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A VALUE-BASED NETWORK ANALYSIS FOR STAKEHOLDER ENGAGEMENT THROUGH PREFABRICATED CONSTRUCTION LIFE CYCLE: EVIDENCE FROM CHINA

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Abstract. Over the past decade, prefabricated construction has increasingly gained popularity in addressing environmental concerns while meeting the high construction demand, particularly in developing countries. Accordingly, the concept of stakeholder engagement increasingly garnered attention as it is highly relevant for understanding and explaining the relationships among various stakeholders, like contractors, suppliers, and producers, especially within the fragmented context of prefabrication. To further the field, this study aims to provide a comprehensive qualitative and quantitative analysis for stakeholder engagement in the realm of prefabricated construction via a value-based network. This value-based network analysis is utilized to model multiple relationships between stakeholders as value exchanges, thus enabling to engage them though management with a focus. Specifically, A total of 110 values were identified and analyzed among 12 stakeholders throughout the whole lifecycle via an extensive literature review, interviews, and questionnaires directed at prefabrication practitioners in China. This data collection process garnered 194 valid responses with a 64.7% response rate. The findings show that enhancing stakeholder engagement requires improvements in both the abilities and experiences of developers, and in the collaborative relationships among key stakeholders. These improvements can be achieved by prioritizing the engagement of prefabrication consultants and encouraging the government to issue policies that support developers, producers, and consultants in fostering collaboration. This in-depth network analysis offers practical insights for decision-makers in the management of core stakeholders and value-based relationships, thereby improving stakeholder engagement. Additionally, it expands the current body of knowledge on stakeholder engagement by incorporating the value-based network analysis into the exploration of its stakeholders and relationships.

Keywords: prefabrication, stakeholder engagement, values, life cycle.

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1. Introduction

Recently, there has been a surge in interest in stakeholder engagement from both the academic and industrial spheres in relation to construction projects, especially in light of the escalating adoption of prefabricated construction. It is widely known that prefabricated construction, characterized by standardized design, factory production, on-site assembly, and life-cycle data management (Luo et al., 2021; Tao et al., 2018), is an innovative and sustainable construction approach with a great increasingly popularity. For example, Ministry of Housing and Urban-Rural Development of the People's Republic of China [MHURD] (2022) has aimed to develop the prefabricated construction to comprise over 30% of all new building by the year of 2025. Compared to traditional cast-in-situ construction, stakeholders in prefabricated construction play an increasingly significant role. Their engagement notably affects various aspects of prefabricated construction performance, including cost, quality, and time (Teng et al., 2017; Liu et al., 2018; Chen et al., 2023). From the industry's observation, stakeholders lack a systematic understanding of both their individual role and interrelationships among them (MHURD, 2017). For example, the developer lacks strength in project management; Moreover, it is imperative that the government abstain from implementing policies that could negatively impact the widespread adoption of prefabricated construction; Meanwhile, other stakeholders may find themselves unclear on the matters of initial investment and operational adjustments. All these factors result in diminished engagement performance, further limiting development of prefabricated construction. Accordingly, how to engage multiple stakeholders, including contractors, suppliers and producers, within the context of prefabricated construction remains a concern (Luo et al., 2019; Yuan et al., 2021).

In fact, the success of prefabricated construction projects over design, production, transportation, and assembly hinges on multi-stakeholder engagement (Qu et al., 2023). Its implementation could manifest as a complex value engineering process, entailing not only technical challenges but also the realization of value creation activities (Yuan et al., 2021). Basically, stakeholders can mutually satisfy other stakeholders' needs via creating values as their roles of engagement are of different salience (Bahadorestani et al., 2020b). The creating values are defined as the outputs coming from one stakeholder that can meet other stakeholders' needs throughout the whole project life cycle (Cameron, 2008). Different values existing among multi-stakeholders, including both direct and indirect, form a value-based network for facilitating stakeholder engagement to alleviate the aforementioned issues. To be more specific, clarifying these values among multi-stakeholders helps understanding stakeholder needs, concerns, and interests. As a result, it becomes possible to engage stakeholders in a more targeted way, ensuring their perspectives are reasonably considered and that decisions align with their interests. In this case, more attention is needed to be paid for relationships among stakeholders and their values. However, the systematic analysis of stakeholder values through life cycle is still relatively few, largely owing to lacking lacking effective qualitative and quantitative analysis. Additionally, A full picture of the interrelationships among these values remain ambiguous, thus preventing stakeholders from effectively engaging with each other.

The objective, thereby, is to propose a value-based network analysis for understanding stakeholder engagement within prefabricated construction in developing countries, i.e., China. This endeavor yields twofold contributions. In terms of practical implications, the findings of this paper aim to equip the developers with a deeper understanding how to manage prefabricated construction processes from a life cycle perspective. It also guides government in forming more appropriate policies and assists other key stakeholders in adopting more clearable measures for effective engagement and transformation. On an academic front, this paper aims to enrich the existing body of knowledge pertaining to stakeholder engagement by focusing on a full picture of the value-based network analysis.

The rest of this study is organized as follows: Section 2 presents key concepts and literature, identifying the research gap. Section 3 illustrates the detailed research methodology: SVN analysis and data collection processes. Data analysis and results are then discussed in Section 4. Section 5 presents conclusions, main implications, limitations, and further research.

2. Literature review

2.1. Traditional cast-in-situ construction vs Prefabricated construction

Cast-in-situ construction also known as cast-in-place construction, is a traditional method where the walls and slabs of the building are cast on the site within the formwork (Asamoah et al., 2016; Lansang, 2022; Vasishta et al., 2023). This method has been mostly utilized for various types of constructions, however, it has received widespread criticism for the requirement of a larger labours and a longer time (Vyas, 2015). The high potential for material wastage is another major concern in relating to cast-in-situ (De Souza et al., 2016; Neithalath & Schwarz, 2009; Turai & Patil, 2022). To address the environmental issue, prefabricated construction, though it is not new, considerably has developed by many practitioners and researchers as a practice of "sustainable construction" owing to its benefits of shortening time, reducing overall cost and improving environmental performance for waste minimization (Gorgolewski, 2005; Jaillon & Poon, 2008; Tam et al., 2007; Zhou et al., 2022). Prefabricated construction, often referred to off-site construction or off-site manufacture, involves creating components of building within a factory, where all tools and materials are available, then assembling them on the construction site to complete the project (Hong et al., 2018; Li et al., 2014; Luo et al., 2021). It breaks the traditional construction method of "Qin Brick, Han tile" and achieves sustainability by standardization of building components and industrialization of construction method (Xiao, 2020). The latest research from Chang et al. (2018), Hwang et al. (2018a, 2018b), Jayawardana et al. (2023), and Yunus and Yang (2012) has examined these promising benefits over traditional cast-in-situ construction as well as its widely utilization in many countries and regions.

As a popular transformation from traditional cast-in-situ construction. Prefabricated construction introduces not only benefits but also complexity and uncertainty due to highly decentralized and fragmented attributes, with dispersed workplaces, and numerous stakeholders (Luan et al., 2022; Yuan et al., 2021). Generally, prefabricated stakeholders include but are not limited to governments, owners/developers, producers/manufacturers, designers, contractors, and end-users (Hu et al., 2019; Luo et al., 2019). Among these, concerns associated with the multi-stakeholders are typically occurring throughout the whole life cycle, i.e., feasibility study, design, manufacturing and transportation, construction and operation and maintenance (Luo et al., 2019; Wang et al., 2022; Wuni & Shen, 2020; Yuan et al., 2021; Zhou et al., 2023). Take China as an example, the capital cost of prefabricated construction is approximately 15% higher than that of traditional construction (Liu et al., 2023). This primarily stems from design that do not adequately consider the nuances of production, transportation, and assembly processes. Moreover, production often fails to align with on-site assembly (Estrada et al., 2007; Mossman & Sarhan, 2021). Consequently, potential stakeholders, particularly developers, are hesitant to adopt prefabricated construction. This reluctance exacerbates the fragmentation and discontinuity of the prefabricated construction industry chain, creating further obstacles in the path of its widespread adoption. Therefore, how to engage multiple stakeholders in prefabricated construction projects has been the crucial factor for its implementation.

2.2. Stakeholder engagement

Stakeholder engagement has grown into a widely used construct in business and society research as it is highly applicable to understanding and explaining the relationships between organizations and stakeholders and outcomes of these relations (Kujala et al., 2021, 2022; Mitchell et al., 2022; Sachs & Kujala, 2021). Previous studies have explained the conceptual and theoretical development of stakeholder engagement as a way of practicing the stakeholder theory (Freeman et al., 2017; Jones et al., 2017; Shah & Guild, 2022; Strand & Freeman, 2015). Considering the complexity and uncertainty of construction projects, the importance of stakeholder engagement in crucial project management, such as addressing conflicting interests (Bahadorestani et al., 2020b), achieving sustainability (Bal et al., 2013; Eyiah-Botwe et al., 2016) and managing stakeholders (Missonier & Loufrani-Fedida, 2014) cannot be ignored.

Stakeholder engagement in construction projects can be conceptualized in different ways, and most referring to the process of meaningful involvement of those who are engaged in making decisions about programs (Collinge, 2020; Mathur et al., 2008; Okedara et al., 2020; Rodriguez-Melo & Mansouri, 2011). For example, Hu et al. (2019) and Li et al. (2014) indicated that identifying roles and requirements of stakeholders serves as the fundamental basis for effective stakeholder engagement when it comes to addressing complex stakeholder network. Doran and Giannakis (2011) and Savage et al. (2010) argued that the interactions and relationships among stakeholders brings about resource and capability complementation, which is paramount to engage stakeholders for project implementation. Tengan and Aigbavboa (2017) identified key stakeholders and the level of stakeholder engagement in decision-making process of construction projects in Ghana. These studies emphasize fostering various modes of relationships among stakeholders, which can be an effective management tool to facilitate collaboration, satisfy value requirement and boost performance (Bal et al., 2013; Mathur et al., 2008; Mok et al., 2015). In other words, the stakeholders should be built relationships, and have the obligation to satisfy requirements of the other related stakeholders via providing values (Bahadorestani et al., 2020b). Furthermore, the values not only serve to fulfil individual stakeholders' goals but also advance the holistic objectives of project. However, stakeholder engagement is not always effective, resulting in negative impacts on project performance, due to diverse goals and various stakeholders interests involved across fragmented construction processes (Luo et al., 2019).

Some research insight on stakeholder engagement have also focused on prefabricated construction project. For example, Teng et al. (2017) proposed an industrial symbiosis model to analyse stakeholder relationships and mutual connections that influences their symbiosis levels. Luo et al. (2019) prioritized stakeholder-associated risks embedded across PC supply chains. Gan et al. (2018) explored how to address the barriers to prefabricated construction development through engaging stakeholders. While these previous studies provide as a solid foundation, there is still lacking a quantitative analysis for the multi-stakeholders and the interactions of their values in engaging stakeholders. As mentioned above, prefabricated construction is featured with more stakeholders and complicated, fragmented processes than traditional cast-in-situ construction (Xue et al., 2018). For example, the designer conducts drawings without considering the needs of the producer and contractor, resulting in increased construction costs. Thus, a systematic effective quantitative analysis is needed to comprehensively explore specific exchange of value-based relationships among stakeholders (Hu et al., 2019).

2.3. Stakeholder engagement analysis methods

To figure out the appropriate quantitative method for stakeholder engagement in prefabricated projects, A series of methods, including salience, position, and matrix models, were reviewed to identify and classify stakeholders and relationships. For instance, A classical tool, Stakeholder Circle™ was developed to identify, prioritize stakeholders, and map their influences on projects, without considering stakeholders' attributes (Bourne & Walker, 2008). To compensate, Nguyen et al. (2009) proposed a quantitative method for evaluating stakeholders' impact, considering the attributes of stakeholders. De Schepper et al. (2014) applied a dynamic dual model to identify key stakeholders in Public-Private Partnerships. However, these methods concentrate on identifying, classifying stakeholders, analyzing their influences rather than demonstrating boundaries between stakeholders and revealing their relationships (Mok et al., 2015).

Case study, game theory, and network-based analysis are then introduced to enhance stakeholder engagement. For example, Hu et al. (2019) analyzed the evolution of stakeholder engagement practices through the case study of Australian projects; Jayasena et al. (2021) used a case study in Sri Lanka to ensure stakeholder engagement in smart city projects. Gu et al. (2018) and Li et al. (2020) adopted a game model for quality supervision among construction stakeholders; besides, the utilization of network-based analysis to address stakeholder interactions, interdependencies and relationships have surged in recent years, particularly in large and complex projects (Mok & Shen, 2016). This includes but are not limited to Analytic Network Process (ANP) (Aragonés-Beltrán et al., 2017), Social Network Analysis (SNA) (Nguyen et al., 2020) and Stakeholder Value Network (SVN) (Bahadorestani et al., 2020a). Particularly, SNA has been widely employed in construction sector, which enables to describe stakeholders' characteristics, interrelationships, and influences (Nguyen et al., 2020; Zheng et al., 2016). This is because construction project is a social network comprised of diverse stakeholders with interdependent and collaborative relationships. In this context, stakeholders' behaviors are influenced and constrained by networks (Chinowsky et al., 2008). Take Dadpour et al. (2019) as an example, they employed SNA to identify stakeholders and their concerns at different phases of construction projects; Similarly, Nguyen et al. (2020) explored patterns of interrelationship and connection among stakeholders on off-site construction projects. However, SNA is challenging to quantify the important relationships that encompass a series of diverse values from multi-stakeholders in prefabricated construction (Yang et al., 2011), which is crucial to implement effective stakeholder engagement (Ward & Chapman, 2008).

To fill this gap, this study adopts the advanced SVN to investigate stakeholder's overall relativity and provide insights into values among stakeholders (Cameron et al., 2008; Feng & Crawley, 2009; Sutherland, 2009). The SVN, based on social exchange theory, unifies both social and economic relationships into a common framework, under which all stakeholder relationships are formed by the use of subjective utility analysis and the comparison of alternatives. Thus, it could make up the weakness of SNA by putting value to each valuable activity among stakeholders, thus acting as an efficient and effective quantitative tool to evaluate both direct and indirect values among stakeholders in projects, teams, and assignments (Hein et al., 2017; Zheng et al., 2019). As a result, SVN has also been successfully employed in building information model (BIM) (Zheng et al., 2019), industrial symbioses (Hein et al., 2017), energy conversation (Fu et al., 2011), and transportation (Pereira et al., 2018).

3. Research methodology

A four-step based-SVN is presented as Figure 1. Firstly, the current state of prefabricated construction was reviewed to highlight the research gap in prefabrication studies. Next, a list of stakeholders, who are defined as those can affect or is affected by the achievement of objectives, aligning with the stakeholder theory (Baumfield, 2016) and their values in prefabricated construction projects was identified through a literature review and further validated through in-depth expert interviews. Subsequently, questionnaire was conducted to collect data on stakeholders' perceptions of the importance and urgency. Finally, the key stakeholders, values, and their relationships were determined, and effective measures for enhancing project performance were identified by emphasizing the crucial roles of important stakeholders and their associated values.

3.1. Identifying stakeholders and values

In this study, the developer acts the role of the focal organization, as it takes the lead in conducting feasibility studies, negotiations, and coordinates the implementation and operation of the project (Hein et al., 2017; Qu et al., 2023; Zheng et al., 2019). The values exchanged among stakeholders in prefabricated projects are presented through different perspectives: value flow, value path, and value cycle. Value flow represents direct values exchanged between any two stakeholders. Value path refers to indirect values that traverse through three or more stakeholders. A value cycle represents a loop of value path, where the developer serves as both the starting and ending point of the value exchange. Please see Figure 2.

The commonly mentioned five stakeholder groups via literature review are developers, designers, manufacturers, main contractors, and subcontractors (Li et al., 2017), which form the initial stakeholder list for this study. Next, chain-referral sampling, where the existing five stakeholder

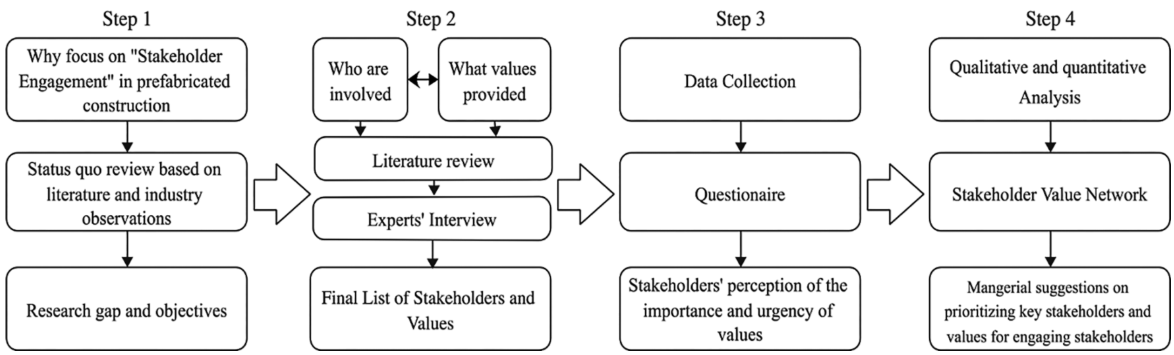

Figure 1. Research design for stakeholder engagement

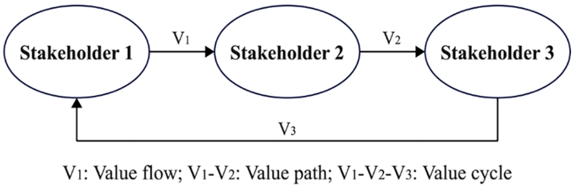

Figure 2. Value flow, value path and value cycle

groups are required to provide referrals to other stakeholders are employed. The sampling process as follows: five representatives of the initial list with over five years of prefabrication experience were asked to evaluate the stakeholder list and expand with other potential stakeholders based on their working experience, until no additional stakeholders would be found. Ultimately, 12 stakeholder groups were identified, i.e., government (**G**), financial institution (**F**), the developer (**DV**), the designer (**DS**), general contractor (**GC**), subcontractor (**SC**), the producer (**P**), prefabrication consultant **(PC),** the supplier (**S**), logistics enterprise (**L**), facility manager (**FM**), and end-user (**U**).

In terms of identifying the values between the twelve stakeholders, stakeholder characterization templates (SCT) were adopted (Zheng et al., 2019). SCT provides a clear structure to identify what value stakeholders contribute to and acquire from other stakeholders. The SCT structure mainly contained four aspects, namely, the role, objective, needs and inputs for each stakeholder. Based on the initial results determined by literature review, the semi-structured interview was further conducted. Forty-one experts ranging over twelve stakeholders, i.e., 3 government officials, 2 financial staffs, 5 developers, 2 designers, 4 manufactures, 3 transporters, 4 contractors, 3 subcontractors, 4 suppliers, 2 property managers, 4 users, and 5 consultants were selected to supplement the results to ensure the results' validity and accuracy. Table 1 shows the distribution of the experts in terms of stakeholder group, numbers, main positions, education level and years of experience. Ultimately, a total of 110 value between stakeholders were identified in Appendix. Each value with details was coded. The letters consisted of the codes of two stakeholders, representing the value provided by the former for the latter. For example, DV-G_1 represents the first value provided by **DV** (developer) for **G** (government).

In this study, the developer is supposed to be the focal organization as it invests and initiates the project (Mao et al., 2015). The developer builds direct or indirect value relationships with the other 11 stakeholders. SVN can be further established through these value relationships and those between the eleven stakeholders. The network in Figure 3 takes the developer and its stakeholders with direct value relationships as an example to illustrate the SVN network.

3.2. Questionnaire development

A questionnaire was developed to collect quantitative data of the stakeholders' perceptions of the identified 110 values in prefabricated projects in terms of the degree of urgency and importance. Construction practitioners who involved in or are involving in prefabrication, off-site or modular projects in China were the targeted questionnaire respondents. The respondents covered mentioned 12 stakeholder groups. The questionnaire is structured as two parts: the first part is gathering the respondents' basic profile information, such as gender, age, and year of experience. The second part requires respondents to evaluate the score of urgency N and importance I of values that are provided with them from other stakeholders based on their perceptions, please ask for Supplement document for reference to the questionnaire.

The urgency N of value flow refers to the degree of need for this value flow, which is measured by the question, i.e., how would you perceive the presence or absence of the fulfillment of this value flow (Fu et al., 2011). The importance I of value flow reflects the degree of importance for this value flow for meeting stakeholder's need, which is measured by the question, i.e., if this need were to be fulfilled, how important would this value flow be in fulfilling the need (Fu et al., 2011; Hein et al., 2017). The measurement scales of urgency N and importance I adapted from Zheng et al. (2019) are shown in Tables 2 and 3, respectively.

Table 1. Expert profile

Stakeholder group	No.	Main position	Education level	Years of Experience
Government	3	Division head	Master or above	5≤
Financial institution	2	Business manager	Bachelor or above	3≤
Developer	5	General manager, business manager	Master or above	5≤
Designer	2	Business manager	Master or above	5≤
Producer	4	General manager, factory manager	Master or above	5≤
Logistics enterprise	3	Business manager	Bachelor or above	3≤
General contractor	4	General manager, project manager	Master or above	5≤
Subcontractor	3	General manager, project manager	Bachelor or above	5≤
Supplier	4	General manager, business manager	Bachelor or above	3≤
Facility manager	2	Business manager	Bachelor or above	5≤
End-user	4	Senior scholar	Master or above	3≤
Prefabrication consultant	5	Professor, project manager	Master or above	5≤

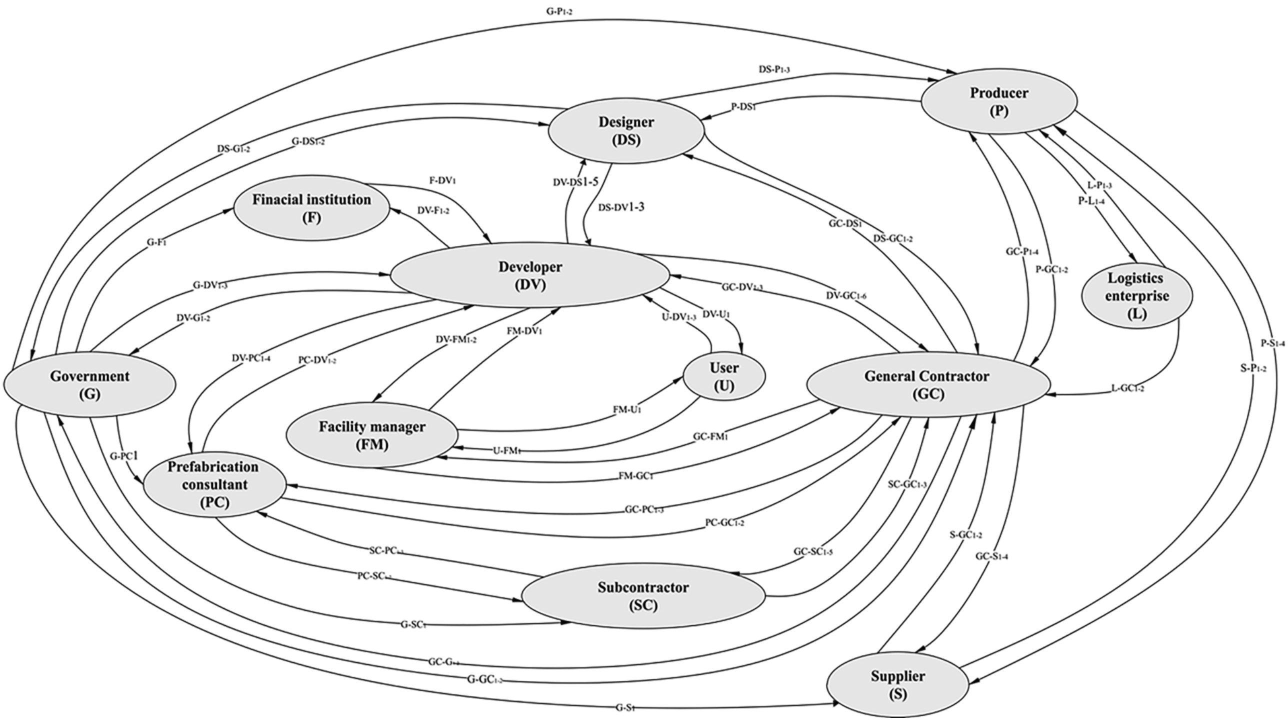

Figure 3. Value-based network

Table 2. Measurement scale for urgency *N* of value flow

Categories	Numerical value	Intensity score *N*	Options for the question
A	0	N_A = 0.11	Satisfied by its presence, but I would not regret its absence
B	1	N_B = 0.19	Satisfied by its presence, but I would somewhat regret its absence
C	2	N_C = 0.32	Satisfied by its presence, but I would regret its absence
D	3	N_D = 0.54	Its presence is necessary, and I would regret its absence
E	4	N_E = 0.92	Its presence is essential, but I would regret its absence

Note: N = 0.11×1.7 numerical value.

Table 3. Measurement scale for importance *I* of value flow

Categories	Numerical value	Importance score *I*	Options for the question
1	1	R_1 = 0.11	Not important; I do not need this value to fulfill this need
2	3	R_2 = 0.33	Somewhat important; It is acceptable to fulfill this need
3	5	R_3 = 0.55	Important; It is preferable to fulfill this need
4	7	R_4 = 0.77	Very important; It is strongly desirable to fulfill this need
5	9	R_5 = 0.99	Extremely important; It is indispensable to fulfill this need

Note: I = 0.11×numerical value.

Before handing out the questionnaires, a pilot study of six practitioners in prefabricated projects in China was carried out, to ensure the words and phrases of 110 values in the questionnaire were easily understood.

3.3. Quantitative analysis

(1) The utility score of value flow (U_v)

The utility score of value flow (U_v) could be figured out (Sutherland, 2009), upon respondents' perceptions of urgency N and importance I of value flow were collected through questionnaire. The U_v has been explained by multi-attribute utility theory and employed to select most important value flow. The U_v in each stakeholder group is calculated using Eqn (1) (Feng, 2013):

$$U_{v,i} = \left(\sum_{n=1}^{n} N_{i,n} \times I_{i,n} \right) / n, \quad (1)$$

where $U_{v,i}$ denotes the utility score of the i_{th} value flow in the specific stakeholder group; n is the total number of respondents in this stakeholder group. In case of one respondent in the stakeholder group, i.e., n = 1; then the utility score of i_{th} value flow $U_{v,i} = N_i \times I_i$. In this study, mean value of the U_v is preferred as more than one respondent in the stakeholder groups.

(2) The utility score of value path (U_p)

The utility score of value path (U_p) is calculated by the multiplicative rule, see Eqn (2). In other words, the U_p equals the multiplicative result of all value flows going through this path. Importantly, when the value path beginning and ending with the developer, this equation also could be used to figure out the utility score of value cycle, i.e., U_c:

$$U_p = \prod_{j=1}^{x} U_{v(j)},\ 2 \ll x \ll 12, \tag{2}$$

where U_p denotes the utility score of the value path with involving x value flows; $U_{v(j)}$ refers to the score of the j_{th} value flow in the path. In this study, the value path may contain minimal 2 and maximum 12 value paths.

(3) Weighted value flow occurrence (*WVFO*)

After identifying the utility score of value flow, value path and value cycle, WVFO was introduced as an indicator of key value flows, which reflects the impact of value flow for the focal organization, i.e., the developer in this study, on influencing project performance (Sutherland, 2009). It is calculated as in Eqn (3):

$$WVFO_f = \sum_{c=1}^{n} U_c \varphi_{fc} \,/ \sum_{c=1}^{n} U_c, \tag{3}$$

where f indicates a specific value flow; n is the total number of value cycles beginning and ending with the developer; U_c is the utility score of the c_{th} value cycle. Furthermore, φ_{fc} equals 1 if value flow f is included in the c_{th} value cycle, or 0 if not.

(4) Weighted stakeholder occurrence (*WSO*)

Similarly, another indicator, WSO emphasizes the multi-valve exchange of the stakeholders, and helps to identify the important stakeholders. WSO contains both the utility scores of the value cycles U_c and the number of relevant value cycles, as shown in Eqn (4):

$$WSO_s = \sum_{c=1}^{n} U_c \varphi_{sc} \,/ \sum_{c=1}^{n} U_c, \tag{4}$$

where s indicates a specific stakeholder; n is the total number of value cycles for the developer in this study; U_c is the utility score of the c_{th} cycle; and if the stakeholder is included in the c_{th} cycle, φ_{sc} = 1, if not, it is 0.

4. Research results and discussion

4.1. Questionnaire respondents

300 questionnaires were handed out from November 2019 to January 2020[1] via electronic media, such as phone, zoom and email, of which 194 valid questionnaires were returned (64.7%). The profile information is presented in Table 4.

Using data from the 194 valid questionnaires collected in China, all value paths in prefabricated projects between any two stakeholders have been searched by *R* algorithms, see the Table 5. The italic numbers on diagonal represent the number of value cycles beginning and ending with each stakeholder.

In particular, the bold number indicates there are 99,555 value cycles beginning and ending with the developer, scores of which falls between the minimum score, i.e., 0.0001 and the maximum score, i.e., 0.3868. It is proven that the distribution of these value cycles follows a power-law distribution, as depicted in Figure 4.

It shows that there are 88,612 value cycles with a score greater than 0.001, representing 89% of the total value cycles; 298 value cycles have a score over 0.01, accounting for only 0.2% of the total. This indicates that a few cycles possessing high scores help to drive stakeholder engagement in prefabricated projects, which thereby should be

Table 4. Respondent profile

Categories	Profile	Percentage
Years of experience	1 < year ≤ 2	30.82%
	2 < year ≤ 5	43.71%
	5 < year ≤ 10	16.74%
	> 10	8.73%
Company type	State-owned	50.52%
	Private	49.48%
Stakeholders	General contractor	16.49%
	Developer	10.82%
	Government	9.28%
	Designer	4.12%
	Sub-contractor	4.12%
	Financial institution	4.12%
	Supplier	3.16%
	Logistics	1.55%
	Prefabrication consultant	7.22%
	Producer	10.82%
	Facility manager	10.82%
	End-user	17.01%

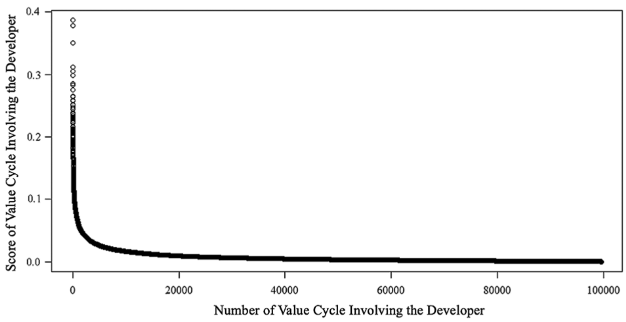

Figure 4. Score distribution of value cycles involving the developer

[1] Before lockdown due to COVID-19 crisis.

prioritized to improve performance (Fu et al., 2011). Key value flows, cycles and stakeholders for the developer could be further analyzed on a basis of the utility scores of these value cycles.

4.2. Key value flow analysis

The WVFO scores of the 99,555 value flows in such value network were further calculated based on Eqn (3), and the most 20 important value flows were ranked, see Figure 5. Prefabrication- training provided by the consultant to the developer ($PC\text{-}DV_1$) is the most significant value flow, with highest WVFO score, i.e., 0.2027. It suggests that investment in prefabrication training and skills is imperative in current prefabrication industry. Prefabrication construction in China has ushered a booming stage, which will witness increasing number of prefabricated constructions in coming years. However, laborers who lack prefabrication knowledge and experience have been a major barrier in adopting prefabrication in projects (Mao et al., 2015), which implies the important role of the ($PC\text{-}DV_1$).

Prefabrication management system (PMS) involving quality, schedule, and cost ($PC\text{-}DV_2$) ranks the second place, with the WVFO score of 0.1890. Same as the first value flow, it is provided with the developer by the consultant. From the developer's perspective, PMS has been indispensable to achieve the predetermined project objectives (Hu et al., 2019). In addition, PMS involves resources

Table 5. Numbers of value paths searched between stakeholders

	G	F	DV	DS	P	L	GC	SC	S	PC	U	FM
G	*87,026*	17,691	8,846	17,032	13,104	52,416	4,531	32,725	38,213	33,761	28,812	28,615
F	3,220	*3,222*	1	3,636	5,092	20,368	2,115	20,083	16,192	30,480	2,115	2,115
DV	3,220	3,222	***99,555***	3,636	5,092	20,368	2,115	20,083	16,192	30,480	2,115	2,115
DS	8,188	31,282	11,715	*88,535*	10,775	43,100	2,809	34,761	29,388	31,488	33,961	33,625
P	9,900	17,362	3,811	12,945	*94,259*	4	2,037	20,825	13,732	19,084	12,049	11,937
L	20,960	42,050	10,805	31,275	7,307	*29,228*	6,089	56,853	52,944	51,288	34,483	34,169
GC	1,942	3,742	958	2,364	3,652	14,608	*10,1002*	5,217	12,234	3,570	2,864	2,863
SC	12,810	20,754	4,494	12,642	14,934	59,736	8,223	*67,521*	58,398	6,798	21,588	21,579
S	15,108	27,008	6,098	18,346	5,186	20,744	4,020	35,212	*51,932*	32,588	19,802	19,608
PC	6,168	12,572	3,666	7,568	8,928	35,712	2,998	17,290	32,144	*81,696*	13,902	13,894
U	14,306	16,106	958	16,402	23,462	93,848	8,455	83,903	75,190	12,3302	*7,301*	6,343
FM	13,958	15,758	958	15,964	23,204	92,816	8,449	82,793	74,362	12,1802	956	*11,321*

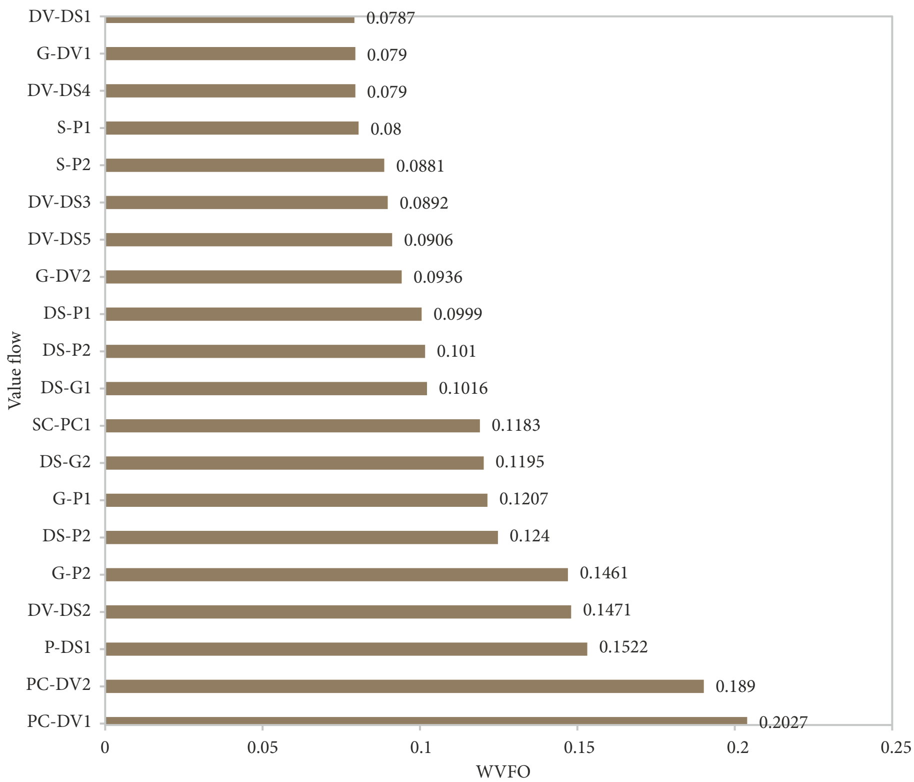

Figure 5. Top 20 value flows

controlling and coordinating, such as humans and material, throughout project phases of planning, designing, constructing, and operating (Kerzner, 2017). Advanced management theories and tools, such as lean construction, optimization theory, and behavioral science, could also be employed in PMS (Al-Aomar & Setijono, 2012). Given the scarcity of prefabrication practices and experience, however, it is particularly challenging for Chinese developers to conduct PMS (Mao et al., 2015). Accordingly, the developer is likely to seek better PMS support from the consultant.

Reports of manufacturing resources regarding types and parameters of prefabricated molds and equipment $PC\text{-}DS_1$, is the third important value flow, with its WVFO score of 0.1522. This value is provided with the designer by the producer. The early involvement of the producer in the design of prefabricated components is crucial for enhancing manufacturing performance (Pheng et al., 2015).

4.3. Key value cycle analysis

Six important value cycles are sorted out with the top-ranking utility scores via Eqn (2), see Figure 6.

The value cycles of **A**, **B**, and **C** are beginning and ending with the developer through the designer alone. Specifically speaking, the developer provides designer the requirements and expectation of co-design ($DV\text{-}DS_2$). In turn, the designer provides the drawing ($DS\text{-}DV_2$), design change scheme (DS-DV_1), and accurate project budget estimates ($DS\text{-}DV_3$) based on standardized production and installation of components to the developer. The value cycle **D** indicates that the developer values the prefabrication guidelines and standards from the government ($G\text{-}DV_2$) to be in place. In turn, the developer can obtain more government support by providing better detailed prefabricated project information ($DV\text{-}G_2$). Generally, it is tough for the developer to successfully implement prefabrication projects in the absence of policy support, legal guidelines, and standards (Mao et al., 2015; Rahman, 2014). The value cycle **E** demonstrates the details of how co-design affects prefabrication performance. In cycle **E**, the designer provides design change with general contractor effectively ($DS\text{-}GC_1$) is included, as design change is inevitable during on-site installation of prefabrication components (Li et al., 2018). Also, it is efficient for the designer to consider the construction capabilities of the general contractor when changes occur. General contractors, as a result, will deliver project to developer in shorter time with higher quality, lower cost ($GC\text{-}DV_2$). The value cycle **F** involves the collaboration relationship among designer, producer, and general contractor, which has been proved positive in prior studies in improving efficiency of resources such as equipment and labor and reducing design change and project cost (Gan et al., 2018; Li et al., 2016; Xue et al., 2018). It is also in line with the third most important value flow, i.e., $P\text{-}DS_1$, which emphasis the multi-stakeholders' collaboration.

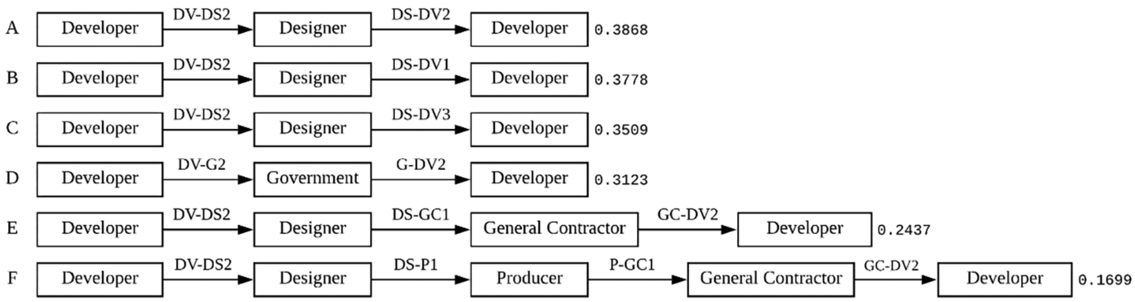

Figure 6. Top six value cycles

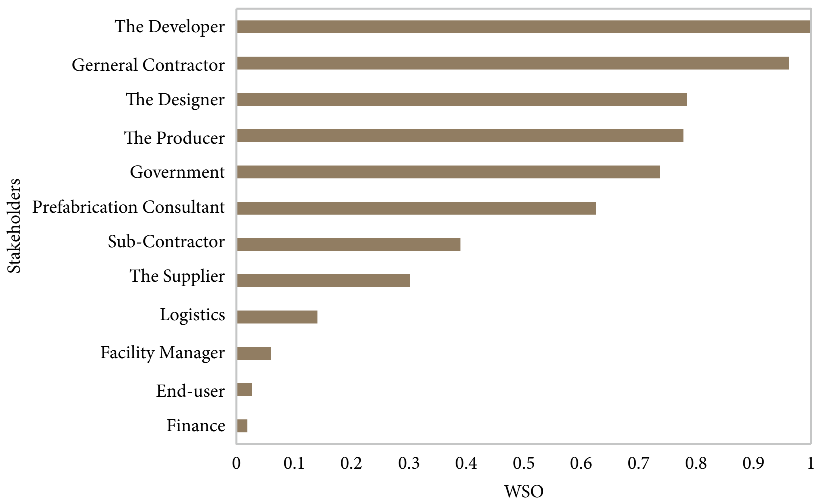

Figure 7. WSO analysis

4.4. Key stakeholder analysis

The WSO scores of twelve stakeholders is calculated based on Eqn (4), reflecting their importance to developer, see Figure 7. Six important stakeholders are identified out with the top-ranking WSO, namely, developer, general contractor, designer, producer, government and prefabrication consultant. As mentioned in the results of value flows and cycles, the collaborative exchanging values among developer, designer, producer and general contractor, and the supportive values coming from government and prefabrication consultant, are important to create value and improve project performance.

As the developer is focal organization in this study, its WSO score is 1 due to participating into all value cycles. Then, the general contractor takes the second place with WSO score of 0.962. The higher WSO score is, the more important stakeholder and associated values are. Particularly, the developer largely depends on general contractor in the prefabricated project implementation. Next, the designer and producer have almost same WSO, at 0.784 and 0.778, respectively. As discussed in value flow analysis, the designer is crucial through co-design with general contractor and the producer. The producer, a new stakeholder, plays three roles in prefabricated projects, i.e., decision supporter, manufacturer, and coordinator, greatly affecting prefabrication performance (Hu et al., 2019). Meanwhile, limited understanding on prefabrication that developer has makes government being the fifth important stakeholder, as further assisting the developer in promoting prefabrication development by government policies, guidelines, and incentives. Specially, prefabrication consultant also plays an important role in prefabricated construction. This is because developer and other stakeholders lack mature prefabrication knowledge, experience, management system, theories and tools in the initial stage of Chinese prefabricated construction.

4.5. Discussion

A value-based network analysis combing both qualitative and quantitative aspects was utilized to identify, analyze, and improve the stakeholder engagement of prefabricated construction through the whole life cycle stages. Compared with previous relevant methodologies, like ANP (Aragonés-Beltrán et al., 2017) and SNA (Nguyen et al., 2020), this value-based network analysis quantifies the stakeholder engagement concerning their exchanging values.

A total of twelve stakeholders were identified. Various researchers have conducted stakeholder analysis of prefabrication construction. For example, Li et al. (2017) divided stakeholders into five groups, i.e., developers, designers, manufacturers, main contractors, and subcontractors. Previous research adopted different stakeholders' classification, covering a series of the internal and external entities such as the developers, designers, users, contractors, suppliers, supervisors, sales agent, facility managers, surveyors, capital providers, research institutions, and public authorities (Teng et al., 2017). However, some stakeholders, such as consultants, were not analyzed. In fact, they are playing an important role in driving prefabricated construction development, due to stakeholders lacking experiences and skills in the initial stage of China's prefabricated construction.

A total of 110 values among stakeholders were identified based on SCT, which shows ideal connections among stakeholders through the whole prefabricated construction life cycle. These values include direct, indirect, tangible, and intangible connections among stakeholders, which can reflect the systematic and accurate stakeholder relationships comparing with the existing studies (Teng et al., 2017; Xue et al., 2018).

These 12 stakeholders, along with their 110 values, comprise the prefabricated construction value network. A value-based network analysis based on SVN is employed to engage stakeholders in a more targeted and meaningful way, ensuring their perspectives are reasonably considered and that decisions align with their interests. This study put developer as the focal organization in value network due to its pioneered prefabricated construction adoption and contribution, which is in line with Teng et al. (2017), Li et al. (2014), and Liu et al. (2018). The key stakeholders, value flows, paths and cycles are determined, based on the quantitative analysis of value network of U_v, U_p, *WVFO* and *WSO*.

The results of *WVFO* are illustrated in Figure 5. The results indicate the most 20 important value flows of 99,555 value flows in the value network. Three of the most important value flows, named $PC\text{-}DV_1$, $PC\text{-}DV_2$ and $PC\text{-}DS_1$, are figured out. $PC\text{-}DV_1$ and $PC\text{-}DV_2$ represent prefabrication training and PMS provided by the prefabrication consultant to the developer. This highlights the important role that prefabrication consultant plays in driving prefabricated projects in China. These results pointed out the importance of engagement of consultant, which is limitedly studied in present studies. In practice, consultants provide various professional service regarding financing, design, construction in traditional construction projects. In prefabricated construction projects, prefabrication consultants provide PMS oriented to quality, schedule, and cost as well, further facilitating prefabricated construction. Therefore, on one hand, the developer should work with the consultants collaboratively to address the prefabrication knowledge and skills shortage; On the other hand, the prefabrication consultants should emphasize on the labor training and skill development when providing service to the developer. $PC\text{-}DS_1$ means reports of manufacturing resources provided by the producer to the designer. Indeed, the ability of the producer to produce a mass quantity of prefabricated components relies on the designer providing standardized modes or design specifications, which is the key to achieving economies of scale, reducing costs, and improving quality and efficiency (Pan et al., 2007). However, the designer usually overlooks the manufacturing capabilities of the producer (Gan et al., 2018; Zheng et al., 2016), resulting in challenges and inefficiencies during the production process (Xue et al., 2018). Therefore, the designer should collaborate with producer at an early stage by incorporating their inputs into the design process.

The results of key value cycle analysis are illustrated in Figure 6. Six important value cycles, named A, B, C, D, E and F, are determined, and analyzed. The value cycles of A, B and C are exchanging value flows between developer and designer, comprising of $DV\text{-}DS_2$, $DS\text{-}DV_2$, $DS\text{-}DV_1$, and $DS\text{-}DV_3$. This indicates the designer needs to build collaboration with the developer at initial stage, which greatly positively influences prefabrication performance (Hu et al., 2019; Xue et al., 2018). Otherwise, it will alleviate higher project cost, thus being major factor hindering the application of the prefabrication technology (Mao et al., 2015; Pan & Goodier, 2012). It is evidenced that the cost of production and on-site assembly can be reduced by 5.6% and 15.3% through co-design (Xue et al., 2018). The value cycle of D is exchanging value flows between developer and government, comprising of $DV\text{-}G_2$ and $G\text{-}DV_2$. In fact, most developers in China have limited understanding of the prefabrication, especially during the current transformation period. It is imperative for developer to obtain more guidelines and standards published by government (Gan et al., 2018). This is in line with the status quo in the initial development stage of prefabricated construction in China, where the government leads the prefabrication development. The value cycles of E and F are exchanging value flows among developer, designer, producer, and general contractor, demonstrating their collaborations. Establishing a collaborative relationship between the designer and the general contractor ensures the constructability of the prefabrication project (Pan & Goodier, 2012). In fact, some collaborative construction methods have been studied in traditional construction, such as integrated project delivery (Lahdenperä, 2012), engineering–procurement–construction (EPC) (Yang et al., 2019), and early contractor involvement theory (Lahdenperä, 2012). These methods focus on effective information exchange between stakeholders, ensuring procedures meet the requirements and aims of each stakeholder. To better engage stakeholders in the prefabricated projects in China, some of these modes could also been advocated. However, these collaborative methods are not widely adopted in real world, because of limited collaborative consideration and undeveloped stakeholders' capability (Li et al., 2018; Mao et al., 2015). Thereby, the developer should shed more light on alliancing stakeholders, and the designer, producer, and general contractor should improve their capability to meet developer's requirement (Lahdenperä, 2012).

The results of WSO are illustrated in Figure 7. Six core stakeholders are demonstrated as developer, general contractor, designer, producer, government, and consultant. This result reflects that general contractor is prominent as it undertakes main construction body of prefabricated construction project. Furthermore, the designer and producer are also crucial for prefabricated construction performance, via providing co-design and prefabricated construction components. At the same time, government and consultant also have big influences in prefabricated construction, which is in line with the results of key value flows and cycles. Interestingly, the WSO of prefabrication consultant is relatively high, which is not mentioned and analyzed in existing studies (Teng et al., 2017). This is because the popular application of prefabricated construction in China leads to them being prioritized partners with the developer. High demand of prefabricated construction expertise makes the prefabrication consultant critical for adding value in prefabricated projects.

5. Conclusions

This study adopted a value-based network tool to analyze stakeholder engagement in the life cycle of prefabricated construction. This methodology mainly included a qualitative analysis to identify stakeholders and their exchanging values based on social exchange theory, and a quantitative analysis via stakeholder value network to analysis key stakeholder roles and values. The results revealed that (1) the prefabricated construction ability and experiences of developer need to be improved to enhance stakeholder engagement, (2) the collaborative relationship among the key stakeholders, named developer, designer, producer and general contractor, should be promoted in prefabricated construction, which has big impacts on stakeholder engagement, (3) government should issue some policies focusing on motiving developer and producer to engage in prefabricated construction such as finance support and standards.

Managerial implications and measures are summarized based on the results. Firstly, training and PMS coming from consultant is important for developer to perform prefabricated construction projects. Therefore, consultants should be engaged in the initial stage of China's prefabricated construction. Secondly, collaborative construction methods, like EPC and IPD, can be developed in the prefabricated construction to target the core stakeholders and values identified in this study. Thirdly, the policies of improving the development of consultant and the collaboration of stakeholders, which are issued by government and industrial organization, should be also provided to engage stakeholders.

The contribution of this study is twofold. From a theoretical view, it has explored the effective stakeholder engagement by an innovative value-based network analysis of stakeholder roles and relationships to enrich the existing knowledge body of prefabricated construction performance and development. This is not only an extensive application of existing theories of stakeholder engagement and SVN, but also a theorical enrichment in the field of project management. From a practical point of view, this study provides an in-depth analysis that could be used as the decision-making references to improve stakeholder engagement by managing core stakeholders and value-based relationships. This study also provides clues for the advancement of digital construction, particularly through capturing the key value information in the building information systems. The value-based network plays a crucial role in facilitating the exchange of information within such systems.

Admittedly, this study has limitations. Firstly, the analysis of stakeholder perceptions of value flows was measured from a static perspective, while these perceptions may evolve dynamically throughout the life cycle of the project. Future studies could incorporate a longitudinal approach to capture the changes in stakeholder perceptions over time. Secondly, it should be noted that this study specifically pertained to prefabricated construction projects in China with a focus on the initial development phase. However, this value-based network analysis is applicable in developed countries, making it conducive to cross-country comparisons.

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Data availability statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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APPENDIX

	G	F	DV	DS	P	L	GC	SC	S	PC	U	FM
G	—	G-F$_1$: Policy support	G-DV$_1$: Policy support G-DV$_2$: Prefabrication-related laws, regulations, and standards G-DV$_3$: Project subsidies	G-DS$_1$: Policy support G-DS$_2$: prefabrication-related design regulations, requirements, and standards	G-P$_1$: Policy support G-P$_2$: Prefabrication-related manufacturing technology standards		G-GC$_1$: Site construction standards and regulations G-GC$_2$: Supervision and inspection	G-SC$_1$: Supervision and Inspection	G-S$_1$: Policy support	G-PC$_1$: Prefabrication-related laws, regulations, and standards		
F		—	F-DV$_1$: Efficient Loan									
DV	DV-G$_1$: Response to prefabrication use DV-G$_2$: Implementation information on prefabrication, e.g., construction recording	DV-F$_1$: Better return of loan from prefabrication project DV-F$_2$: Feedback of prefabrication use	—	DV-DS$_1$: Prefabrication-based contract terms, including responsibility and risk sharing. DV-DS$_2$: Design requirement of coordination with general contractor and factory DV-DS$_3$: demand of design, e.g., design function, structure, and purpose for prefabrication DV-DS$_4$: design service fee DV-DS$_5$: Future opportunities			DV-GC$_1$: Prefabrication-based contract terms, including requirements, responsibility, and risk sharing. DV-GC$_2$: Construction fee DV-GC$_3$: Supervision and inspection DV-GC$_4$: Requirements for coordination construction with designer and factory DV-GC$_5$: Future opportunities DV-GC$_6$: Design drawings confirming to prefabrication requirements			DV-PC$_1$: Prefabrication-based consultant contract terms, including requirements, responsibility, and risk sharing. DV-PC$_2$: Consultant service fee DV-PC$_3$: Project management requirement DV-PC$_4$: Future opportunities	DV-U$_1$: High-quality facility	DV-FM$_1$: Prefabrication-based facility management contract terms, including requirements, responsibility, and risk sharing. DV-FM$_2$: Facility management service fee
DS	DS-G$_1$: Response to prefabrication use DS-G$_2$: Drawings		DS-DV$_1$: Design drawings confirming to prefabrication requirements. DS-DV$_2$: Prefabrication-related Budget DS-DV$_3$: Feasible solution for engineering change	—	DS-P$_1$: Coordination-based design information for components DS-P$_2$: Deep-designed production drawing DS-P$_3$: Cooperation and support		DS-GC$_1$: Timely response for engineering change DS-GC$_2$: Demand of coordination design					

	G	F	DV	DS	P	L	GC	SC	S	PC	U	FM
P				P-DS$_1$: Manufacturing ability report, including mould and equipment	——	P-L$_1$: Demand of components transportation quantities, time, and destination P-L$_2$: Transportation requirements P-L$_3$: Transportation-related Contract P-L$_4$: Transportation service fee	P-GC$_1$: Components P-GC$_2$: Cooperation and support		P-S$_1$: Information for components demand, including quantity, categories, and sequence. P-S$_2$: Feedback of material use P-S$_3$: Procurement contract P-S$_4$: Procurement fee			
L					L-P$_1$: Transportation service, e.g., device, personnel, time, and route L-P$_2$: Dynamic information during transportation process L-P$_3$: Cooperation and support	——	L-GC$_1$: Transportation information L-GC$_2$: Transportation information., plan, quantity, time, and route					
GC	GC-G$_1$: Response to prefabrication use GC-G$_2$: Construction information on prefabrication		GC-DV$_1$: Improved project quality and project management GC-DV$_2$: Less Engineering change orders. GC-DV$_3$: Engineering delivered with better quality	GC-DS$_1$: Constructive ability report, including labor and equipment	GC-P$_1$: Production Drawings needed to be deep-designed. GC-P$_2$: Demand of components, including quantity, categories, and sequence. GC-P$_3$: Supervision and inspection GC-P$_4$: Feedback of components use		——	GC-SC$_1$: Design drawings confirming to prefabrication requirements. GC-SC$_2$: Requirements for specialized engineering construction, e.g., time, schedule, and technology GC-SC$_3$: Supervision and inspection GC-SC$_4$: Sub-contract GC-SC$_5$: Sub-contract fee	GC-S$_1$: Information for components demand, including quantity, categories, and sequence. GC-S$_2$: Inspection GC-S$_3$: Procurement contract GC-S$_4$: Procurement fee	GC-PC$_1$: prefabrication-based construction information, e.g., schedule, quality, and cost GC-PC$_2$: problems and need GC-PC$_3$: Cooperation and support		GC-FM$_1$: Response of prefabrication maintenance need
SC							SC-GC$_1$: Detailed construction information., schedule, quality, and labor SC-GC$_2$: Specialized engineering delivered. SC-GC$_3$: Cooperation and support	——		SC-PC$_1$: prefabrication-based construction information, e.g., schedule, quality, and cost SC-PC$_2$: problems and need SC-PC$_3$: Cooperation and support		

	G	F	DV	DS	P	L	GC	SC	S	PC	U	FM
S					S-P_1: Production materials S-P_2: Cooperation and support		S-GC_1: Materials S-GC_2: Cooperation and support		—			
PC			PC-DV_1: Prefabrication-related training PC-DV_2: Prefabrication project management system, including quality, schedule, and cost management				PC-GC_1: Optimized construction schedule to improve quality, efficiency, and cost performance. PC-GC_2: Constructability assessment report	PC-SC_1: Constructability assessment report PC-SC_2: Optimized construction schedule to improve quality, efficiency, and cost performance		—		
U			U-DV_1: Feedback of end-users U-DV_2: Purchase or lease Contract U-DV_3: Purchase or lease fee								—	U-FM1: Property fee
FM			FM-DV_1: Feedback of prefabrication project operation and maintenance				FM-GC_1: Feedback of prefabrication project operation and maintenance				FM-U_1: Efficient Facility management service	—