication rate, PH experience, and Contract payment method. Furthermore, joint strategies were developed based on the results of the multiple sensitivity analysis of the BBN model. Developers facing the high prefabrication rate challenge are suggested to reduce the risks by procuring high-qualified general contractors and adopting unit-price contracts. For developers with limited PH experience, adopting the Engineering-Procurement-Construction (EPC) procurement method is most efficient in reducing the TCs. The findings of this study contribute to the current body of knowledge concerning the effect of stakeholders' decisions on TCs.

KEYWORDS Transaction costs (TCs); Prefabricated housing (PH); Bayesian Belief Network (BBN); Developers

5.1 Introduction

Nowadays, sustainable development has become a promising direction for global construction practitioners. As a country with the largest construction market worldwide, with a total output value reached 24.84 trillion Chinese YUAN (CYN) in 2019 (PRC, 2019), China has put much effort into incorporating sustainability in construction projects. Adopting prefabrication in the house building sector is one of the major practices to achieve sustainability while ensuring higher quality, innovative products, and established management processes (Wang & Yuan, 2011). China's authority defines prefabricated housing (PH) as: "*Residential buildings that are assembled on site using prefabricated components*" (MOHURD, 2018). However, the Chinese construction industry's transformation from the use of conventional methods towards prefabrication is facing significant challenges. The new approach risks a mismatch between the existing governance system and the new PH supply chain, thus causing extra effort, time, and costs, and through this, higher transaction costs (TCs) (Wu et al, 2019; Zhai et al, 2014).

TCs generally refer to the costs of transactions beyond the materials cost of the product (Antinori & Sathaye, 2007). TCs are commonly identified in the traditional construction industry (Li et al, 2015), and they are more noteworthy in the innovative industries because of their higher proportion of total costs (Gooding

TOC

& Gul, 2016). However, in the field of PH, knowledge and evidence of TCs are still limited. In this study, TCs in the PH industry are defined explicitly as costs in terms of risks, time delay, information search, negotiation, contracting, organization set-up, monitoring, and enforcement (Wu et al, 2019).

Generally, the occurrence of TCs contributes to the increase in total construction costs, which can also lead to disputes, delays, abandonment, and low efficiency in the supply chain. The occurrence of TCs limits the efficiency of production and diminishes the stakeholders' enthusiasm (Qian et al, 2015). Accounting for quite a large percentage of the total cost, TCs bring both burdens and losses to stakeholders (Whittington, 2008). In China's context, project developers are generally recognized as the leading actor in the promotion of PH (Mao et al, 2015). These developers are also recognized as bearing more TCs than the other PH stakeholders (Wu et al, 2019). Therefore, it is of high necessity and value to understand and minimize the TCs from the developers' perspective.

As the clients of most private PH projects in China, developers are the decision-maker that defines the characteristics of the project and organizes the project team (Xue et al, 2018). Many of the TCs in the project development process are positively related to developers' choices in project characteristics, project management, and stakeholder management. Particularly, the project procurement methods chosen by the developer define particular transaction procedures, which essentially can affect the TCs in the projects (Coggan et al, 2013). Developers' decisions on contract payment methods determine the contractual relationships in PH projects' development, which results in different TCs for communication and coordination (Rajeh et al, 2015). The capability of the partners and contractors that the developers choose to collaborate with determines whether effective communication, mutual trust, and sound relationship can be ensured for PH projects development (Xue et al, 2018).

Private stakeholders in China's PH industry have minimal knowledge about the TCs, especially when they are still struggling with adapting to the prefabrication production mode (Wu et al, 2020). In this circumstance, it is even a challenge for the developers to make rational choices to avoid unexpected TCs. In practice, the choices open to developers can be limited by external or internal constraints. For example, a developer's experience on PH is a fixed condition, to be taken as a 'given'. This knowledge base can be improved in the long run, but hardly within a single project's development process, as all tasks are new, and choices to be made are for once only at the project level. Besides, the constraints might stem from the policies. For example, the required new-built PH projects' prefabrication rate should be higher than 40% in Shanghai (SMPG, 2017). In general, these constraints bring more challenges to the developers to make rational choices for lowering TCs in PH projects. As Winch (1989) claims, TCs tend to be higher in a situation that the ability to make rational decisions is limited or bounded. In academia, little is known on how the developers' choices influence the TCs in PH, let alone with rational strategies on minimizing TCs.

In response to the challenges in practice and the research gap in academia, this study aims to investigate the influences of developers' choices on TCs and to provide strategies for reducing TCs for China's PH projects. The following sub-questions are being answered in this study:

- **How are the developers' choices in related to TCs in PH projects?**
- **What are the most critical choices that can significantly influence developers' TCs?**
- **What are valuable strategies that developers can take to minimize TCs when facing various challenges?**

5.2 Developers and Transaction costs in the prefabricated housing

5.2.1 Role of developers in China's prefabricated housing

In China's PH industry, developers usually initiate the project, explore the consumers' demands, and set up the project organization. The development of PH in China is still in a transformation stage; therefore, the activities and practices of the stakeholders are not strictly defined. In this immature market, the developers' roles sometimes are a mix of the architect, consultant, or component supplier (). Wu et al (2019) define the transaction process of PH projects as five phases: 1) concept; 2) design; 3) manufacturing; 4) construction; and 5) operation and maintenance. Figure 5.1 demonstrates the development process of a typical Chinese PH project. It should be noted that developers are the critical stakeholder that links with the client, designers, contractors, government regulatory bodies, and the public (Wu et al, 2019). Most characteristics of the projects (e.g., scale, location, type) are decided by the developer in the conceptual phase (Mao et al, 2015). In the design and construction phase, other stakeholders, such as architects, consultants, general contractors, suppliers, etc., are hired by the developer (Zhang & Yu, 2020). Generally, during the whole development process of PH, the developer's choices largely determine the development process and characters of the stakeholders.

Having intensive contractual relationships and interactions with others, developers impose their significant influence on the transactions throughout the development process (Wu et al, 2020). According to Williamson (1985), decisions determine the asset specificity, frequency, and uncertainties of the transactions, determining the transaction costs (TCs). As such, developers' rationality in making choices is essential to the TCs, even to the success of the PH projects (Xue et al, 2018). However, in practice, developers may not always be able to make rational choices. Bounded rationality acknowledges that the decisions of rational people are bounded by the information available, time, cognition, and their ability to foresee all contingencies (Simon, 1950). Constrained by their internal or external environment, the irrational choices of the developers in many cases can result in higher TCs and low economic efficiency of PH projects.

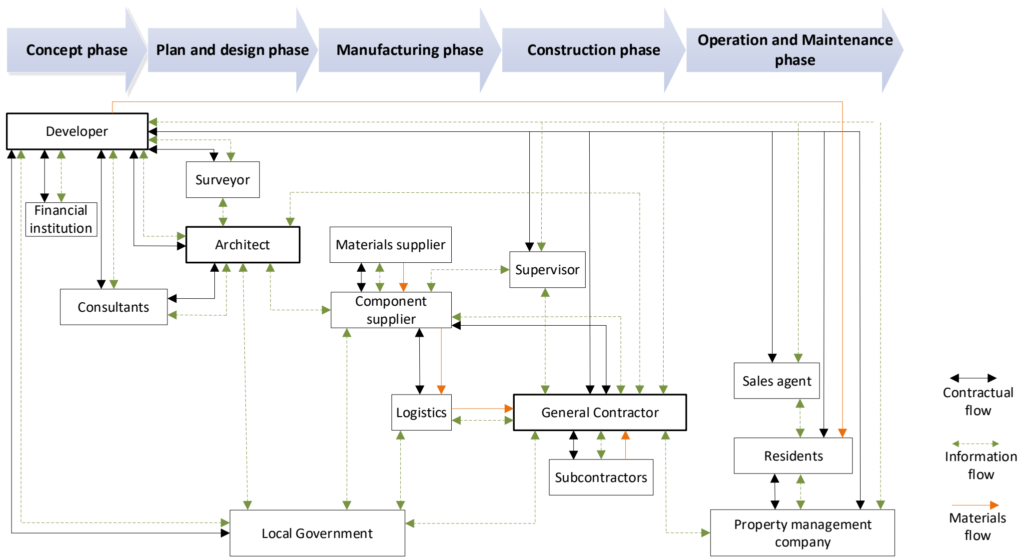

FIG. 5.1 A development process of a typical PH project in China (Wu et al, 2019)

5.2.2 Transaction costs from the perspective of developers

PH introduces a novel transaction mode in China's construction market, one which poses several challenges to stakeholders (Sha, 2004). By taking the role of the client in most PH projects, developers are bearing more TCs than other stakeholders in Chinese PH projects (Wu et al, 2019). Based on Wu et al (2019) and Wu et al (2020), Table 5.1 summarizes the source of TCs in a typical PH project from the developers' perspective. According to the TCs theory, TCs in the PH are summarized into three categories: costs of due diligence; costs of negotiation; and costs of monitoring and enforcement.

TABLE 5.1 Sources of TCs in PH projects from the perspective of developers

TCs category	Code	Sources of TCs	References
Costs of Due Diligence	CDD_1	Preparation of a project brief.	(Kiss, 2016)
	CDD_2	Evaluating the project's feasibility.	(Antinori & Sathaye, 2007)
	CDD_3	Identifying experienced partners.	(Kamali & Hewage, 2016)
	CDD_4	Consultation about prefabrication in the conceptual and design phase.	(Mao et al, 2015)
	CDD_5	Learning new technologies, digesting fresh information, and adapting the organization to the prefabrication mode.	(Wu et al, 2019)
	CDD_6	Decision-making regarding prefabrication technologies, prefabrication rate, etc.	(Wang et al, 2021)
	CDD_7	Preparing and participating in the land-bidding.	(Buitelaar, 2004)
	CDD_8	Land surveying	(Buitelaar, 2004)
	CDD_9	Procurement of the general contractor	(Wu et al, 2019)
	CDD_{10}	Drafting, negotiating, and signing the sale contracts.	
Costs of Negotiation	CN_1	Obtaining approvals and permits	(Qian et al, 2016)
	CN_2	Preparing and negotiating for the financing.	(Antinori & Sathaye, 2007)
	CN_3	Information searching, digesting, and communication for architectural design.	(Kamali & Hewage, 2016)
	CN_4	Information collection, communication, and coordination to complete the detailed design.	(O'Connor et al, 2015)
	CN_5	Setting up the project organization.	(Qian et al, 2015)
	CN_6	Communication, negotiation, time delay, and rework from the design change.	(Tam et al, 2015)
	CN_7	Taxation paid by the developer in the whole project development process.	(Xue et al, 2018)
Costs of Monitoring and Enforcement	CME_1	Dispute costs.	(Lu et al, 2015)
	CME_2	Communication, monitoring, and quality inspection for the assembly.	(Wu et al, 2019)
	CME_3	Advertising, popularization, and promotion of PH projects.	(Wu et al, 2019)

1. Costs of Due Diligence: It refers to the investigation of information, including searching for and assessing the acquired information. Apart from the TCs from project brief and feasibility study in conventional projects, efforts to look for potential partners with PH experience are identified as a significant source of TCs (Kamali & Hewage, 2016). Larsson & Simonsson (2012) cited the challenge of a lack of knowledgeable professionals for PH, especially experienced architects and engineers. Besides, for the decision-making in PH projects, the long lead-in time, additional work for information collection and analysis are also recognized as hindrances (Goodier & Gibb, 2007). TCs can arise from procuring activities, such as the preliminary design, translation of the client's needs, training, and site visits (Rajeh et al, 2015). Moreover, TCs from information analysis and exchange for contract signing could also be considerably higher due to the application of prefabrication (Mundaca, 2007).

2. Costs of Negotiation: It includes the efforts of obtaining permits, negotiating the design planning, and arranging finance. The architectural design of PH projects requires more effort to search, learn, and communicate compared with its conventional counterpart (Kamali & Hewage, 2016). Notably, detailed design in a PH project would typically consume the extra time of professionals taking the feasibility of assembly into account (O'Connor et al, 2015). Moreover, the design change is among the most severe hindrances in PH projects (Tam et al, 2015), generating communication, negotiation, time delay, and rework.

3. Costs of Monitoring and Enforcement: Costs for preparing a monitoring plan, continual supervision of production performance, and other activities to enforce contracts. To ensure the efficiency of executing the construction contracts, enforcement measures, such as construction monitoring and quality inspection for the assembly, are also taken by the developers (Rajeh et al, 2015). Additional time and costs can arise from formulating solutions for the disputes (Lu et al, 2015). Besides, as the owner of most private PH projects in China, developers are responsible for TCs from advertising for selling housing (Wu et al, 2019),

5.2.3 How the developers' choices influence TCs

The TCs theory expounds that stakeholders are vital in determining the TCs (Williamson (1985). In China's construction industry, the significant determinant of the economic efficiency for project developments is the choices made by developers (Li et al, 2012). At the project level, each choice of the developers may set off a chain reaction in the subsequent activities, therefore influencing TCs. Through an extensive review of the literature, this study investigates the influence of developers' choices on TCs of PH from seven aspects, as explained in the following sections.

1 Prefabrication rate

The prefabrication rate is measured by the ratio of the prefabricated volume to the total volume of the materials for a building (Hong et al, 2016). It is currently the most applied method in China to evaluate the prefabrication level of a PH project (Jin et al, 2020). Based on the application of PH in China, this study defines the level of prefabrication rate of PH in China as three levels: low (<25%), medium (25%-50%), and high (>50%).

The prefabrication rate is connected to Williamson's factor of asset specificity, which has a close association with TCs (Shahab et al, 2018). Developers' decisions about different prefabrication rates determine the TCs for due diligence, negotiation, and monitoring. Specifically, the prefabrication rate determines a PH project's technical complexity, thus influencing the costs for subsequent activities, such as: identifying experienced partners; consulting; learning techniques; and procuring the general contractors (Ho & Tsui, 2009). For example, the different levels of prefabrication rate influence negotiation costs, the costs of architectural design, detailed design, and design changes rate (Jiang et al, 2018). Moreover, the costs by developers of monitoring the assembly work differ significantly when the prefabrication rates are at different levels.

There is a relationship between the prefabrication rate and the general contractor qualification for PH projects. In the relatively immature PH market of China, most contractors are inexperienced in PH, especially for projects with a high prefabrication rate. Therefore, from the developers' perspective, when a high prefabrication rate has been set as the target, procuring a high-qualified general contractor would be less risky.

2 Project procurement method

The project procurement method defines procedures and routines tailored to a particular transaction (Coggan et al, 2013); therefore, it is vital for the TCs in a project. Nowadays, commonly-adopted contract procurement methods in China include the traditional Design-Bid-Build (DBB), Design-Build (DB), and Engineering-Procurement-Construction (EPC) (Wu et al, 2019).

TCs of negotiations vary greatly, based on the amount of information to be processed and codified in different procurement situations (Carbonara et al, 2016). In the DBB procurement method, the detailed design is usually completed before construction because the stages of design and construction are separated.

Thus, intensive negotiation and coordination between the architect, component supplier, and the contractors are needed at the design phase to ensure technology consistency for a successful assembly. Comparatively, in the integrated delivery modes, such as DB, there are lower TCs for detailed design but higher TCs for negotiation during construction (Ding et al, 2018). Furthermore, for procuring the general contractor, the cost of due diligence depends on the procurement method. Costs for searching and evaluating the candidate contractors are different for DB and DBB projects, depending on whether the prefabricated components supplier is integrated into the developers' business model (Liu et al, 2018).

The payment method often highly corresponds with the project procurement method adopted. Clearly, lump-sum and cost-plus-fee are the dominant contract payment methods, particularly for the DB projects (Chen et al, 2016). The procurement method determines the purchasing process to gain the product. The appropriate payment method is the strategy of paying for the product. Naturally, a rational and reasonable match between the project procurement system and the contract payment method is expected to maximize the project performance in the implementation (Ding et al, 2018).

3 Contract payment method

The most frequently-adopted contracts in Chinese PH projects fall into four types, based on payment methods, including: Lump-sum; Unit-price; Cost-plus-fee; and Guaranteed maximum price. The varied contract payment methods can lead to the diversity of TCs in the construction project (Li et al, 2014). Compared with the cost-plus-fee contract, the lump-sum contract allocates more uncertainties to the general contractor. Therefore, additional costs of contractual disputes are more likely to arise in lump-sum contracts (Müller & Turner, 2005). Besides, the payment method determines the developers' costs for monitoring and enforcement of the contract. For example, the unit-price arrangement necessitates more monitoring from the developers. It is mainly applied in projects where the volume of work is still an assumption (Ding et al, 2018). In addition, when adopting different contracts and considering the different requirements for the contractors, the developer's costs on searching, assessing, and procuring the general contractor are different (Wang et al, 2006).

4 Collaboration experience

The theory of information asymmetry and knowledge of specificity all point out that previous collaboration experience within a group of stakeholders is a critical influencing factor of TCs (Jobin, 2008). The skills, knowledge, and experience of particular staff are specific to a transaction (De Schepper et al, 2015). When the developers have a group of familiar co-operators, their due diligence costs can be significantly reduced to identify partners and procure the contractors (Wong et al, 2017). The challenges of communication, negotiation, and coordination from the detailed design and design changes can be better addressed if stakeholders have had previous collaboration (Coggan et al, 2013).

5 Experience of PH

The general experience of PH can contribute to lowering the TCs, especially when the lessons learned from completed projects can be kept in the organizational memory and used in future projects (Guo, 2016). Developers' experience from past PH projects contributes to saving TCs in due diligence, such as project briefing, feasibility study, learning, decision-making, etc. (De Schepper et al, 2015). The skills they acquired from similar projects also smooth the communication and negotiation for financing (Wu et al, 2021). In the design phase, developers with and without experience in PH undertake different workloads for the architectural design and the detailed design (Li et al, 2018).

6 Competitiveness of developer

According to the TCs theory, the capability/competitiveness of the contractual partners imposes a significant influence on the transaction and the TCs related (Williamson, 1985). In China's housing development market, the annually-released list of the Top 100 Real Estate Enterprises indicates the developers' competitiveness based on 52 business indices, including measures such as profitability, solvency, sustainable development, and operational capacity.

The developers' ranking indicates their different resources to guarantee production. Compared with enterprises ranking lower than 100, the top 10 enterprises that have reached revenue of more than 85 billion CYN (2019) naturally have advantages in learning new technologies, identifying partners, financing, etc. (Statista, 2020). Also, because of solid capability and a decent reputation, construction enterprises are more willing to cooperate with competitive developers (Wang et al, 2021). As a result, developers' procurement costs will be reduced. Similarly, the professional background of high-ranked developers smooths their negotiation with the local authorities and financial institutions. Moreover, the extant literature shows that large developers put more effort into advocating and generally promoting prefabrication, leading to the promotion of PH in China (Liu et al, 2017).

7 Qualification of the contractor

The qualification of the general contractors reflects their assets, main personnel, completed project performance, and technical equipment (MOHURD, 2015). The relevant Chinese authority evaluates the residential contractors on four levels: from special grade (highest level), through the first, second and to the third grade (lowest level). The contractors with high qualifications usually have an excellent background to build trust and confidence in cooperation (Li et al, 2014). Besides, contractors with different qualifications indicate different professionalization levels, resulting in different negotiation capabilities. A high-qualified contractor would improve the quality and efficiency of the detailed design because PH requires contractors' opinions to ensure the feasibility of the detailed design (Li et al, 2018). Moreover, developers' costs of monitoring and enforcement depend upon the qualification of the general contractors. Lu et al (2015) state that good contractors implementing sound contract management reduce the costs for monitoring, and fewer disputes during construction arise.

To summarize the statements above, Table 5.2 describes the hypothesized relationships between the developers' choices and categories of TCs.

TABLE 5.2 Hypothesized relationships between the developers' choices and TCs

Developers' choices	Category of the TCs	Related sources of TCs	References
Prefabrication Rate	Costs of Due Diligence	Identifying experienced partners.	(Li et al, 2018)
		Consultation about prefabrication.	(Ho & Tsui, 2009)
		Learning new technologies, digesting new information, and adapting the organization to the prefabrication mode.	(Ho & Tsui, 2009)
		Procurement of the general contractor	(Ho & Tsui, 2009)
	Costs of Negotiation	Information searching, learning, and communication for the architectural design.	(Jiang et al, 2018)
		Information collection, communication, and coordination for the detailed design.	(Jiang et al, 2018)
		Communication, negotiation, time delay, and rework from the design change.	(Jiang et al, 2018)
	Costs of Monitoring and Enforcement	Communication, monitoring, and quality inspection for the assembly.	Williamson, 1975
Project Procurement Method	Costs of Negotiation	Information collection, communication, and coordination to complete the detailed design.	(Ding et al, 2018)
	Costs of Due Diligence	Procurement of the general contractor	(Liu et al, 2018)
Contract Payment Method	Costs of Due Diligence	Procurement of the general contractor	(Wang et al, 2006)
	Costs of Monitoring and Enforcement	Dispute costs.	(Ding et al, 2018)
		Communication, monitoring, and quality inspection for the assembly.	(Wu et al, 2021)
Collaboration Experience	Costs of Due Diligence	Identifying experienced partners.	(Wong et al, 2017)
		Procurement of the general contractor	(Wong et al, 2017)
	Costs of Negotiation	Information collection, communication, and coordination to complete the detailed design.	(Coggan et al, 2013)
		Communication, negotiation, time delay, and rework from the design change.	(Coggan et al, 2013)
	Costs of Monitoring and Enforcement	Dispute costs.	(Wu et al, 2021)

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TABLE 5.2 Hypothesized relationships between the developers' choices and TCs

Developers' choices	Category of the TCs	Related sources of TCs	References
PH Experience	Costs of Due Diligence	Preparation of a project brief.	(Guo, 2016)
		Evaluating the project's feasibility.	(De Schepper et al, 2015)
		Identifying experienced partners.	(De Schepper et al, 2015)
		Consultation about prefabrication in the conceptual and design phase.	(Wang et al, 2021)
		Learning new technologies, digesting new information, and adapting the organization to the prefabrication mode.	(Guo, 2016)
		Decision-making for adopting prefabrication technologies and the prefabrication rate.	(De Schepper et al, 2015)
		Procurement of the general contractor	(Wang et al, 2021)
	Costs of Negotiation	Preparing and negotiating for the financing.	(Wu et al, 2021)
		Information searching, learning, and communication for architectural design.	(Li et al, 2018)
		Information collection, communication, and coordination to complete the detailed design.	(Li et al, 2018)
Competitiveness of Developer	Costs of Due Diligence	Identifying experienced partners.	(Wang et al, 2021)
		Learning new technologies, digesting new information, and adapting the organization to the prefabrication mode.	(Liu et al, 2017)
		Procurement of the general contractor	(Wang et al, 2021)
	Costs of Negotiation	Obtaining approvals and permits	(Wang et al, 2021)
		Preparing and negotiating for the financing.	(Wu et al, 2021)
	Costs of Monitoring and Enforcement	Advertising, popularization, and promotion of PH projects.	(Liu et al, 2017)
Qualification of the General Contractor	Costs of Due Diligence	Procurement of the general contractor	(Li et al, 2014)
	Costs of Negotiation	Information collection, communication, and coordination to complete the detailed design.	(Li et al, 2018)
		Communication, negotiation, time delay, and rework from the design change.	(Li et al, 2018)
	Costs of Monitoring and Enforcement	Dispute costs.	Lu et al (2015)
		Communication, monitoring, and quality inspection for the assembly.	Lu et al (2015)

5.3 Methodology

The Bayesian Belief Network (BBN) model is adopted in this study to explore strategies for the developers to reduce TCs in PH. To develop the BBN model for predicting TCs, a perception-based survey was conducted in China's PH industry to obtain information about the choices of the developers and TCs. The single contributor sensitivity analysis and multiple sensitivity analysis predict the influence of developers' choices on TCs and provide strategies for minimizing the TCs. Figure 5.2 illustrates an overview of the development of the BBN model and data analysis.

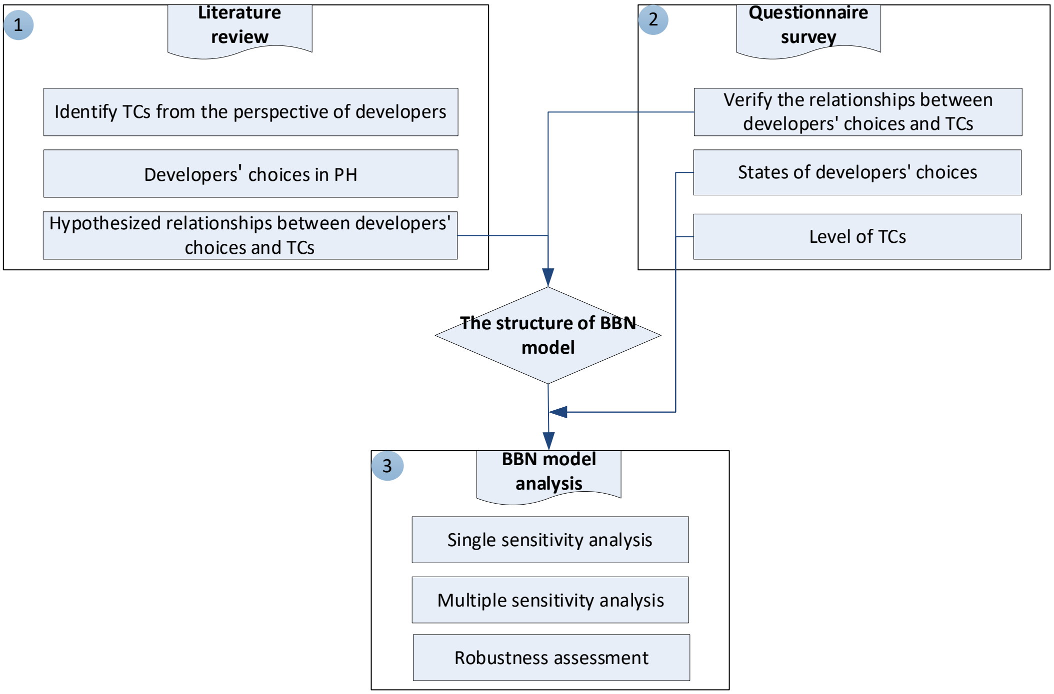

FIG. 5.2 Overview of the research design

TOC

5.3.1 Questionnaire survey

For developing the BBN model, a perception-based questionnaire survey was conducted in China. From 20th December 2019 to 8th March 2020, the questionnaires were developed and distributed through an online survey tool - wj.qq.com. With the assistance of the secretary of a professional organization - precast.com.cn, the questionnaires were distributed to around 1500 of their members. It is an organization established in 2010 by several provincial Building Industrialization Associations in China, which provides a reliable platform to reach PH professionals. Setting up a verification that only the respondents currently working for PH developers can continue filling out the questionnaire, 589 valid responses were received. The valid samples were collected from 31 of 34 provinces in China (no sample from Tibet, Hong Kong, and Taiwan).

The questionnaire was designed with three sections. The first section collected the information about the states of developers' choices (with the explanation of the states given). Table 5.3 shows the descriptive statistics of the choices. The second section was designed to evaluate the twenty sources of TCs using a five-point Likert-type scale from 1 (extremely low) to 5 (extremely high). The third section asks for the strength of the connection between developers' choices and related TCs ("1" = No connection; "5" =Significant determinant).

TABLE 5.3 Descriptive statistics of developers' choices

	Developers' choices	Code	States	Percent %
F1	Prefabrication Rate	1	Low	44,1
		2	Medium	44,9
		3	High	10,9
F2	Project Procurement Method	1	DBB	35,7
		2	DB	27,9
		3	EPC	17,8
		4	Others	18,6
F3	Contract Payment Method	1	Lump-sum	49,0
		2	Unit-price	23,5
		3	Cost-plus-fee	17,4
		4	Others	10,1
F4	Collaboration Experience	1	Yes	72,9
		2	No	27,1
F5	Experience of PH	1	Low; <3	43,3
		2	Medium 3-10	40,9
		3	High; >10	15,8
F6	Competitiveness of Developer	1	TOP 10	19,4
		2	10-50	20,6
		3	50-100	18,6
		4	Lower than 100	41,3
F7	Qualification of the General Contractor	1	Special grade	30,0
		2	First grade	40,1
		3	Second grade	17,8
		4	Third grade	12,1

5.3.2 Bayesian belief network

A Bayesian belief network (BBN) is a directed graphical model representing conditional probabilities among variables (Dogan & Aydin, 2011). The BBN model is a powerful and flexible tool for modeling the causal interrelationships among some variables. Zhou et al (2008) stated that BBN is an effective method for analyzing safety behavior in construction projects by investigating the relationships between safe work behavior and their contributors. García-Herrero et al (2013) used BBN to explain the relationships between work demands and occupational stress. With the ability to update the belief values, probabilistic analysis, and examine complex inferences, the BBN is useful for assessing the value of information and achieving rational decision-making (Jitwasinkul et al, 2016).

A BBN consists of two critical parts - qualitative and quantitative (Van Der Gaag, 1996):

1) The qualitative part is to forming the relationships among the variables, which can be represented by directed acyclic graphs (DAGs). The graph constructs complex causal relationships, consisting of nodes representing discrete or continuous variables, and links causal relationships between nodes. Those nodes designated as the starting ones, (and so do not have an inward arrow), are called the **parent** nodes. The other nodes, which have inward arrows connected to them, are the **child** nodes. In this study, all the nodes are represented by discrete variables;

2) The quantitative part of a BBN is the parameters-learning. The joint conditional probability distributions model the dependence relations among the variables. The calculations are based on the original Bayes rule:

$$P\left(A/B\right)=\frac{P\left(B/A\right)P\left(A\right)}{P\left(B\right)} \quad (1)$$

The complexity of Bayesian Networks is related chiefly to the connectivity of nodes rather than the number of variables in the network. The complexity of the model increases with the number of variables and their states. In order to run the calculations, it is necessary to define the states for all the variables. There is a **conditional probability table** (CPT) for each variable, which presents the probabilities of the variable according to various states of its parent nodes. Specifically, a variable X_i with its parents, $pa\left(X_i\right)$, specifies a conditional probability distribution, $P\left(X_i\middle|pa\left(X_i\right)\right)$. The joint distribution of $P\left(\chi\right)$ is defined by the Bayesian network as:

$$P\left(\chi\right)=\prod_{i=1}^{n}P\left(X_i\middle|pa\left(X_i\right)\right) \quad (2)$$

Where $P\left(\chi\right)=P\left(X_1,\ldots,X_n\right)$; $pa\left(X_i\right)$ is the set of parents of X_i.

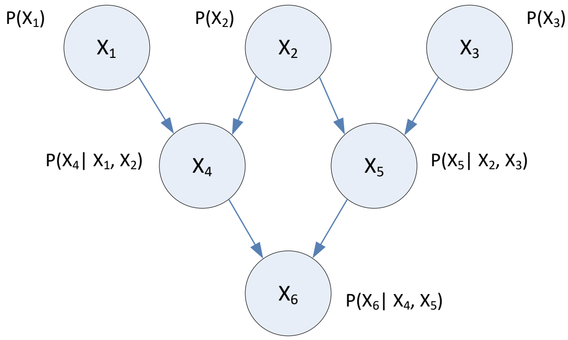

FIG. 5.3 An example of a simple Bayesian Belief Network

One of the most significant advantages of using Bayesian Networks is to facilitate flexible inference with partial information. Figure 5.3 gives an example of BBN. When the information of other variables $\left(U=\left\{X_1,X_2,X_3,X_4,X_6\right\}\right)$ is available, the probability of the variable X_5 can be calculated as:

$$
\begin{aligned}
P\left(X_5|U\right)&=\frac{P\left(X_1\right)P\left(X_2\right)P\left(X_3\right)P\left(X_4|X_1,X_2\right)P\left(X_5|X_2,X_3\right)P\left(X_6|X_4,X_5\right)}{\sum_{X_5}P\left(X_1\right)P\left(X_2\right)P\left(X_3\right)P\left(X_4|X_1,X_2\right)P\left(X_5|X_2,X_3\right)P\left(X_6|X_4,X_5\right)}\\
&=\frac{P\left(X_5|X_2,X_3\right)P\left(X_6|X_4,X_5\right)}{\sum_{X_5}P\left(X_5|X_2,X_3\right)P\left(X_6|X_4,X_5\right)}
\end{aligned}
\qquad (1)
$$

According to Eq. (1), the conditional independence of all variables in the BBN can be calculated. In our research, the Netica software was used for data analysis. This tool supports different exact and approximate inference algorithms, parameters, and structure learning.

5.4 Bayesian Belief Network model

The input of the BBN model for TCs requires three main elements: 1) A validated structure that describes the relationships between the nodes (including the relationships between choices, the relationships between the choices and the TCs) ; 2) States of the choices; and 3) Values of all the TCs.

5.4.1 Structure of the BBN model

The first step before BBN calculation is to formulate the structure of the causal network. The Bayesian Network for controlling TCs is structured through extensive literature studies and a questionnaire survey. The relationships between developers' choices have been clarified by the literature study, which can be further validated by the third section of the questionnaire. Precisely, the influence of each choice on the TCs is calculated by the mean of TCs within the same category. The most significant influences (Threshold=3.3) are verified as the effective relationships, as marked in Table 5.4.

TABLE 5.4 The validated relationships between the developers' choices and TCs

Developers' Choices	Sources of TCs	Mean of the influence	Category of the TCs	Mean of the influence
Prefabrication Rate	CDD_3	3,22	Costs of Due Diligence	3.26
	CDD_4	3,30		
	CDD_5	3,32		
	CDD_9	3,21		
	CN_3	3,32	Costs of Negotiation	3.28
	CN_4	3,11		
	CN_6	3,41		
	CME_2	3,38	Costs of Monitoring and Enforcement	3.38*
Project procurement method	CDD_9	3,25	Costs of Due Diligence	3,25
	CN_4	3,33	Costs of Negotiation	3,33*
Contract payment method	CDD_9	3,16	Costs of Due Diligence	3.16
	CME_1	3,43	Costs of Monitoring and Enforcement	3.40*
	CME_2	3,38		
Collaboration experience	CDD_3	3,42	Costs of Due Diligence	3.07
	CDD_9	3,32		
	CN_4	3,43	Costs of Negotiation	3.47*
	CN_6	3,51		
	CME_1	3,53	Costs of Monitoring and Enforcement	3.53*
PH Experience	CDD_1	3,26	Costs of Due Diligence	3.33*
	CDD_2	3,28		
	CDD_3	3,33		
	CDD_4	3,36		
	CDD_5	3,42		
	CDD_6	3,37		
	CDD_9	3,26		
	CN_2	3,44	Costs of Negotiation	3.44*
	CN_3	3,32		
	CN_4	3,56		
Competitiveness of the Developer	CDD_3	3,46	Costs of Due Diligence	3.38*
	CDD_5	3,36		
	CDD_9	3,31		
	CN_1	3,35	Costs of Negotiation	3.40*
	CN_2	3,45		
	CME_3	3,27	Costs of Monitoring and Enforcement	3.27
Qualification of the General Contractor	CDD_9	3,24	Costs of Due Diligence	3.24
	CN_4	3,40	Costs of Negotiation	3.40*
	CN_6	3,40		
	CME_1	3,39	Costs of Monitoring and Enforcement	3.37*
	CME_2	3,35		

Table 5.5 summarizes the relationships for structuring the BBN model. This structure demonstrates the relationships of variables on two levels: First, it clarifies the relationships between the developers' choices and three categories of TCs. Costs of the due diligence are impacted by the developers' experience of PH and their competitiveness. The primary determinants of the negotiation costs are the project procurement method, developers' collaboration experience, competitiveness, and PH experience. Developers' choices, regarding the prefabrication rate, contract payment method, qualification of the general contractor, and the collaboration experience, are the prominent influencers of the Costs from monitoring and enforcement. Second, the structure reveals the determinant effect of the project procurement method for deciding on the payment method. The qualification of the general contractor is influenced by the prefabrication rate and the project procurement method. Given the described relationships above, Figure 5.4 visualizes the structure of this BBN model.

TABLE 5.5 TABLE 5.5 Description of the relationships for structuring the Bayesian Belief Network

Code	Node description	Preceding node(s)	Following node(s)
F1	Prefabrication rate	--	F7, CME
F2	Project procurement method	--	F3, F7, CN
F3	Contract payment method	F2	CME
F4	Collaboration experience	--	CN, CME
F5	Experience on prefabrication	--	CDD, CN
F6	Competitiveness of the developer	--	CDD, CN
F7	Qualifications of the contractor	F1, F2	CME
CDD	Costs of due diligence	F5, F6	TCs
CN	Costs of negotiation	F2, F4, F5, F6	TCs
CME	Costs of monitoring and enforcement	F1, F3, F4, F7	TCs
TCs	Transaction costs	CDD, CN, CME	

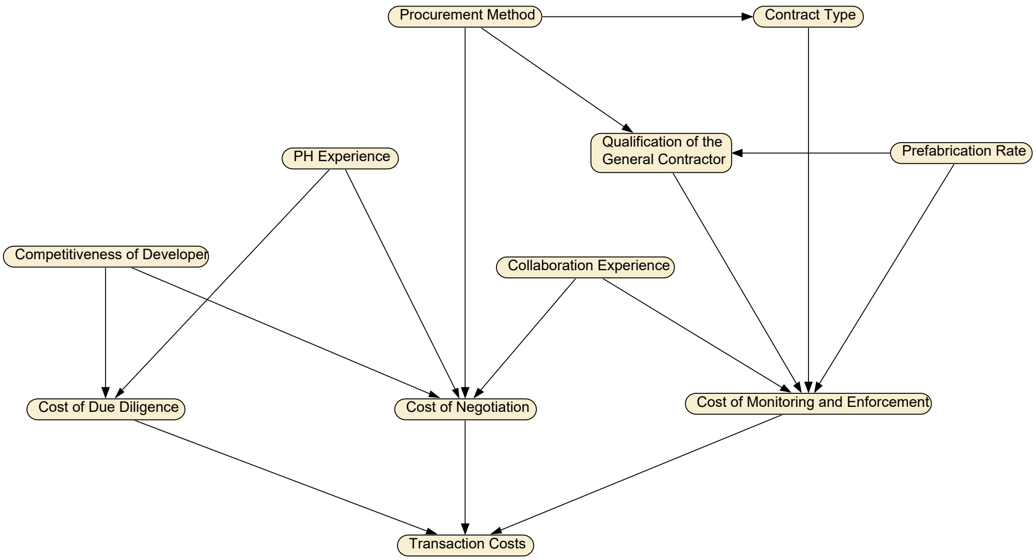

FIG. 5.4 The structure for the Bayesian Belief Network model of TCs in PH

5.4.2 Conditional probability distributions of the Bayesian Belief Network model

Based on the validated relationships among the developers' choices and the TCs, the processed data were imported into Netica 23.0 for analysis. Case-learning is the approach adopted in this study for input data in Netica. The setting of **Expectation-maximization** (EM) learning was used because there are minimal missing values of the raw data from the questionnaire (Norysys). Figure 5.5 shows the final developed BBN model for the TCs and developers' choices for China's PH projects.

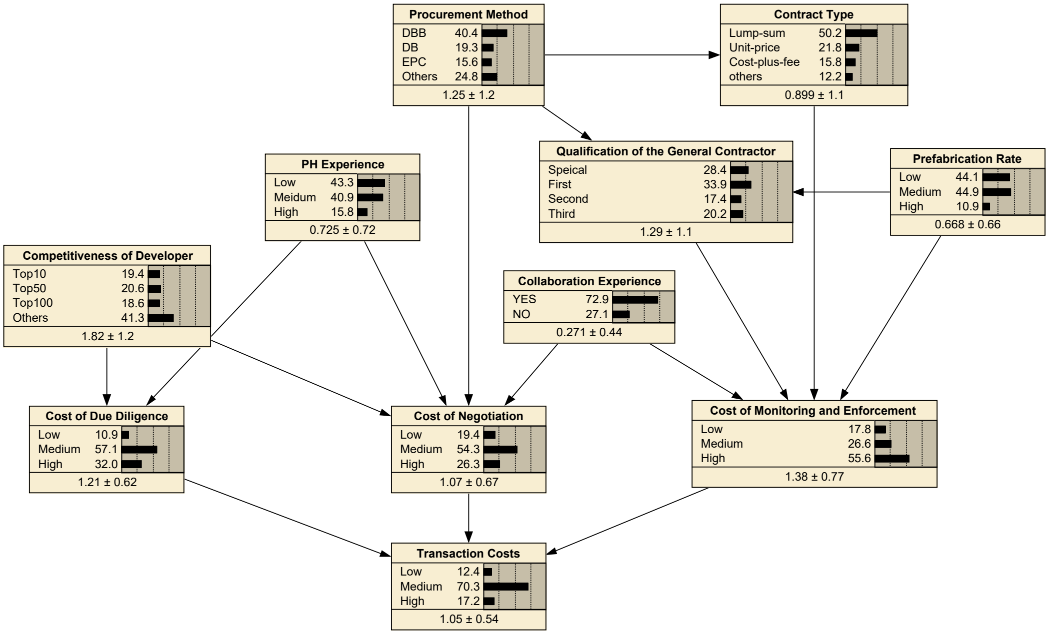

FIG. 5.5 Bayesian Belief Network model of TCs

The original contribution from the use of the BBN model arises from its handling of uncertainties from developers' choices and representation of dependence relations between those choices and TCs. The uncertainties under different situations can be measured by using the conditional probability table (CPT). The CPT shows the probability (in terms of percentage) of the factor that is determined by the survey data in this study. For example, the conditional probability of node (F7) relies on its parent nodes – Prefabrication rate (F1) and Procurement Method (F2), conventionally written as P(P(F7|F1), F2). In this case, there are twelve possible conditional probability states, which are assigned based on knowledge of the parent node, such as (F1= Low, F2 = DBB), (F1= Low, F2 = DB), and (F1= Low, F2 = EPC). The total of the probabilities of the perceived behavioral control node in each role should be equal to one, which is illustrated in Table 5.6. Accordingly, the elements for the CPT of F7 would be 4 x 3 x 4 x 2 x 3 = 288. The sample size of this research is decided by the largest elements in the conditional probabilities table among all the nodes. As a consequence, at least 288 samples should be input to ensure that adequate data can be supplied to make the conditional probability table, a condition which is met in this study.

TABLE 5.6 Conditional Probability Table of Qualification of the General Contractor - P(F7|F1, F2)

Condition		F7 Qualification of the General Contractor			
F1 Prefabrication rate	F2 Procurement Method	Special grade	First level	Second level	Third level
Low	DBB	0.341	0.295	0.182	0.182
Low	DB	0.190	0.477	0.286	0.048
Low	EPC	0.353	0.471	0.118	0.058
Low	Others	0.222	0.222	0.111	0.444
Medium	DBB	0.436	0.385	0.154	0.026
Medium	DB	0.190	0.514	0.216	0.081
Medium	EPC	0.250	0.400	0.250	0.100
Medium	Others	0.467	0.267	0.133	0.133
High	DBB	0.600	0.398	0.001	0.001
High	DB	0.091	0.634	0.273	0.091
High	EPC	0.285	0.571	0.143	0.001
High	Others	0.250	0.740	0.001	0.001

5.5 Results

In order to investigate the impacts of developers' choices on the TCs, sensitivity analyses were conducted. The single sensitivity analysis was applied to identify simple strategies that make the most efficient improvement in TCs. The multiple sensitivity analysis investigated the most efficient joint strategy for developers to minimize TCs when facing challenges/constraints.

5.5.1 Single sensitivity analysis

For assessing the sensitivity of each choice to the final TCs, the method - Sensitivity to Finding is adopted. The sensitivity of a variable to the finding can be measured by the index of mutual information (MI). MI reflects the level of predictability of one parameter when the information of another parameter is available (Mohammadfam et al, 2017). As shown in Table 5.7, the MI results between developers' choices and the TCs indicate the importance of the choices to the TCs.

TABLE 5.7 Sensitivity analysis result of the node “TCs”

Node	Node description	MI	Percent	Variance of Beliefs
TCs	Transaction costs	1.16813	100	0.2752644
CN	Costs of negotiation	0.34292	29.40	0.0652630
CDD	Costs of due diligence	0.18339	15.70	0.0297689
CME	Cost of Monitoring and Enforcement	0.08189	7.02	0.0148604
F1	Prefabrication rate	0.01342	1.15	0.0024190
F5	PH Experience	0.02393	2.05	0.0046792
F3	Contract payment method	0.00733	0.63	0.0012935
F2	Procurement method	0.01373	1.18	0.0024144
F6	Competitiveness of the Developer	0.00201	0.17	0.0003896
F7	Qualification of the General Contractor	0.00084	0.07	0.0000922
F4	Collaboration experience	0.00057	0.02	0.0000252

Table 5.7 shows that the MI value of “Costs of Negotiation” is the largest, which means it is the most critical contributor to the final TCs. Additionally, according to the simple sensitivity analysis, it can be inferred that the choices having the most considerable effect on the TCs are: Prefabrication rate (F1), PH Experience (F5), and Contract Payment Method (F3).

The MI index only indicates the strength of the influence between two nodes. To further investigate the specific impact of these dominant choices, the proportions of TCs at different levels are calculated considering various states of the choices (As shown in Table 5.8). Our survey results showed that the Low-level prefabrication rate results in the lowest possibility (15.2%) of high TCs. This possibility increased to 32.8% when a high prefabrication rate was set up. Besides, it is not surprising that the higher developers’ experience, the lower the level of TCs. The possibility of High TCs was only 8.60% when the experience was at a high level. As for the influence of the Contract Payment Method (F3) on the TCs, adopting the lump-sum contracts was founded to result in the lowest possibility of “High” TCs.

TABLE 5.8 The achievable proportion of TCs by changing the most influential choices

Influential choices			TCs		
		States	Low	Medium	High
F1	Prefabrication Rate	Low	11.7	73.1	15.2*
		Medium	13.5	71.1	15.5
		High	10.1	57.1	32.8
F5	PH Experience	Low	12.6	64.7	22.6
		Medium	14.9	70.3	14.9
		High	5.48	85.9	8.60*
F3	Contract Payment Method	Lump-sum	11.3	73.5	15.2*
		Unit-price	14.4	68.8	16.8
		Cost-plus-fee	14.0	68.7	17.3
		Others	11.5	62.0	26.5

** The lowest possibility to cause a “High” TCs.*

5.5.2 Multiple sensitivity analysis

In addition to the simple strategies about individual choices, developers can further reduce the TCs by considering more than one choice. Multiple sensitivity is one of the main advantages of the BBN model. The posterior probability of a variable can be determined by integrating two or more hypotheses. The automatic inference function of the BBN model investigated the most beneficial combinations of the choices in different situations. Table 5.9 illustrates the most positive joint strategies for minimizing TCs.

1 For developers facing the challenge of a high prefabrication rate:

For certain types of projects, the prefabrication rates are required by the local authority or decided by the decision-maker of the real-estate companies. In those cases, high TCs will occur at a 32.8% of possibility. The investigations were carried out to explore the joint strategies. Notably, with high prefabricated rates, the possibility of high TCs can be reduced dramatically from 32.8% to 11.2% when procuring special-grade general contractors and adopting unit-price contracts. This strategy also fits the situation when a medium-level of prefabrication rate is required.

2 For developers with limited experience for PH:

Currently, there are still limited numbers of experienced developers for PH projects in China. As analyzed, limited experience raises the chance of high TCs from due diligence and negotiation. Investigations were carried out to adjust other choices that impact the costs of due diligence and negotiation. The BBN model indicated that the possibility of incurring "High" TCs is 22.6% and 14.9% when developers with experience for PH at low-level and medium-level, respectively. This possibility can be reduced when the EPC procurement method was adopted (as shown in Table 5.9). Especially for the developers with medium-level of experience, the choices of using EPC contract showed an extremely low possibility (5.45%) of the redundant TCs.

3 No constraints for developers' choices:

An ideal situation to minimize the TCs is to allocate the influential choices to their most favorable states without constraints. For the developers who have an absolute right to make the choices, investigations by the BBN model were carried out to identify the most efficient choices for minimizing the TCs. As illustrated in Table 5.9, the lowest possibility (21.3%) of "High" TCs is achieved when the most influential choices are ordered at certain states (F1=Low; F5= High; F3= Lump-sum).

TABLE 5.9 Joint strategies for minimizing TCs when developers facing different challenges

Scenarios		Combined choices	TCs (%)		
			Low	Medium	High
No constraints		F1=Low F5=High F3=unit-price	3.25	94.2	2.58
Prefabrication rate	Medium	F3=unit-price F7=Special grade	11.3	68.6	20.1
	High	F3=unit-price F7=Special grade	16.3	73.5	11.2
Experience on PH	Low	F2= EPC	20.1	59.4	20.5
	Medium	F2= EPC	1.86	92.7	5.45

5.5.3 Robustness assessment of the BBN model

In order to enable the further applicable adoption of this BBN model in the PH industry, it requires its accuracy and robustness to be at an acceptable level. Therefore, the robustness of it is tested by 62 randomly selected new cases. As shown in Table 5.10, the error rates for predicting the TCs on the LOW level and HIGH levels are 20.00% and 21.05%. With a total error rate of 11.29%, the established BBN's prediction accuracy is generally acceptable.

TABLE 5.10 Robustness test of the BBN model using the values of TCs in 62 random cases

TCs (actual)	TCs (predicted)			Error rate (%)
	Low	Medium	High	
Low	8	2	0	20.00
Medium	1	32	0	3.03
High	0	4	15	21.05
Total error rate:				**11.29%**

5.6 Discussion

5.6.1 Relationships between developers' choice and the nature of the TCs

1 Cost of Due diligence

The statistics results of the survey indicate that the *PH Experience* and the *Competitiveness of the Developer* are the primary determinants of the due diligence costs. By their very nature, the developers' capability is the principal influence of the due diligence costs in PH projects.

This study shows that the richer the experience the developers have, the lower TCs will be, which is similar to the argument of Coggan et al (2013). The challenges of information-searching, learning, and governance could be better addressed if stakeholders have had previous experience in similar transactions. Besides, developers' competitiveness indicates a significant influence on TCs due to the differences in due diligence efforts. Their reputation and operational capacity mirror their capability to respond to the changes and risks; therefore, the bidding and partners-searching costs differ considerably (Haan et al, 2002). Compared with small enterprises, competitive real estate developers naturally have advantages in learning new technologies, identifying partners, financing, etc., (Statista, 2020).

2 Cost of Negotiation

Negotiation costs are influenced by the *PH Experience, Collaboration Experience*, *Competitiveness of the Developer*, and the *Procurement Method.* As observed, developers' choices regarding the efficiency of information exchange influence the negotiation cost most considerably.

PH Experience and Collaboration Experience showed significant influences on the TCs of negotiation, indicating the benefits of frequency to the information exchange. Frequent transactions reduce uncertainty over the transaction and this creates trust between the parties involved (Williamson, 1985), reducing the TCs from the coordination and negotiation. Besides, the survey indicated that different procurement methods lead to the variation of TCs on the aspect of negotiation. The procurement method determines the frequency of transaction in the project supply chain. The greater the frequency of transactions, the more the TCs are associated with coordinating and negotiating (Chen et al, 2013). Moreover, developers with different competitiveness devote different levels of effort in negotiations for production activities, e.g., obtaining approvals and financing.

3 Cost of Monitoring and Enforcement

Developers' choices for the *Prefabrication rate*, *Contract Payment Method, Qualification of the general contractor*, and the *Collaboration Experience* reveal significant influences on the TCs arising from monitoring and enforcement. Notably, developers' TCs of monitoring and enforcement are determined mainly by their choices regarding uncertainties and risks.

The questionnaire survey indicated that the prefabrication rate determines the technical complexity of the architectural design, the detailed design, and the design change, which directly impacts the volume of the monitoring tasks. A high prefabrication rate usually means high technical uncertainties in manufacturing, transportation, and assembly. Correspondingly, more supervision and monitoring are necessary from the developers to ensure the quality of the products. Besides, the developers' risks are depending on the procurement methods adopted (Li et al, 2014). For example, extra costs from monitoring and quality inspection for the assembly vary between the DBB and EPC projects due to the difference in developers' responsibilities. Similarly, the TCs from monitoring and enforcement are different when procuring general contractors with varying qualification levels. Additionally, the previous collaboration experience contributes to reducing TCs because of decreasing efforts to enforce contract execution (Mettepenningen & Van Huylenbroeck, 2009).

5.6.2 Simple strategies for developers to minimize the TCs

The single sensitivity analysis of the BBN model indicates that the *Prefabrication Rate*, *PH Experience,* and *Contract Payment Method* are the three most influential choices determining the developers' TCs. Accordingly, simple strategies are recommended for the developers to minimize the TCs.

Pursue a best-matched prefabrication rate instead of the highest rate

The *Prefabrication Rate* is a significant explanatory factor to developers' TCs in PH. Although a high prefabrication rate grows the TCs, it does not mean that developers are encouraged to keep the prefabrication rate low. To set the prefabrication rate, developers are suggested to consider the local government's requirements and their companies' capabilities. First, developers are advised to follow the mandatory regulations about prefabrication rate if they apply to the projects' regions. Second, in the regions with no mandatory policies yet established, developers are suggested to implement the most efficient prefabrication rates that best match their supply chains. For the private real estate companies, an appropriate upswing in the prefabrication rate might increase the short-term TCs regarding learning and organization adaption. Nevertheless, in the long term, the improvement of the prefabrication rate entails benefits on integrating the supply chain, shortening onsite working time, and saving resources.

Minimize the TCs by experience learning

For developers with rich *PH experience,* a higher possibility of lowering TCs in PH is indicated for projects. However, in China's context, the leading companies of PH are mainly large-scale developers (e.g., top 50 real estate companies). Lacking experience is more of a barrier to small companies. However, *PH Experience* of a company is not possible to be improved in the short-term. Alternatively, a sustainable development strategy for small-scale real estate companies is to learn from the experienced large developers. First, the small-scale developers are encouraged to learn by visiting large companies and successful PH projects. It is a proven effective method for reducing TCs in other fields (Kiss, 2016). Second, a more efficient strategy is to hire professionals/skilled workers who have experience in PH. Although the hiring of experienced workers would increase labor costs, it reduces costs from adapting, information-searching, consulting, etc. The increasing numbers of professional employees improves a company's professionalism, enhancing production efficiency, reducing the TCs, and becoming more competitive for attracting co-operators (Wang et al, 2021). Generally, experience-learning and hiring experienced employees are conducive to enlarge the developers' market size and bring the benefits of scale-economics.

Allocate the risks rationally by choosing appropriate contract payment methods

The *Contract Payment Method* indicates how risks are allocated between the developers and the general contractor, and risk is a vital source of TCs in the concept of TCs (Dorward, 2001). This study shows that the possibility of rising TCs by the lump-sum contracts is lower than the unit-price and the cost-plus-fee contracts. It is because the lump-sum contracts assign more risks to the general contractor rather than to the developers. In this sense, developers' workload on monitoring and enforcement is less in the lump-sum contracts than the other types of contracts. As such, the lump-sum agreement usually is beneficial to be adopted by the developers for the PH project. Despite this fact, it does not mean that lump-sum is always the best type of contract for Chinese PH projects. In practice, developers are suggested to use the unit-price contracts in projects where the design and specifications for the prefabrication parts are not complete (Li et al, 2014). The lump-sum contract is more applicable when the scope of the project is clearly defined. Additionally, the cost-plus-fee is the least recommended payment method since the cost risk would be borne by the developers entirely, while the contractors have less incentive on cost-control in those cases.

5.6.3 Joint strategies for developers to minimize the TCs

Joint strategies were investigated when developers face various challenges. Accordingly, some practical implications are concluded for the developers to reduce the benefits lost from TCs.

In the current exploring stage of PH in China, numerous developers face the technical challenge of the high prefabrication rates. In this case, the BBN model predicts a positive result when procuring special-grade general contractors and unit-price contracts. It is an approach to reduce uncertainties of the transactors and the transactions according to the TCs theory (Winch, 1989). A high prefabrication rate indicates a high technical complexity, for which support is sought from the high-certificated general contractors, which is conducive in controlling the uncertainties. This is in line with the arguments of Wu et al (2021). Meanwhile, adoption of the unit-price contract is applicable for high uncertainty projects, which is similar to the well-established construction management theory (Picornell et al, 2017). With the PH development, there would be more critical technical challenges other than the high prefabrication rate. Eliminating the uncertainties from stakeholders and transactions can always be an applicable rule to minimize the TCs for technical-complicated PH projects.

This study demonstrated that the lack of experience causes high TCs. However, the developer's shift towards being experienced cannot be changed in a short period. The BBN model's multiple sensitivity analysis revealed that adopting the EPC contracts is an effective strategy for inexperienced developers to minimize their TCs. This result supports the current advocating for EPC by Chinese authorities (GOSC, 2019). In an EPC mode, the general contractors charge the whole process for design, procurement, manufacturing, and construction. Some of the EPC contractors even own their affiliated factories to provide prefabricated components/modules. For the inexperienced developers, EPC means fewer efforts to transfer information between contractors, e.g., architects, construction companies, suppliers, etc. Therefore, TCs can be vitally reduced because of less inter-organization interaction, thus, the highly-efficient negotiation. In general, in a PH project, in which the developer is not well-experienced, the adoption of EPC would be a wise choice to minimize their TCs.

The BBN model indicated an ideal theoretical situation when a highly-experienced developer imitates a low-prefabricated project (Prefabrication rate < 20%), while the Lump-sum contract is adopted, TCs can be optimized. Notably, this result can only be reached when the assumption of no-constraints is met. As analyzed, high experience and low prefabrication rate all indicate the reduction effect on the TCs of

PH. Simultaneously, the adoption of lump-sum contracts reflects the completeness of the design, resulting in fewer TCs. Therefore, it can be concluded that the developers' TCs can be minimized when their risks in the PH projects remain low. In line with simple strategies, developers are suggested to decide the prefabrication rate that matches the scope of their experience/capabilities instead of stretching beyond themselves and pursuing a high rate. Another implication to the developers is to improve the completeness of the design and technical illustration, by which the TCs can be minimized in the subsequent construction process (Li et al, 2015).

5.6.4 Policy recommendations

The investigations in this study have presented the critical influence of developers' choices on the TCs of PH projects. Notably, the stakeholders' behaviors and the TCs are also highly dependent on the institutional/political environment (Coggan et al, 2013). Therefore, corresponding policy provisions are also expected to provide a supportive political environment for minimizing TCs and promoting the PH.

1 The local governments are suggested to set up the required target prefabrication rate considering the practical situation of the applied region to avoid too much pressure on the market (Gao & Tian, 2020). As stated, a high prefabrication rate entails higher uncertainties, thus high TCs, especially to those inexperienced developers. In China's context, the accomplishment of local requirements on PH influences the assessment of developers' performance. It may result in developers' blind pursuit for the advocated high prefabrication rate, which is eventually paid for by the overrunning of investment targets, delayed construction period, and poor quality. Hence, rational requirements on prefabrication rates are expected by considering the differences in the local PH progress, developers' capability, and project type.

2 The government is recommended to stimulate the inexperienced and the small-scale developers to participate in the PH market. This study showed that rich PH experience and the strong competitiveness of developers bring rewards in terms of significant reductions in TCs. Yet, the current leaders in successful implementation of PH in China are primarily large-scale developers. By contrast, the small companies cannot share the benefits of PH. However, the latest analysis of Chinese policies revealed that there are not yet particular policies to facilitate small enterprises (developers) to promote PH (Luo et al, 2020).

5.7 Conclusions

The private stakeholders are the primary practitioners for the development of Prefabricated Housing (PH). However, in China's immature PH market, the occurrence of increased Transaction Costs (TCs) both harms the benefits of the stakeholders, and in turn, hinders the development of PH. As the most influential private stakeholders, developers can significantly influence the TCs of PH by making informed and better choices. This study investigated the influence of the developers' choices on the TCs in the PH projects. The results of the questionnaire survey verified the determining relationships between the developers' choices and the nature of TCs: 1) The capability of the developers is the primary influence upon the due diligence costs; 2) Developers' choices regarding the efficiency of information exchange determine the negotiation costs; 3) Developers' decisions that define the uncertainties and risks can impose considerable influence on the TCs of monitoring and enforcement.

A Bayesian belief network (BBN) model was applied for presenting the causal relationships between the developer' choices and TCs, exploring the potential strategies for reducing the TCs. The single sensitive analysis identified developers' choices on the three key aspects that impose determining impacts on the TCs: namely, (1) the Prefabrication rate; (2) their PH experience; , and (3) the Contract payment method. Simple strategies are recommended to developers concerning: (1) Gradually improving the prefabrication rate to determine a best-matched prefabrication rate, instead of merely pursuing the highest; (2) Learning from experience and hiring skilled/experienced employees, especially for the small-scale real estate companies; and (3) Choosing the appropriate contract payment methods to allocate the risks rationally for minimizing the TCs.

The joint strategies were recommended based on the multiple sensitivity analysis results for the developers facing different challenges. First, in projects that required high prefabrication rates, TCs can be controlled by procuring high-certificated general contractors and adopting unit-price contracts. Second, for developers with limited PH experience, adopting the EPC procurement methods can vitally lessen their TCs thanks to high-efficient negotiation. Third, TCs can be minimized in an ideal situation when a high-experienced developer adopts a low Prefabrication rate (< 20%) and a Lump-sum contract.

To provide a supportive political environment for promoting the PH, the local governments are suggested to set up the required prefabrication rate considering the local market to avoid imposing too much pressure. Moreover, the government is recommended to stimulate the inexperienced and the small-scale developers to participate in China's PH market.

The significant contribution of this study is to introduce an approach for the developers to understand the relationships between their choices and the TCs. Practical strategies are recommended for developers to minimize the TCs in different situations. Going one step further, by introducing the BBN approach, this study enables the developers to analyze and predict the TCs in PH projects. Hence, better decisions can be expected to maximize the economic efficiency of the PH projects. Besides, this study also provides insightful information for the policy-makers to develop a healthy institutional environment for promoting the PH. Furthermore, taking the developers' perspective as an example, the findings and methods in this study can be further applied to analyze the TCs of other stakeholders. Despite these contributions, one limitation of this study that should be noted is that the joint strategies are based on three typical situations. For developers facing other constraints or more than one constraint, further investigations need to be carried out.

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6 Conclusions

6.1 Introduction

With a general aim of achieving 30% of the Prefabricated housing (PH) among newly-built buildings, the implementation of PH has seen a prevalent development in China. At the same time, new obstacles appear due to the advancement of the PH industry and the growing number of practitioners. The whole industry and the stakeholders face the challenges of overrun costs, high prefabrication technology, inexperienced workers, inefficient management process, etc. Therefore, high transaction costs (TCs) occur in the PH project development process since additional efforts are consumed for overcoming these challenges. In turn, the occurrence of TCs shrinks the potential and actual benefits of PH for the stakeholders and hinders the advancement of the PH sector. Nevertheless, in both the industry and in academia of the PH field, the understanding of TCs remains as an overlooked topic. Therefore, this study was conducted to discover the potential strategies for reducing the TCs by considering stakeholders' practical demands in China's PH market.

The overall aim of this study is to investigate the TCs in the PH supply chain and ultimately reduce the TCs for the stakeholders in China. To achieve this aim, **three key elements** have been addressed throughout the thesis: supply chain, transaction costs, and stakeholders. Figure 6.1 gives an overview of the three key elements in the four main chapters.

First, the research scope of this thesis is the whole supply chain of PH, a position which is maintained throughout the thesis. As defined in Chapter 2, the PH supply-chain in this study includes five phases of the project development process: 1) Concept, 2) Planning and Design, 3) Manufacturing, 4) Construction, and 5) Operation and Maintenance. The investigation of TCs is confirmed within these five phases.

Second, the investigation of the TCs is a deepening and broadening ‘digging’ process. Since TCs is a theoretical framework never previously applied in the PH field, Chapter 2 introduces TCs by first identifying and defining them. Subsequently, the perceptions and causes of TCs are investigated in Chapters 3 and 4, respectively. To gain more practical inspiration, Chapter 5 discusses how stakeholder’s decisions determine the TCs.

Third, Figure 6.1 illustrates that the focus regarding “stakeholders” is narrowed down and becomes more precise as the reader progresses from Chapter 2 to Chapter 4. The research objectives started with a broad scope, including all the stakeholders to identify a complete list of TCs in PH (Chapter 2). As the study progressed, the target groups are narrowed down to the six key stakeholders (Chapter 3) and eventually centers upon the most influential key stakeholder-developer (Chapter 4 and 5). To sum up, the deep investigation of TCs and narrowing-down of the stakeholders contribute to solid research of TCs in China’s PH market.

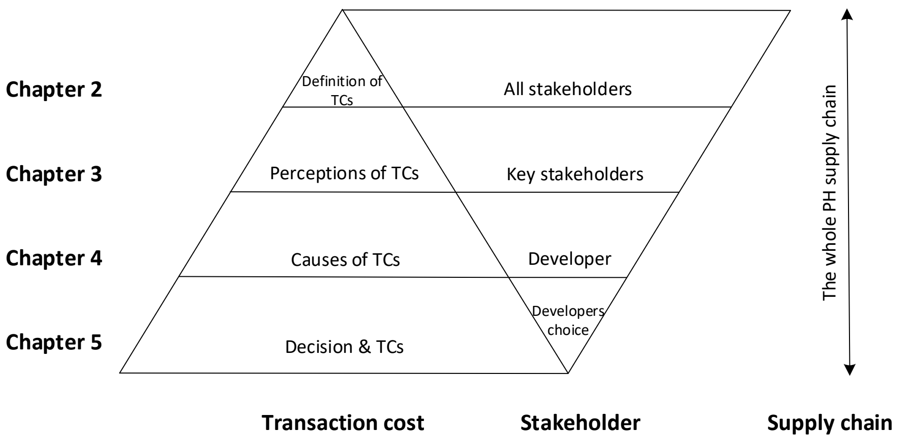

FIG. 6.1 Overview of the three key elements in this thesis

This Chapter 6 presents the conclusions and recommendations drawn from this research. Section 6.2 replies to the research questions set in Chapter 1 of this thesis, summarizing the main findings of this study. Section 6.3 sums up the reflections of this research. Section 6.4 provides recommendations for the private stakeholders and the policy-makers. Section 6.5 brings attention to the contributions to knowledge. To complete, further studies according to the limitations of this research are proposed in section 6.6.

6.2 Research Questions and the Key Findings

The main research question of this thesis is "How do transaction costs occur in the PH projects' development process, and what strategies can be taken by the stakeholders to reduce the transaction costs?" For answering this question, four questions were formulated, each represented in one chapter of this thesis. This section summarizes the findings of the four core chapters of this thesis, with each chapter covering one major research question and related sub-questions. Table 6.1 summarizes the responses to the research questions and corresponding sub-questions in the corresponding chapters.

TABLE 6.1 Summary of the responses to the research questions

Chapter	Key research questions	Sub-questions	Highlighted Summaries of main findings
Chapter 2	What are the TCs in the PH supply chain, and how do they occur in the production activities?	What are the key stakeholders and their TCs?	Six key stakeholders include the developers, general contractors, architects, local governments, supervisors, and component suppliers
		How TCs appear in the PH supply chain?	· TCs occur along with the flow of contracts, information, and materials. · Most TCs occur in the conceptual and the construction phases.
		How to understand the nature of TCs in PH?	TCs of PH are categorized into three types by their nature: due diligence costs, negotiation costs, monitoring, and enforcement costs.
Chapter 3	How do the key stakeholders perceive the TCs in the development of PH projects in China?	What are the critical TCs in PH projects?	The Assembly, Detailed Design and Design Change are the most critical sources of TCs.
		How do the stakeholders perceive TCs from the perspective of their roles?	· Developers: assembly and design change; · General contractors: assembly and hiring skilled labor; · Component suppliers: detailed design.
		What are the similarities and differences of stakeholders' perceptions of TCs in PH?	· Stakeholders commonly emphasized the TCs related to the specificity of PH; · The private stakeholders tend to emphasize TCs from their production activities · Governments have an objective understanding of all TCs in the supply chain.
Chapter 4	What are the influencing factors of TCs from the developers' perspective?	What are the TCs of most concern in PH from the perspective of the developers?	Disputes, Design Changes, Learning, Assembly, and Decision-making.
		What are the influencing factors of developer-related TCs in PH?	Qualification of the general contractor, Local mandatory policies, Owner type, and Competitiveness of the developer.
		How do the influencing factors impact their correlated TCs?	· A supportive local mandatory policy environment lowers developers' TCs for searching partners. · TCs for decision-making of public projects are higher than of private projects. · Competitive developers spend higher TCs for procuring the general contractors

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TOC

TABLE 6.1 Summary of the responses to the research questions

Chapter	Key research questions	Sub-questions	Highlighted Summaries of main findings
Chapter 5	How can the developers minimize the TCs by making rational choices in different scenarios?	How do the developers' choices relate to the TCs in PH projects?	· Developers' capability is the principal influence of the due diligence costs; · Developers' choices regarding information exchange efficiency influence the TCs of negotiation; · TCs of monitoring and enforcement are determined mainly by developers' choices regarding uncertainties and risks.
		What are the most critical choices that can significantly influence the TCs in PH projects?	Prefabrication Rate, PH Experience, and Contract Payment Method are the three most influential choices determining the TCs.
		What are the strategies for the developers to minimize TCs when facing various challenges?	Simple strategies: · Pursue a best-matched prefabrication rate instead of the highest; · Minimize the TCs by experience learning; · Choose appropriate contract payment methods to allocate risks rationally.

6.2.1 TCs in the development process of China's PH projects

Q1: What are the TCs in the PH supply chain, and how they occur in the production activities?

This fundamental question is answered by exploring the sources of TCs throughout the supply chain and regarding the key stakeholders of PH (Chapter 2). The analysis of the TCs in the whole supply chain reveals that TCs occur along with the flow of contracts, information, and materials. TCs arise when efforts are devoted to preparing contracts, negotiating the agreements, and contract enforcement before and after contracts. The intensive information exchange between the stakeholders incurs the TCs in terms of time and labor costs. The flow of the materials always engages the transaction activities that consume the corresponding TCs. Moreover, the interviewees reflect that TCs may appear everywhere in the PH supply chain but not equally distributed among phases. The conceptual and the construction phases are identified as the phases where the majority of TCs occur in a PH project.

High centralities of the key stakeholders entail stronger resource control abilities to influence the transaction process and TCs of PH. Through two cases in Chongqing, the social network analysis identified the developer, general contractor, local government, supervisor, architect, and components supplier as being the six central stakeholders. Among them, developers and general contractors are recognized as the most influential stakeholders that bear more TCs than the others. The responsibilities of architects are broadened beyond those customarily expected only in the design phase, which is the result of the immature PH market. Notably, unlike other stakeholders, the most critical TCs for the local government are permits and monitoring costs, which are rooted in their central position in promoting PH.

Through analysis of the nature of the identified TCs, the TCs of PH are categorized into three types: due diligence costs, negotiation costs, monitoring and enforcement costs. The analysis of TCs nature shows that the due diligence costs are mostly related to the specificity of the prefabrication, such as identifying partners with PH experience, proposing prefabrication solutions, labor education, etc. The scope of negotiation costs in PH includes efforts on communication, negotiation, and coordination. The negotiation costs are usually concerned with labor and time, which occur throughout the whole development process. Besides, the monitoring and enforcement costs often rise in the manufacturing, construction, and maintenance phase, which are mainly paid by the supervision companies and the local governments.

6.2.2 Stakeholders' perceptions of transaction costs in prefabricated housing

Q2: How do the key stakeholders perceive the TCs in the development of PH projects in China?

Chapter 3 identified the Assembly, Detailed Design, and Design Change as the most critical sources of TCs in PH. Assembly is commonly recognized as a task that entails additional TCs, which can be explained by the fact that it is a new procedure in the PH project compared to traditional construction projects. Detailed design of PH projects can generate high TCs due to the further considerations needed for the component design, transportation, lifting, and assembly to form the building. In addition, design changes in PH projects are highly related to the arising of TCs, which can lead to the redesign, reconstruction, or even changing the molds for components.

The TCs of most concern are recognized for each key stakeholder. The developers concern most about the Assembly and Design Change. Developers believe that Design Changes give rise to hidden losses, which are mainly reflected in the decline in developers' reputation and the reduced willingness of other stakeholders to cooperate with them. The general contractors perceive the Assembly and Hiring skilled labor as the critical source of TCs. The work of assembly put forward higher requirements for workers' skills than traditional on-site work, which generates extra costs for hiring and training workers from the contractors' perspective. Similarly, Assembly is also identified as the most critical TC by the architects and the local government. As a new stakeholder in construction, component suppliers evaluate the Detailed Design as a difficult task because of their intensive involvement in completing it with other stakeholders.

The qualitative analysis of the questionnaire survey data indicates the consistency and variance of stakeholders' perception of TCs. By the nature of TCs, it is observed that stakeholders in the PH industry in China are putting more of their attention on TCs related to the asset specificity of PH. For example, the three most important TCs – Assembly, Detailed Design, and Design Change – are highly-related to prefabrication specificity. Another common perception of stakeholders is that they emphasized TCs from innovation activities where high uncertainties and risks may arise. For instance, being more complicated than found in traditional construction projects, design changes in PH projects may cause remanufacturing or reassembly, and even lead to mold changes.

6.2.3 Factors influencing Transaction costs in prefabricated housing projects

Q3: What are the influencing factors of TCs from the developers' perspective?

From the perspective of the developers, the five most important sources of TCs are Disputes, Design Changes, Learning, Assembly, and Decision-making. Suppose one is seeking the underlying TCs of most concern in PH. In that case, the primary sources of the TCs are mostly information costs. Hobbs (1997) defined the information costs as those arising ex-ante to exchange and include obtaining information on price, product, and identifying suitable trading partners. The information costs stem from two aspects: Information searching and information exchange. Learning and Decision-making are the typical activities that result in the cost of information searching and analysis. TCs from the Design Change and Assembly are mainly linked with the information exchange.

Chapter 4 recognized that the four most influencing factors of TCs are: Qualification of the general contractor, Local mandatory policies, Owner type, and Competitiveness of the developer. The specific determinants of the four influencing factors to the correlated TCs are investigated by the multiple ordered logistic regression analysis. First, the Qualification of the general contractor is a significant explanatory parameter to four sources of TCs in PH: Dispute costs; Preparing and negotiating for the financing; Preparing and participating in the land-bidding, and Taxation paid by the developer. Second, a supportive local mandatory policy environment shortens developers' time-consuming for searching partners. By popularizing mandatory policies, developers' time and efforts for negotiating the contracts will be largely reduced. Third, developers' TCs for decision-making of public projects are more likely to be higher than those of private projects. This is explained by the fact that developers consume more effort for negotiation and coordination in the public projects, in that the governments usually hold greater power than the real estate developers. Fourth, competitive developers spend higher TCs for procuring the general contractors. A developer with excellent operational capacity is always prudent in selecting a general contractor. As a result, more TCs, especially time costs, are spent on attending meetings, preliminary design, transition observation, training, and site visits to ensure procurement quality.

6.2.4 Rational decisions for minimizing the transaction costs of prefabricated housing

Q4: How can the developers minimize the TCs by making rational choices in different scenarios?

The statistical results in Chapter 5 reveal the relationships between the developers' choices and the nature of TCs. Most considerably, the developers' capability is the principal influence of the due diligence costs in PH projects. The TCs of negotiation are impacted by the developers' choices regarding information exchange efficiency. As for the developers' TCs of monitoring and enforcement, they are determined mainly by developers' choices regarding uncertainties and risks in PH projects. Moreover, the BBN model indicates that the Prefabrication Rate, PH Experience, and Contract Payment Method are the three most influential choices determining the developers' TCs in PH projects. A high prefabrication rate usually grows the TCs in PH projects. Developers with rich PH experience indicate a higher possibility of lowering TCs. Moreover, the influence of the contract payment method shows that developers' TCs in the lump-sum contracts are lower than the unit-price and the cost-plus-fee contracts.

Simple strategies for the developers are developed according to the determining effects of their most influential choices. First, developers are suggested to pursue a 'best-matched' prefabrication rate instead of the highest rate. The local government's requirements and companies' capabilities are the baselines of developers' decisions to set the prefabrication rate. Second, developers are suggested to minimize the TCs by experience learning. Especially for the small-scale developers, a sustainable development strategy is to learn from the experienced large developers. Third, choosing appropriate contract payment methods is a promising strategy for minimizing TCs through allocating risks rationally. Additionally, when Chinese developers face various challenges, joint strategies are provided for reducing their benefits lost from the unexpected TCs. For the developers who experience the challenges from a high prefabrication rate, the procurement of special-grade general contractors, and adoption of unit-price contracts contribute to the lowest level of TCs. By contrast, for the inexperienced developers, the BBN model suggests that adopting the EPC contracts is an effective strategy to fewer efforts to transmit information, and therefore, lower TCs.

6.2.5 Overall conclusion

This thesis uncovers the nature of TCs in the PH supply chain, collects the stakeholders' perceptions, and investigates the causes of TCs. The answers to the research questions presented in the previous section result in four overall main conclusions to the main research question: How do transaction costs occur in the PH projects' development process, and what strategies can be taken by the stakeholders to reduce the transaction costs?

- By nature, there are three types of TCs in the Chinese PH supply chain: due diligence costs, negotiation costs, monitoring, and enforcement costs.
- Assembly, Detailed Design, and Design Change are the most critical sources of TCs in PH.
- Developers and general contractors are the most influential stakeholders that bear more TCs than the others.
- Essentially, stakeholders in China's PH industry put more of their attention on TCs related to the specificity of prefabrication.
- From the developers' perspective, Local mandatory policies, Qualification of the general contractor, and Competitiveness of the developer are the most influential factors that influence the TCs of PH projects.

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These findings contribute to the strategies of minimizing TCs for the government, developers, general contractors, architects, supervision companies, and component suppliers. Generally, recommendations for the private stakeholders are to reduce TCs related to their own production activities, and suggestions for the government are more to minimize the overall TCs of PH projects by providing a supportive policy environment. For the private stakeholders, improving firms' competitiveness is a strategy to smooth the procurement, financing, and permission permit, reducing the TCs. Activities of learning, cooperation, and computer-based designing are recommended to reduce high TCs from uncertainties. For the government, policy implications are provided for lowering TCs on both the project level and industry level. According to the stakeholders' perception of TCs, comprehensive education and qualification system for PH are expected by the market. The most influencing factors suggest popularizing the mandatory policies and incentivizing small and medium-sized enterprises in the PH industry.

6.3 Reflections

6.3.1 Reflections on the data and Methods

In this study, the most frequently applied data collection approaches are interviews and questionnaire surveys. As the first study that explores the TCs for PH, interviews are used as an effective method for collecting first-hand information from the Chinese market. In Chapters 2 and 3, semi-structured interviews are conducted to validate the rationality of the theoretical TCs, to explain the content of TCs, and recognize the critical TCs related to particular stakeholders. In Chapter 4, the semi-structured interviews with the developers are designed to verify the factors that influence TCs and explain how they affect TCs. There were several challenges both before and during the interviews. Before conducting the interviews, serious consideration was given to the knowledge of the target groups when selecting the interviewees. For example, when selecting professionals, the author targeted those who operate at the management level to ensure they have a sophisticated understanding of the whole supply chain and have gained rich practical experience on PH. During the interviews, since TCs is a concept not commonly used in practical production, it was challenging for the author to translate this academic term to the interviewees. To make the interviews more intelligible, the professional term *Transaction Costs* was not used. Instead, questions were asked such as: “What are the redundant costs for these activities from your opinion?”; “Can you please introduce the efforts that you have made to fulfill this task?” and “What are the difficulties when carrying out this work?” As a result, it was easier for the interviewees to share their investments in the listed activities in terms of time, capital, labor, efforts, etc.

The questionnaire survey is adopted as another primary method for data collection. For conducting the questionnaire survey, thoughtful considerations were given on the content design, respondents, and study area. First, it is common knowledge that the hard-to-measure nature of TCs makes the measurement a challenge. Instead of measuring them by numbers, this study evaluates the TCs of PH through the perceptions of the professionals. Second, a massive application of PH in China’s construction market had just been started after 2010 since publishing a milestone policy - Plan on Green Building (MOHURD, 2013). With such a short history of implementation, it was quite challenging to find respondents with ample experience (e.g., >10 years) in China’s PH market. With the help of the professional organization, approximately 1000 valid questionnaires were collected for this Ph.D. study. The validated samples in the survey were all from people who were working on a PH project that presents the current norm. Third, the study area of the survey was expanded from one representative city – Chongqing (Chapter 1 and 2) to the whole of mainland China (Chapter 4 and 5). At the stage for exploring the TCs of PH, Chongqing is a city that can well represent the current PH implementation in Chinese cities. With the narrowing-down of the research scope and the deepening of the research questions, the valid samples in Chongqing were insufficient due to the higher requirements for sample selection. For this reason, questionnaires were sent to developers in the whole of China to collect more comprehensive and reliable data in PH.

For the data analysis, statistical analysis, social network analysis, logistic regression analysis, and the Bayesian belief network model were used. The Bayesian Belief Network (BBN) model has the highest requirements on the sample size and completeness of the data. Our survey collected 589 valid samples, a number that is much more than the requirements of the largest elements in the conditional probabilities table among all the BBN model nodes. As for the completeness of data, there is a high requirement by BBN, which means that the input from each questionnaire should be with no missing data. The reason is that the calculation of BBN is based on parameters-learning for forming the joint conditional probability. The author selected 589 among 703 questionnaires returned as valid. The strict data screening guarantees the reliability of the data for the performance of the BBN model. As a result, 89% of prediction accuracy illustrates the good robustness of this model.

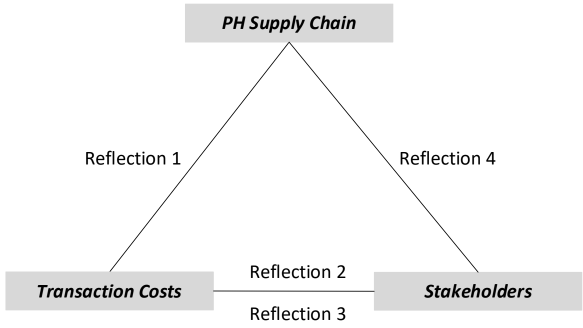

FIG. 6.2 Reflections based on three key elements

6.3.2 Reflections on the findings

From identifying the TCs to strategies for reducing TCs, the main findings of this study always revolve around the three key elements: supply chain, transaction costs, and stakeholders. If one looks beyond the apparent findings, the inner relationships between the three key elements are revealed. Combining the TCs theory and the PH practice in China, the author presents a reflection on four topics, as shown in Figure 6.2.

1 The interaction between the PH supply chain and transaction costs

In exploring the TCs of PH projects, an interactive relationship between the supply chain efficiency and the TCs is revealed in China's market. Theoretically, the setting up of the supply chain affects the TCs. In tracing the influencing factors of TCs, this study found out that the factors that define the attributes of the supply chain are the primary causes of TCs (Chapters 4 and 5). The project delivery method defines the particular transaction procedure of the supply chain, thus, influencing the TCs. The contract payment method reflects the payment frequency, and therefore, directly impacts the TCs. For setting up the supply chain, the decisions on procuring unfamiliar partners and applying high prefabrication implant latent uncertainties. Thus, high uncertainties easily incur TCs as a result. This conclusion confirms the argument of TCs by Winch (1989), claiming that TCs tend to be higher in an emerging field where the environment is uncertain. In this sense, reducing the uncertainties of the supply chain will contribute to lower TCs in the PH projects. Additionally, TCs are pretty specific in certain states of the supply chain. When the attributes of a PH supply chain changes, the TCs embedded change correspondingly.

In practice, TCs determines the efficiency of the PH supply chain. High TCs in projects' development process increase the total construction costs, leading to disputes, delays, and abandonment. The unexpected TCs in projects' development consume the input for a planned PH product. In other words, high TCs cause low efficiency of the PH supply chain. People perceive PH projects in China with poor efficiency because of high TCs which are typically identified as challenges of PH, as elicited in the literature (Gan et al, 2019; Xue et al, 2018; Yao et al, 2020). Therefore, reducing TCs can improve the efficiency of the supply chain and enhance productivity. In this sense, stakeholders will be benefited from strategies of reducing TCs of the PH projects.

2 Stakeholders' intentions to reduce transaction costs

In exploring the stakeholders' TCs, the intentions of the stakeholders on reducing TCs vary. The private stakeholders show a firm intention to lower their TCs, whereas the public stakeholders show less intention to reduce their TCs, since they believe that these TCs are inevitable (Chapter 2). Stakeholders' different intentions towards TCs reduction is the result of their perceptions of TCs. However, the reasons behind the variance of stakeholders' perceptions of TCs are not clear. It is reflected from the interviews that the reasons of various perceptions of TCs are mainly on three aspects: interests, roles, and burden of TCs. Table 6.2 compares the difference between the private and public stakeholders on these three aspects. Detailed discussions regarding how perceptions vary between the stakeholders are determined by these three characteristics of the public and private stakeholders, and are given as the following.

First, the private stakeholders have a relatively limited understanding of TCs. In contrast, the government experts have expressed a clear understanding of TCs by explaining the academic and economic meaning. Stakeholders' basic knowledge of TCs mirrors their diverse interests in the PH. As stated in Table 6.2, private stakeholders are profit-driven, therefore more sensitive to the capital costs than unmeasurable hidden costs. On the contrary, public stakeholders care more about the promotion of PH rather than the expenditure of the government departments. Second, private stakeholders tend to emphasize TCs from their production, while the public stakeholders pay more attention to the most critical TCs in the PH supply chain instead of only the TCs they bear. This is rooted in their different roles in the supply chain. The role of the practitioners entails a realistic view of the private stakeholders, through which the TCs in their production draw their most attention. The role of administrator endows the Chinese government having a general and objective view of the PH industry. Third, the TCs that private stakeholders concern

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about are mostly due diligence and negotiation. At the same time, monitoring and enforcement are the primary sources of public stakeholders' TCs. The reason behind this is their different burden of TCs. Participants in different stages and tasks, private and public stakeholders, bear various TCs in a PH project. Chapters 2 and 3 reveal private stakeholders' great concerns on additional efforts for negotiation and communication. In contrast, public stakeholders' burden of TCs is mainly associated with their monitoring and enforcement responsibilities in PH.

FIG. 6.3 Reason of various perceptions between private and public stakeholders

	Private stakeholders	Public stakeholders
Role	Practitioners of PH projects.	Administrators of PH projects.
Interest	Naturally profit-driven.	The goal is to promote PH development.
Burden of TCs	Bear TCs mostly related to due diligence and negotiation.	Bear TCs related to monitoring, e.g., the approvals and supervising work.

3 Stakeholders' power in influencing transaction costs

The power of stakeholders shows a dominant influence on TCs in the PH field. Regarding the original principal of TCs economic theory, Williamson (1985) had claimed the fundamental determining effects of actors in transactions. The findings in this thesis align with the construction management theory and the TCs economic theory. In China's PH industry, the influences of stakeholders on the TCs are primarily reflected by their decisions and capabilities.

In general, the TCs and the efficiency of the PH supply chain are largely depending on the decisions of stakeholders. Their decisions define the project characteristics, project teams, and project development process, affecting the TCs. In the context of China, developers' decisions regarding the uncertainties and efficiency of information exchange impose considerable influence on the TCs. For example, developers' efforts to monitor and enforce the construction contracts follow the project delivery methods they apply. In setting up the prefabrication rate for a PH project, the corresponding considerations should be given to the uncertainties in the architectural design, the detailed design, and the design change. Besides, when the developers choose to cooperate with the partners with collaboration experience, TCs of coordination and negotiation can essentially save on account of the trust built before. As such, rational decisions of the key stakeholders, especially the developers, are of utmost importance to the success of PH projects.

Stakeholders' capability defines the transaction environment and the operation efficiency, determining the TCs. Higher qualified general contractors contribute to lower TCs in PH, which is in line with Li et al (2014), who believe that capable contractors could contribute to a more stable environment with lower TCs. The developers' competitiveness is recognized as the principal influence of the due diligence costs in PH projects. With different capabilities, developers devote various efforts for negotiation in the development process, e.g., obtaining approvals and financing. A counter-intuitive finding is that competitive developers pay higher TCs for procuring contractors. This applies, even though, their TCs in the whole supply chain are believed as low because of the prudent decision in the early stage of the project. Moreover, the capability of the local government determines the TCs because of their dominant power in policy-making, permission approval, and monitoring. Local governments are involved in the development process and serve as the policy-maker developing an institutional environment outside of the project supply chain. The supportive policy environment is conducive to a healthy market for PH, and an efficient administration process convinces the development of the PH projects. Thus, their functions determine that their impacts on TCs are unique and unchangeable from the private stakeholder's side to some extent.

4 The value of governmental transaction costs for the PH development

In the Chinese context, the effect of governmental TCs is quite positive for the PH industry. For promoting the PH, the public stakeholders pay TCs on the aspects of due diligence, negotiation, and monitoring. Intending to maximize the social benefit rather than profits on the project level, public stakeholders believe that the existence of TCs is inevitable for promoting PH in China. The value of governments' interventions to secure a favorable transaction environment for the innovation industry has been claimed in previous studies (Qian et al, 2013). Similarly, in the PH industry, paying for reasonable TCs is necessary for the government to promote PH at its early development stage. The value of the public stakeholders' TCs is reflected on both the project and industry levels.

At the project level, TCs of public stakeholders are mainly born by the local governments. As the administrator, local governments have a unique birds-eye view of the entire supply chain. Local governments' TCs in a PH project are more likely to arise from permission approval, monitoring, and publicity. The local governments' expenditures for permit approval ensure that the projects' planning and design are eligible according to the regulations and standards. Governmental monitoring of the components' quality can effectively reduce the future quality problems in the consequent construction. Basically, the TCs of public stakeholders control the uncertainties of project development from a general view. In this sense, the rational TCs paid by the local government are necessary and valuable thanks to its contribution to reducing the TCs of the private stakeholders.

At the industry level, TCs of the public stakeholders are invested by both the central government and the local governments. The TCs of the central government are most from the policy-making, while the TCs of the local government are mainly for policy implementation and monitoring. Policies impact TCs through directing how exchange takes place, which, in turn, imposes influence on TCs to both public and private parties. In the Chinese PH industry, the government's most often-used policy tool includes guiding policies, regulations, mandatory policies, and incentives policies (Jiang et al, 2019). First, the central government is responsible for guiding industry development. The guiding policies are therefore issued, for which extensive due diligence is needed to grasp the real situation of the market. Second, another primary resource of central governments' TCs is the formulation of industry norms. These are favorable for improving technical consistency and regulating industry management. Although the regulation-forming leads to an increase in TCs of the government itself, it minimizes the information asymmetry between the stakeholders, thus saves time on communication and negotiation. Third, the mandatory local policies reveal a significant effect of influencing the TCs of PH (Chapter 4). The mandatory policy is an approach of popularization of PH, through which the robust understanding and acceptance of PH among the public can be developed. The design and briefing of the mandatory policy generate TCs to the public stakeholders; consequently, the private stakeholders pay less for the information-searching costs. Fourth, the incentive policy is also one of the local government's significant measures to promote PH. The implementation of the incentives policies directly increases the governmental investments. The provincial government's income could be shrunk due to the incentives of fund support, loan support, tax privilege, floor area reward, and priority land supply. However, these measures bring direct benefits to the enterprises. Finally, the value of the local governments' TCs of policy implementation and monitoring should be recognized. The local governmental investments in the project quality inspection ensure the effectiveness of the policies, whereas these investments require extra efforts, setting up additional institutions, and increased expenditures.

6.4 Recommendations

6.4.1 Recommendations for Private Stakeholders

As stated above, the goal of the private stakeholders is to maximize their benefits in PH. Achievement of this goal means that decent profits are embedded in an efficient and smooth development with fewer TCs. To this end, the redundant TCs in the PH supply chain should be minimized in practice. Based on the findings of this thesis, this section recommends some rational measures for the private stakeholders to reduce TCs.

1 Rational investment for learning. This thesis argues that the learning costs are worth paying in order to reduce the TCs from the mistakes and low efficiency in project development (Chapter 3). For the private stakeholders, the activities of learning include self-learning and learning from others. Keeping the lessons learned from past experience in the memory of the organization are proved as effective measures for TCs reduction in future projects (Guo, 2016). Another self-learning strategy is educating the employees through training and meetings, by which the companies can better adapt to the prefabrication. Moreover, learning from others is another approach to digest new information and technologies. Activities of experience-learning, such as project-visiting and workshops, are encouraged to reduce the high TCs from information-searching.

2 Saving potential hidden costs of uncertainties. This study holds identical views of Williamson (1996), claiming that uncertainties are the main determinants of TCs in the PH supply chain. Although the application of prefabrication entails numerous uncertainties to the private stakeholders, there is space to save the potentials costs from these certainties. Specifically, developers are recommended to set up the aimed prefabrication rate that matches the scope of their experience/capabilities instead of pursuing a high rate, remaining the technical uncertainties low. Besides, developers are suggested to confirm the completeness of the design in order to decrease the risks from subsequent production, thus saving potential hidden costs (Chapter 4). For the general contractors, reducing uncertainties in the early phases is a solution to decrease TCs arising from assembly and design change. A practical solution is employing mature design technologies for assembly simulations, such as having pipeline interferences by using BIM, which results in fewer design changes (Chapter 3). Similarly, using new technologies, computer-aided manufacturing, and

making many variations within standard solutions is possible for the architects. The component suppliers are encouraged to ensure the completeness of component/modular specifications, which is beneficial for decreasing the number of disagreements and disputes in the manufacturing, thus reducing the TCs.

3 Improving companies' competitiveness. The robust competitiveness of stakeholders shows a positive effect on the control of TCs (Chapter 4, Chapter 5). The enterprises' competitiveness cannot change at the individual project level but can be improved in the long term over future projects. Given the argument that general contractors with high qualifications perform better on reducing the TCs, the construction companies are encouraged to enhance their competitiveness. Comparable, the developers should also improve their competitiveness for PH. A practical aspect is upscaling the firm's organizations in adapting to the prefabrication production mode, by which the institutional efficiency can be improved. High institutional efficiency allows a smooth operation, and a more stable environment, reducing TCs. For the other stakeholders, such as the architects, component suppliers, participating in more PH projects is the most applicable strategy to enrich the experience, thus improving competitiveness in this field. A more efficient approach is to hire professionals/workers who have experience in PH. Although the hiring of experienced workers would increase labor costs, it reduces costs from adapting, information-searching, consulting, etc. The increasing number of professional employees improves a company's professionalism, enhances production efficiency, reduces the TCs, and becomes more competitive for attracting co-operators. All in all, improving the firms' competitiveness is conducive to enlarge the market size of PH and brings the benefits of scale-economics.

4 Building good relationships with the other stakeholders. Partner cooperation helps to eliminate redundant TCs and improve the efficiency of the organization's operation. Ensuring the efficiency of projects is not a single party's affair. Instead, it is a collective effort from all interested parties in the partnership arrangement (Osei-Kyei & Chan, 2017). Thus, building good relationships with other parties to improve the predictability of their behavior is a solution to prevent the arising of redundant TCs in PH. Furthermore, this study has made it clear that communication and coordination are among the most concerned sources of TCs in PH by critical stakeholders. Hence, developing long-term cooperative relationships between stakeholders (e.g., between architect companies and developers) is one strategy to smooth the coordination and save costs from information exchange.

6.4.2 Recommendations for Policy-makers

In China, the supportive industrial policies for promoting the PH are believed as necessary and effective, which has been extensively discussed in the extant literature (Gao & Tian, 2020). By exploring the TCs in PH, understanding the perceptions of stakeholders, and investigating the influencing factors of TCs, this study proposes corresponding recommendations for the PH policy.

1 Establishing systemic education and certification regulation is an action to meet the expectations of both the market and the governmental departments. On the one hand, many private stakeholders have mentioned the costs of hiring skilled labor and educating staff in the survey (Chapter 3). The shortage of skilled and competent labor for prefabrication has become an obstacle to PH development in China (Jiang et al, 2018b). On the other hand, the effectiveness of the issued national standards is constrained because of the lack of local supportive regulations regarding the training, education, or skill certification of construction workers. Therefore, for the workers, engineers, and managers who participate in the PH projects, systemic education and certification regulating are necessary to ensure professionalism. Furthermore, apart from training for the employed person, it would be more efficient to put prefabrication in the education system, such as universities and engineer qualification.

2 The development of PH calls for the popularization of the mandatory policies in Chinese provinces. This study expounds on the effect of the mandatory local policies on reducing the TCs of identifying experienced partners, contractors, and end-users (Chapter 4). The mandatory policy is a practical approach for educating stakeholders. The uncertainties on the aspects of the technique can be vastly reduced, contributing to the minimization of TCs. However, in this study, 30% of the respondents stated no mandatory policies in their regions. A recent study by Gao & Tian (2020) also indicated that only 10 out of the provinces in China have supportive PH regulations. Chinese authority promotes the PH by prioritizing the primary promotion regions while promoting PH in the incentive regions is not followed (Jiang et al, 2019). It is, therefore, of high necessity to enforce the implementation of a mandatory generalized policy for PH in Chinese provinces. Furthermore, the mandatory local policies should be issued with detailed implementation measures that suit the local market's PH level. For example, in the primary promotion region, particular requirements on the prefab rate can be set. Simultaneously, the focus of mandatory policies in the encouraged promotion region should focus on qualifying the quality of PH projects instead of only pursuing a high prefabrication rate.

3 Stimulate the inexperienced and the small and medium-sized enterprises to participate in the PH market. Currently, the market-leaders of implementing PH in China are primarily large-sized real estate companies. Developers with a registered capital of over 50 million CYN (large companies) are more competitive for bidding on the aspect of the experience, professional employees, and management system (MOHURD, 2000). In contrast, small developers cannot share the PH market owing to the high initial investment for entering the market. However, the latest Chinese policies analysis revealed that there are no particular policies to facilitate small enterprises for PH development (Luo et al, 2020). Chapter 5 suggests the policy-makers pay more attention to the inexperienced and the small-scale enterprises, issuing corresponding guiding and incentives policies for them. Specific incentives for small-medium enterprises, such as fund support, loan support, tax privilege, and convenient administration procedures, should be put into practice. Supportive policies are conducive for reducing the initial investment of the small and medium-sized developers to participate in more PH projects and to enlarge the PH market. As for the other small and medium-sized suppliers/subcontractors, encouraged policies and supportive regulations should be in place to guide their production of PH. Only when more small-medium-sized contractors enter the PH market, can a complete PH supply chain be integrated to achieve the economic scale of PH.

6.5 Contributions

6.5.1 Contribution to Knowledge

The most meaningful contribution of this study arises from it being the first research addressing the theory of TCs in the PH field. On the one hand, it expands the application of the TCs theory. The TCs theory has been widely applied in many areas as a practical approach to enhancing the project's economic performance, particularly for the innovation industry (Qian et al, 2013). However, as an innovative production method of construction, the PH has not drawn the scholars' attention to the aspect of TCs. As the first research that introduces the TCs theory in the PH area, this thesis develops an original framework for identifying TCs, providing a basis for TCs understanding in PH. On the other hand, this study enriches construction management theory by bringing new insights to PH development. Barriers to PH development have been repeatedly studied (Larsson & Simonsson, 2012; Mao et al, 2015; Zhai et al, 2014), but few studies have reflected on the neglected hidden costs from the perspective of institutional economics.

The applying of TCs in the PH added the knowledge of the forming mechanism of TCs. A body of research efforts has already been able to identify the factors that influence the TCs in various areas (Phan et al, 2017; Shahab et al, 2019). Nonetheless, in the construction industry, very few studies have attempted to research the causes of TCs throughout the supply chain. This study specifies the influencing factors of TCs in the PH (Chapter 4). Mainly, Chapter 5 deepens the investigation of stakeholders' decisions on the TCs by taking the developer as an example. It provides evidence for the other research scholars regarding the stakeholders' behavior and TCs in the PH and construction industries.

The conclusions of this study provide valuable references to the subsequent research scholars for comparable cities and developing countries with transitional construction markets. First, chapters 2 and 3 of this thesis take Chongqing city as the case to gain a fundamental understanding of PH practice in China. It benefits further studies in other regions of China to investigate TCs in the local market. Second, this study generally takes China's market as an example, which provides implications on TCs control in developing the PH projects for countries and regions where the development of PH is in the early stage.

6.5.2 Societal contribution

One of the societal contributions of this study is making the neglected TCs of PH visible. For a long time, Chinese enterprises have been complaining about the high cost of PH projects; their attention was only put on the capital costs (Jiang et al, 2018a; Xue et al, 2018). However, traditional cost management is not adequate for cost reduction, indicating that the cost of PH is still 20% higher than traditional projects in China. The reason is that the harm of the hidden costs is ignored, which is an essential part of the final construction of PH. In traditional construction management, these hidden costs are partly recognized, by only being put as non-specified items on the balance sheets, like "administrative costs" (Antinori & Sathaye, 2007). This study uncovers those fuzzy and ignored parts of the cost. It explicitly identifies the TCs along the PH supply chain. It allows the stakeholders to look beyond difficulties in production and have a complete view of the costs by considering the soft costs. Only when the hidden costs become visible from the practitioner's perspective can they be understood and analyzed. For stakeholders, a clear understanding of TCs will provide a basis to reduce TCs in the projects and thus to improve the economic efficiency of the PH supply chain.

Practically, investigating the influencing factors behind the TCs provides suggestions for the private stakeholders to reduce their TCs in PH projects. In particular, this study helps the developers investigate the nature of their TCs of most concern and further analyze the underlying reasons. Accordingly, suggestions for developers are on the practical level to benefit the controlling of TCs in PH projects. By analyzing the critical sources of TCs, complementary strategies are provided for each stakeholder to lower their TCs at specific phases of the supply chain.

The findings of this study bring implications on the PH governance for the public stakeholders, especially the local government departments. A large number of studies are available for guiding the policy-makers by focusing on their TCs. From a different angle, this study provides suggestions for the government through the perspective of the private stakeholders of PH. First of all, the evidence of private stakeholders' opinions of TCs from the surveys enables the policy-makers to grasp the market needs. Correspondingly, the political supports can be supplied more precious and effectively. Furthermore, the investigation of determinants of TCs expounds on the function of local policies in the PH market. It draws the recommendations for the local authorities to set up reasonable measures to promote the PH in the local regions.

6.6 Limitations of the Study and Recommendations for Future Research

This thesis creatively introduces the TCs in the field of PH, which, however, has several limitations due to time and data resource restrictions. The recognition of these limitations inspires the directions of future research.

First, this study pays most attention to the private TCs, whereas the TCs of government are also worth further investigating. Considering the market demands, this study mainly focuses on the private stakeholders because they are the practitioners and their benefits-loss from TCs is more urgent to be mitigated. In the long run, the operation efficiency of the public stakeholders is also of high importance to the development of PH in China. Numerous research has been done for the policy management of China's PH (Gao & Tian, 2020; Wang et al, 2021); however, none of them consider the governments' institutional efficiency from a TCs perspective. It should be realized that the uncovering of the hidden TCs in the governance organization is an essential step for optimizing policy implementation. Based on the identification process of TCs of private stakeholders in this thesis, TCs of public stakeholders are expected to be explored to apply policy instruments more effectively.

Second, an obvious limitation of this study is that only the developers' perspective is chosen to investigate the causes of TCs. TCs are highly specific to the stakeholders. Thus, apart from the developers, the forming mechanism of TCs from the perspective of the other stakeholders should also be explored. For instance, the general contractor is another identified critical stakeholder of the PH supply chain. Their decisions and behaviors are also of significance to the TCs of PH projects. To improve the efficiency of the supply chain, the precise analysis of each stakeholder's TCs should gain attention in academia and industry.

Third, the last limitation of this research is related to timing. PH in China is experiencing a rapid-developing stage. The market is expected to change continually, and the challenges will also update. TCs theory claims that TCs are highly dependent on the time specificity of the transactions (Choudhury & Sampler, 1997). The data collection and analysis in this study is just a reflection of the current state, which may not be appropriate for explaining TCs when the maturity of the PH industry is different. The developed TCs framework could be adjusted according to actual conditions when applied to different PH development periods. Moreover, this study provides suggestions for the stakeholders to minimize TCs in PH, which is also based on the time specificity of the PH supply chain. The old issues may be eliminated, and new issues are likely to emerge when the supply chain updates and stakeholders' roles change. Therefore, continuous research is expected to identify solutions for TCs management according to the specific states of the market.

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Curriculum Vitae

Hongjuan Wu was born in 1990 in Ningxia, China. In 2013, she obtained her Bachelor of Construction Management at Chongqing University. She then continued to study for a master's degree in the same university with the support of a scholarship. During her master's study, she has participated in several research programs of prefabrication, which inspires her interest in the research of prefabrication construction. In 2016, right after she got the Master's degree in Management Science and Engineering, she received a scholarship from China Scholarship Council to support his Ph.D. research. From September of 2016, she came to the Netherlands to start her Ph.D. at the Department of Management in the Built Environment (OTB department 2015-2019), Faculty of Architecture and the Built Environment, Delft University of Technology. During her Ph.D., she has been working on the topic of prefabricated housing supply chain from a transaction cost perspective. On this topic, she has made several journal publications and presented at international conferences.

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Challenges of prefabricated housing in China

Supply chain, Stakeholders, and Transaction costs

Hongjuan Wu

Recently, the implementation of prefabricated housing (PH) has become prevalent in China to achieve sustainability while ensuring green construction, innovative products, and higher quality. However, numerous challenges arise, such as the overrun costs, inexperienced workers, and the inefficient management process. High transaction costs (TCs) occur in the PH project supply chain since additional efforts are consumed for overcoming these challenges. This study aims to seek insights into TCs of PH and investigate strategies for minimizing the TCs thus smooth the development process of PH projects. Three key elements have been addressed throughout the thesis: supply chain, stakeholders, and transaction costs. Four-step research is employed to uncover the TCs in the PH supply chain, collect the stakeholders' perceptions, investigates the causes of TCs, and explore decisions for reducing TCs. This thesis identifies three types of TCs in Chinese PH projects by their nature: due diligence costs, negotiation costs, monitoring and enforcement costs. Private stakeholders in China's PH industry put more of their attention on TCs related to the specificity of prefabrication. The simple and joint strategies are provided for reducing their benefits lost from the unexpected TCs. Additionally, the value of the governmental TCs has been revealed for reducing the TCs of PH, which inspires and supports the policymakers to develop a healthy policy environment.

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