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# Stakeholder Mapping and Analysis of Off-Site Construction Projects: Utilizing a Power–Interest Matrix and the Fuzzy Logic Theory

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**Abstract:** Stakeholder management is a crucial component in the implementation of off-site construction (OSC) projects, while stakeholder mapping serves as a practical technique to facilitate an in-depth understanding of different project stakeholders. Various topics have been explored in the OSC stakeholder management field, but research on OSC stakeholder analysis based on stakeholder mapping is still lacking. This study addresses this gap by developing two-dimensional (2D) and three-dimensional (3D) stakeholder mapping models. Data were collected from 167 stakeholders involved in OSC projects. The 2D model utilizes a power–interest matrix to classify 12 identified OSC stakeholder groups, while the 3D model further explores these groups by incorporating an additional dimension of stakeholder salience across different stages of project implementation. The results show that OSC stakeholders predominantly fall into the "key players" or "minimal effort" categories across various project stages. Key players include the client, modular manufacturer, main contractor, government, and designer, while the public and industry organizations generally require minimal effort. Additionally, stakeholders such as the supervision company, supplier, and subcontractor play key roles at specific stages, with varying levels of salience throughout the project lifecycle, reflecting shifts in their influence and involvement. The findings contribute to stakeholder management knowledge by providing an in-depth understanding of OSC stakeholders' interrelationships during project implementation, especially through uncovered stakeholder mapping in the OSC field.

**Keywords:** off-site construction; stakeholder mapping; stakeholder analysis; construction projects

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## 1. Introduction

Off-site construction (OSC) represents an innovative manufacturing process, which includes the production of construction components in controlled environments of off-site factories, transportation of these components to construction sites, and installation of these components on-site [1]. Generally, the core principles of OSC are closely related to terms like modular construction, offsite manufacturing, and prefabricated prefinished volumetric construction as per the range of practices and terminologies in their respective countries [2]. Hereinafter, OSC serves as a generic term throughout this paper. The adoption of OSC has been promoted by various factors such as government policies and regulations in the construction industry [3]. Despite this, barriers to its implementation can also be found in the construction sector, such as high initial costs, ineffective logistics, and poor manufacturing capabilities [4].

A project encompasses a diverse array of stakeholders, each engaged at different stages and playing a critical role in its successful delivery [5]. In OSC projects, stakeholders are especially significant due to the complex interactions and dependencies among entities such as developers, suppliers, contractors, manufacturers, designers, public authorities, and end users [6]. As outlined in the Project Management Body of Knowledge (PMBOK), stakeholder management involves identifying stakeholders, analyzing their expectations and impacts, and developing strategies to manage them effectively [7], and effective stakeholder management is essential for enhancing the likelihood of project success [8]. Compared with the stakeholders in traditional construction projects, OSC stakeholders exhibit diverse and varied impacts on project implementation, making it imperative to understand and manage their influences effectively [9].

One widely used approach in stakeholder management is stakeholder mapping, which helps to analyze and categorize stakeholders based on attributes such as power, interest, and salience [10]. Stakeholder mapping helps to reveal the inherent features of project stakeholders (e.g., power, interest, and salience) [11]. Power denotes the ability of stakeholders to exert influence, which can be achieved through coercive, utilitarian, or normative means [12,13]. Interest refers to the stakeholder's interests and concerns related to the problem the project aims to address [14]. Salience is an attribute based on one or more of the three relationship attributes of power, legitimacy, and urgency that stakeholders have [12]. In existing research, Eskafi et al. [11] combined the attributes of power, interest, and salience to provide a stakeholder analysis framework for a case study of the multi-purpose port. Elsaid et al. [15] used a rough–fuzzy hybrid method for stakeholder classification and prioritization, incorporating the attributes of power, interest, and salience.

Although various OSC stakeholder-related topics have been explored such as stakeholder perceptions, behaviors, and relationships [8,16], a comprehensive analysis of OSC stakeholders utilizing stakeholder mapping remains underdeveloped, particularly within the unique context of China. In China, stakeholder management has unique challenges, including the impact of various diverse cultures, rapid economic development, and strict regulatory regimes, which make coordinating various stakeholders more complex. Despite the growing importance of OSC in China, there are a lack of comprehensive stakeholder management strategies that consider the region's specific context. This void leads to many project management inefficiencies, delays, and conflicts, highlighting the need for a systematic approach to stakeholder analysis and management. To address this research gap, this study aims to develop both two-dimensional (2D) and three-dimensional (3D) stakeholder mapping models to analyze the power, interest, and salience of OSC stakeholders at the different stages of project implementation in China. In this study, salience refers to an attribute of OSC stakeholders in terms of power and interest. Questionnaire data were obtained from practitioners in OSC projects in the Chinese construction industry where OSC has attracted much attention. The research findings would enhance the understanding of stakeholders in OSC projects and improve overall project performance.

## 2. Literature Review

### *2.1. Project Stakeholders and Stakeholder Management*

Project stakeholders are the individuals, groups, and organizations that may affect, or be affected by, the implementation of a project, such as project managers, governing bodies, suppliers, and customers [5]. Stakeholders are commonly categorized into internal (e.g., clients, suppliers) and external (e.g., local governments, regulatory agencies) groups for better management [17]. Internal stakeholders tend to be more directly involved in the project, while external stakeholders are more challenging to identify due to their indirect involvement [5]. The significance of stakeholders in project delivery has been well-documented across various dimensions, such as project success, where stakeholder satisfaction is a critical measure [18]. Additionally, from a conflict management perspective, a conflicting relationship between project stakeholders may negatively influence project performance [19]. Stakeholders are also a primary source of uncertainty, and opposition from key stakeholders can derail project implementation [20,21]. Stakeholder management plays a central role in minimizing risks and ensuring project alignment with the needs of key participants [22]. Understanding stakeholder influence and attributes is fundamental to this process [23]. Frameworks such as Yang and Shen's [24] and Karlsen's [25] outline structured processes for managing stakeholders, emphasizing identification, decision-making, and continuous engagement. As projects grow more complex, particularly in large-scale endeavors, effective approaches to manage stakeholder relationships are increasingly necessary to balance conflicting interests and foster collaboration [26].

### *2.2. OSC Project Stakeholders*

OSC is defined as a modern construction method which includes the process of manufacturing components in an off-site factory environment, transporting these components to construction sites, and assembling them at construction sites [27]. OSC has been recognized as an innovative construction approach due to its inherent differences from the traditional on-site construction method [16]. In particular, the OSC approach moves some conventional on-site construction activities into controlled environments of off-site factories, which brings various sustainability-related benefits to its stakeholders [28]. OSC stakeholders are those individuals and organizations who are actively involved in OSC project implementation [8]. For example, developers, designers, users, contractors, module suppliers, and supervisors have been identified as the important stakeholders in the delivery of OSC projects [6]. The effective collaboration of these stakeholders is of great importance to the success of OSC projects [16,29]. This has been confirmed by Wuni and Shen [30], who concluded that the strong working relationships, communication, and information sharing of different stakeholders are the critical success factors of implementing OSC projects. The effective collaboration of different stakeholders can also positively influence the performance of OSC projects such as the cost performance of projects [31]. Nevertheless, promoting the effective collaboration of different OSC stakeholders is not an easy task given the dynamics and complexity of stakeholder relationships [16]. For instance, OSC stakeholder relationships are described as either those of positive symbiosis (both stakeholders can benefit) or commensalism (one stakeholder benefits while the other is not significantly damaged) in the construction industry [6]. To promote the collaboration of stakeholders in the delivery of OSC projects, organizational integration is one of the strategies. This organizational integration can be achieved through innovating procurement approaches where some important stakeholders (e.g., manufacturers) are integrated into the early stages of project implementation [28].

Stakeholder management is a key task in the delivery of OSC projects [32]. Effective stakeholder management is of great importance to the success of construction projects given that different stakeholders are involved in construction projects, and they have unique requirements and conflicting interests [33]. The failed management of stakeholders leads to various problems in project implementation, such as delays and cost overruns [34]. There are identified explorations on the stakeholder management of OSC projects. For instance, Teng et al. [6] identified the stakeholders and explored their symbiotic relationships in OSC projects, and the study revealed that OSC stakeholders can live harmoniously with each other, except for users and developers. Wuni and Shen [32] identified the key result areas for effectively managing OSC stakeholders, including effective collaboration, communication and information sharing, coordination of OSC supply chain segments, and early involvement. Hu, et al. [8] conducted a critical literature review in the OSC stakeholder area and found that OSC stakeholder management studies focused on the "integration, collaboration, and relationships of OSC stakeholders", "identification, roles, and attributes of OSC stakeholders", and "requirements and expectations of OSC stakeholders". Nguyen et al. [16] comprehensively reviewed the literature on OSC stakeholder relationships and found that the key topics included "collaboration", "building information modelling", "social network analysis", and "supply chain". All these explorations have contributed significantly to a better understanding of OSC stakeholders and their management.

*2.3. Stakeholder Analysis and Mapping*

Stakeholder analysis is a crucial step of stakeholder management. Stakeholder analysis explores how stakeholders interact with projects and organizations, which can understand the influences of different stakeholders and determine the right type of action in the delivery of construction projects [10]. Analyzing stakeholders in construction projects is facilitated by the use of stakeholder theory, which provides a solid foundation for identifying, classifying, analyzing stakeholders, and understanding their impacts [35]. A stakeholder analysis leads to the identification and determination of stakeholders' characteristics, such as their positions and roles, expectations, attitudes, and interest [7]. In the research field of OSC, only preliminary explorations on stakeholder analysis can be found such as those regarding stakeholder identification, roles, and attributes [8]. For instance, architects should transform their roles from the "architectural work" model to the "building product" model, and work as an experienced coordinator and interdisciplinary engineer in the implementation of OSC projects [36]. Governments and developers hold central places in the stakeholder network, as they are the most influential stakeholders in OSC projects [37]. These explorations promote a better understanding of OSC stakeholders, which facilitates their management.

Stakeholder mapping is one of the techniques used to analyze and understand stakeholders through various methods [7,10]. One of the most popularly used methods is the power–interest matrix (Figure 1), which classifies stakeholders into groups based on their power and interest in construction projects [10]. The rationality behind the power–interest matrix is that stakeholders hold varied power to influence the implementation of construction projects and they express different levels of interest in project decisions [34]. Gerry and Kevan [38] utilized a two-dimensional (2D) power–interest matrix to explore the roles of various stakeholders in corporate strategic development. Garavan [39] used a 2D power–interest matrix to assess stakeholders in the field of human resource development. By using the power–interest matrix, project stakeholders are grouped into four different categories:

1. Key players who have high power and interest in influencing the implementation of OSC projects;
2. Keep satisfied those who possess high power but demonstrate low interest in OSC projects. Managing stakeholders in this category can be particularly challenging;
3. Keep informed those who display a high level of interest but wield little power in the implementation of OSC projects;
4. Minimal effort is required to manage stakeholders who possess limited power and show low interest in OSC projects.

As shown in Figure 1, stakeholders with high power and interest are the key players and they should be fully engaged and well-managed in the implementation of construction projects. If multiple stakeholders are placed within this quadrant, they are considered as joint participants and should equally participate in the entire decision-making process. Additionally, the stakeholders with high power but low interest should be kept satisfied. Groups in this quadrant are considered potential key stakeholder groups because their high power may increase their interest in the future. Therefore, managing this group effectively is crucial. Those stakeholders with high interest but low power should be kept informed. This group typically shows considerable interest in the entire OSC project, even if they cannot participate in substantive decision-making processes. While considered passive in their involvement, their lack of power can be overcome, for instance, by improving relationships and fostering harmonious interactions with other stakeholders. Moreover, minimal effort would be taken to manage these stakeholders with both low power and interest. Measuring stakeholder salience is also an effective method to analyze project stakeholders, and stakeholder salience measures the degree to which managers give priority to competing stakeholder claims [12]. To measure stakeholder salience, various stakeholder attributes (e.g., the power of stakeholders) should be collected and analyzed [12]. Stakeholder salience has been adopted for stakeholder analysis and management in different kinds of projects, such as the port master planning project [11] and the sustainable energy development project [40].

Furthermore, applying fuzzy logic to generate a three-dimensional (3D) visualization surface can better capture the salience of stakeholders. Eskafi et al. [11] integrated a 3D decision surface to depict the dynamic attributes and potential salience of stakeholders in the overall port planning process. Poplawska et al. [41] applied 3D surfaces effectively to assess and select key stakeholders in the mining sector across various scenarios.

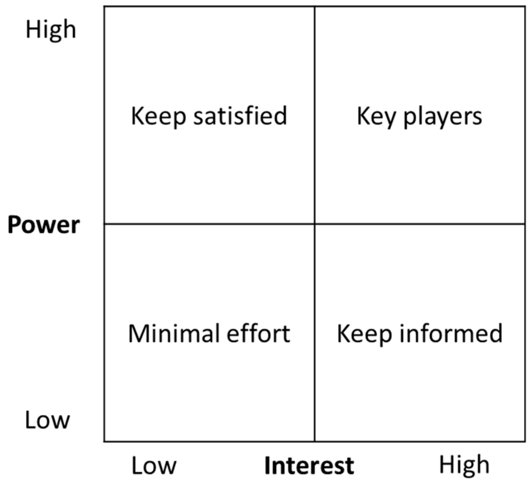


**Figure 1.** The power–interest matrix [38].

### *2.4. Research Gap*

Although OSC stakeholders and their analysis have gained much attention, there remains a research gap regarding the interrelationships among OSC stakeholders through the stakeholder mapping technique. Stakeholder mapping has been effectively employed in various construction projects, such as Newcombe's exploration of stakeholder relationships in railway engineering projects [10]; however, its application within the OSC domain is rather limited. While Teng et al. [6] utilized literature reviews, interviews, symbiosis models, and case studies for analyzing OSC stakeholders and London and Pablo [29] applied the actor–network theory, these methods do not fully leverage the detailed insights provided by stakeholder mapping. The unique characteristics of OSC projects, which differ significantly from traditional construction projects, underscore the necessity for a tailored approach to stakeholder analysis. Integrating stakeholder mapping techniques into OSC research is crucial for comprehensively understanding stakeholder dynamics and improving project management. Addressing this gap will provide valuable insights into managing OSC projects more effectively from a stakeholder perspective, ultimately contributing to enhanced project outcomes and performance.

## 3. Research Methodology

### *3.1. Research Process*

Given that the implementation process of OSC projects can be divided into several stages (e.g., design, prefabrication, construction) and different stakeholders are engaged in these stages, it is necessary to categorize and understand stakeholders accordingly. This study adopts a pragmatic philosophical stance. Pragmatism is chosen because it allows for the use of mixed methods to address complex research problems in real-world contexts, such as OSC projects. This perspective supports the integration of both quantitative and qualitative approaches, recognizing that understanding stakeholder dynamics benefits from both numerical data and contextual insights. This research employs a mixed-methods approach, combining quantitative and qualitative techniques to provide a comprehensive analysis of stakeholders. The mixed-methods approach is justified as it offers a richer understanding of stakeholder dynamics by leveraging the strengths of both approaches. The quantitative phase utilizes statistical methods for mapping and categorizing stakeholders, while the qualitative phase provides contextual insights into stakeholder roles and relationships. The research strategy consists of the following three phases (Figure 2):

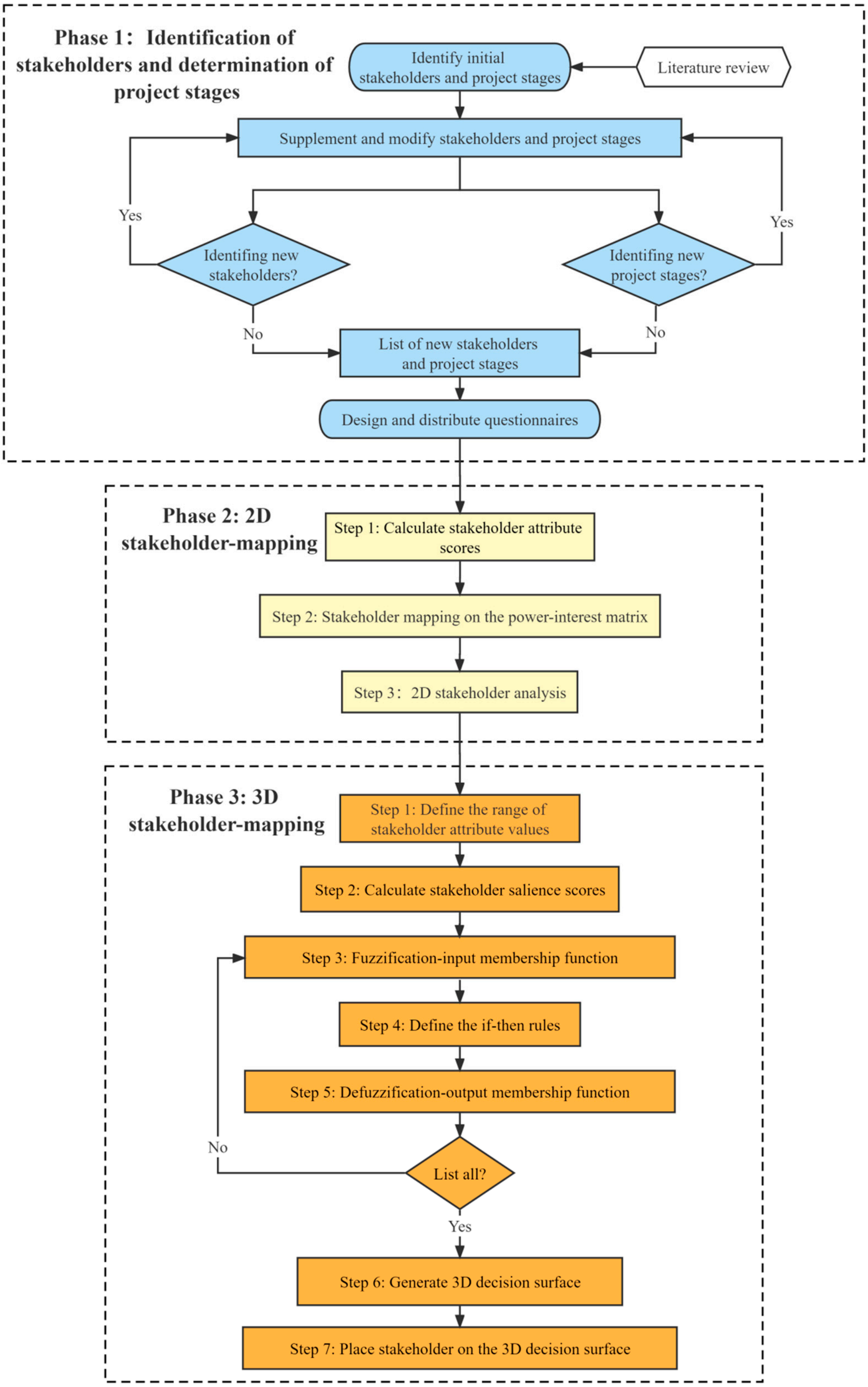


**Figure 2.** The developed research framework in this study.

Phase 1: Identification of stakeholders and determination of project stages

A review of the relevant literature was conducted to identify all potential OSC stakeholders. For instance, Teng et al. [6] revealed various stakeholders in the development of OSC building projects, such as developer, designer, user, module supplier, and supervisor. In the study of Yu, et al. [9], the identified OSC stakeholders included developer, designer, manufacturer, contractor, and supervisor. Based on a comprehensive review of the literature in the OSC stakeholder area, Hu, et al. [8] also identified various stakeholders in OSC projects, such as government, architect, supplier, user, contractor, and subcontractor. The findings retrieved from these studies collectively offer valuable implications for the identification of OSC stakeholders. Through interviews with relevant professional stakeholders, the researchers ensured the representation of various sizes and types of stakeholders involved in OSC projects in different regions in the Chinese context. Finally, 12 OSC stakeholders were identified and included in this study; namely, client, main contractor, modular manufacturer, designer, supplier (e.g., materials, equipment), subcontractor, supervision company, government, end users, facility management company, the public, and industry organizations (e.g., unions, associations). In addition, from the project life-cycle perspective [41,42], the delivery process of OSC projects can be divided into five stages, including conceptual design and feasibility study, detailed design, prefabrication and construction, completion, and operation and maintenance.

Phase 2: 2D stakeholder mapping based on the power–interest matrix

The 2D stakeholder mapping method of the power–interest matrix is used in this study. It is a widely used method to classify and analyze stakeholders based on power and interest [34]. Four stakeholder groups are defined based on the power–interest matrix (Figure 1), including key players (high power and interest), stakeholders to keep satisfied (high power but low interest), stakeholders to keep informed (high interest but low power), and stakeholders with minimal effort (limited power and low interest) [34].

The 2D mapping provides a concise and intuitive visual representation, clearly displaying the positions and differences of stakeholders in terms of power and interest, without the complexity introduced by 3D mapping. Decision-makers can individually assess the grouping attributes of OSC and determine the extent of further engagement with each stakeholder in the project [43]. Despite its usefulness in stakeholder analysis, the 2D stakeholder mapping technique of the power–interest matrix has limitations. It fails to provide insights into the prioritization of stakeholders in the same quadrant [11]. In the decision-making process, a lot of time and energy were saved by considering these specific stakeholders equally. However, in practice, the importance of different stakeholders is not the same, and equal consideration of stakeholders can result in neglecting various aspects. For example, the government has high power in OSC projects and can play a decisive role in their implementation, whereas the client may be more interested in OSC projects based on their needs. However, in the 2D matrix, both are classified as key players and treated equally in the decision-making process. This does not align with the actual situation. It also overlooks the individual uniqueness of stakeholders, as they are simply classified into predefined groups without considering their specific attributes [41]. It can be observed that the 2D stakeholder analysis is regarded as a static and unchanging outcome characterized by specific time and space. Hence, if the individual uniqueness of each stakeholder is disregarded and insufficient attention is given to the stakeholders and their respective attributes, decisions made by the decision-makers may be prone to errors. To address these limitations, a 3D stakeholder mapping framework based on fuzzy logic was developed. 3D stakeholder mapping is not independent of 2D stakeholder mapping; rather, it is an extension study based on the 2D foundation. The calculated salience values are closely related to the power–interest aspects of the 2D mapping. It has the capability to highlight the individuality of each stakeholder, provides a more nuanced understanding of stakeholder dynamics, and enhances the accuracy of the analysis. In this phase, a questionnaire was developed and administered to gather data on stakeholder power and interest.

Phase 3: 3D stakeholder mapping based on the power–interest–salience decision surface

Based on the characteristics of power and interest, the salience has been introduced. It can be described as the extent to which managers prioritize the demands of competing stakeholders [15]. Therefore, this study adopts a 3D stakeholder mapping method on the power–interest–salience decision surface, placing the central point of salience on the 3D decision surface (where salience refers to the attributes of OSC stakeholders in terms of power and interest) and mapping the range of changes according to the dynamic changes in power and interest. When the interest value of stakeholders is relatively large, salience will be biased in the direction of the larger interest axis, and when the stakeholder's power is larger, the salience will be biased in the direction of the larger power axis. When both are large, salience will be at the highest point of the entire surface. By observing the range of salience variation among different stakeholders on the surface, decision-makers can better identify the changes in stakeholder attributes at different stages of an OSC project. At present, existing research has successfully used this model for visual analysis. For example, Eskafi et al. [11] successfully analyzed the importance and prioritization of stakeholders in port master planning by introducing salience based on the two attributes of power and interest; Poplawska et al. [41] introduced the salience attribute based on the analysis of power, urgency, and legitimacy to analyze the prioritization of stakeholders in extractive companies.

### *3.2. Data Collection*

Based on identifying stakeholders and determining project stages, a questionnaire was designed and used to collect data for stakeholder mapping in the Chinese construction industry. The Chinese construction industry was selected given that it is one of the most important leading countries in the delivery of OSC projects, which is mainly driven by government policies and incentives [44]. The questionnaire consisted of three sections. The first section focused on gathering demographic information about participants, including three questions (e.g., stakeholder types, OSC-related working experience). This information helps us to understand the respondents' backgrounds and their overall views and concerns regarding OSC projects, allowing for the consideration of different types of stakeholders' perspectives in the analysis. In the second section of the questionnaire, a total of five questions were set up, mainly to collect the power scores of the different stakeholders in the five stages of implementing OSC projects. The third part of the questionnaire contained five questions, primarily to collect the attention (level of interest) scores of different stakeholders on various decisions in the five stages of OSC projects. To achieve this, the five-point Likert Scale was adopted (0 = no power or interest, 1 = very limited power or interest, 2 = limited power or interest, 3 = moderate power or interest, 4 = high power or interest, 5 = very high power or interest).

Data collection for this study was facilitated using the convenience sampling method, which is a non-probability sampling technique allowing researchers to select individuals who are readily available and accessible to participate [45]. Eligible participants for the questionnaire survey needed to meet two criteria, including involvement and experience in OSC projects and working in different types of companies or organizations related to OSC business. The questionnaires were distributed through "Wenjuanxing (www.wjx.cn)", which is a popularly adopted online platform for data collection in China.

### *3.3. Data Analysis*

#### 3.3.1. 2D Data Analysis

Data analysis using the power–interest matrix is the process of determining the power and interest of different stakeholders at different stages of OSC projects. In this study, the average values of different stakeholders' power and interest at different stages were calculated. These calculated average values were then input into IBM SPSS Statistics 25 to generate scatter plots for the different stages. These scatter plots served as the power–interest matrices in this study. Ultimately, five power–interest matrices were developed for the five stages of OSC projects. The specific operational steps are as follows:

Step 1: Data screening

Import the data collected in "Wenjuanxing (www.wjx.cn)" into the Excel table and eliminate some random or useless data.

Step 2: Data analysis

Calculate the average power and interest scores of stakeholders at different stages based on the questionnaire scores, and import the average scores into SPSS 25.0.

Step 3: Draw 2D mapping

With the help of the scatter diagram drawing function in SPSS 25.0, a scatter diagram of stakeholders regarding power and interest is initially generated, and then the parameters (e.g., data label modes, elements) are adjusted according to the requirements of the 2D matrix to generate a 2D stakeholder mapping.

#### 3.3.2. 3D Data Analysis

Based on the analysis of power and interest scores in the 2D part, the salience value of the 3D part was calculated. The salience function for each stakeholder group was defined during defuzzification [40]. The membership functions of power, interest, and salience were subjectively defined based on the data obtained from the questionnaire survey [40]. The Fuzzy Inference System (FIS) was adopted to implement fuzzy logic [46]. The Mamdani-type inference system, which allows appropriate modelling of human input and assumes fuzzy output membership functions, was utilized in this study [47]. A connection between input variables and output variables could be established, and a decision surface could be generated by using the FIS editor in MATLAB R2022b. Therefore, for dynamic stakeholder mapping, this study applies FIS to develop a 3D decision surface in MATLAB by using power and interest as the input and salience as the output. The following steps are required:

Step 1: The minimum and maximum power and interest values for each stakeholder are identified using Excel 2016. The attribute profile range for each stakeholder is defined based on the minimum, average, and maximum values of power and interest calculated in Phase 2. The illustration below depicts the ranges:

$$\text{Power } (P_{\min}, P_{\text{avg}}, P_{\max}) \quad (1)$$

$$\text{Interest } (I_{\min}, I_{\text{avg}}, I_{\max}) \quad (2)$$

where $P_{\min}$ is the minimum power value, $P_{\text{avg}}$ is the average power value, $P_{\max}$ is the maximum power value, $I_{\min}$ is the minimum interest value, $I_{\text{avg}}$ is the average interest value, and $I_{\max}$ is the maximum interest value.

Step 2: The salience of each stakeholder is calculated by using the average values of the two attributes in Step 1. The salience of stakeholder group x is:

$$\text{Salience}\left(\frac{P_{\min}+I_{\min}}{2}, \frac{P_{\text{avg}}+I_{\text{avg}}}{2}, \frac{P_{\max}+I_{\max}}{2}\right) = (S_{min}, S_{avg}, S_{\max}) \quad (3)$$

where $S_{\min}$ is the minimum salience value, $S_{\text{avg}}$ is the average salience value, and $S_{\max}$ is the maximum salience value

Step 3: The membership function, as the input and output function required by the FIS, is mainly used to illustrate the uncertain value of attributes. Since a crisp threshold cannot be defined for the power and interest attributes, a trapezoidal membership function is used in the fuzzification process to define uncertain values of stakeholder attributes (Figure 3).

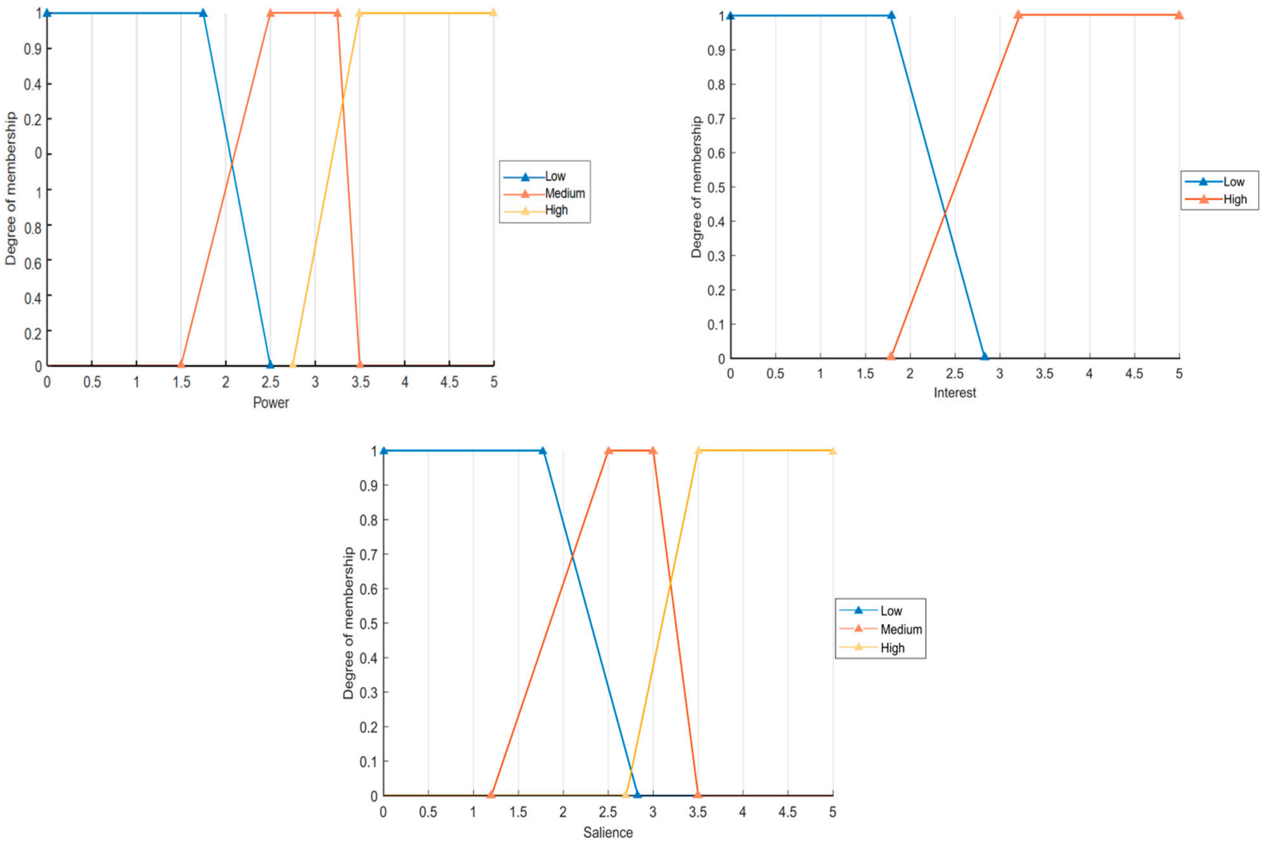


**Figure 3.** Fuzzy membership functions.

Step 4: According to the attribute profile, the if–then rules are defined (Table 1).

**Table 1.** The if–then rules.

| Sequence Number | Antecedent Part | The Latter Part |
|---|---|---|
| 1 | If power is low and interest is low | Then salience is low |
| 2 | If power is low and interest is high | Then salience is medium |
| 3 | If power is medium and interest is low | Then salience is medium |
| 4 | If power is medium and interest is high | Then salience is high |
| 5 | If power is high and interest is low | Then salience is medium |
| 6 | If power is high and interest is high | Then salience is high |

Step 5: The salience membership function is defined in the defuzzification process. Since the fuzzy profile scores of stakeholders are not easy to be judged, the weighted average method is used to defuzzify to obtain clear values in the defuzzification process.

$$Y = \frac{(min_i + 2 * average_i + max_i)}{4} \quad (4)$$

where $min_i$ is the minimum values calculated in Step 1 of Phase 2, $average_i$ is the average values calculated in Step 1 of Phase 2, and $max_i$ is the maximum values calculated in Step 1 of Phase 2.

Step 6: The Fuzzy Logic Toolbox in MATLAB is used to multiply the power and interest membership functions defined in Step 3 to generate a 3D decision surface.

Step 7: The average power, interest, and salience values of stakeholders are used to position stakeholders on the 3D decision surface.

# 4. Research Results

## *4.1. Descriptive Analysis*

A total of 228 questionnaires were collected for this study. After excluding 61 questionnaires due to incompleteness or a large proportion of identical answers, 167 valid responses were retained, resulting in an effective recovery rate of 73.2%. Similar studies utilizing the power–interest matrix, such as those of Eskafi et al. [11] and Aly et al. [48], achieved effective results with smaller sample sizes of 17 and 30 participants, respectively. Therefore, the 167 valid responses were deemed sufficient to achieve the objectives of this study. Table 2 shows the demographic information of participants. The majority of those who participated in the questionnaire were clients (24.6%) and main contractors (17.4%), with the largest proportion (35.3%) having less than 3 years of related work experience. The main responsibilities were construction management (19.8%) and design management (16.2%). The collected data were analyzed for reliability using SPSS 25 by researchers, revealing a Cronbach's Alpha coefficient of 0.885 for the questionnaire, indicating excellent internal consistency.

**Table 2.** The demographic information of participants.

| Classification | Category | Number | Percent (%) |
|---|---|---|---|
| Stakeholder types | Client | 41 | 24.6 |
| | Main contractor | 29 | 17.4 |
| | Designer | 22 | 13.2 |
| | Modular manufacturer | 21 | 12.6 |
| | Supervision company | 17 | 10.2 |
| | The public | 10 | 6.0 |
| | Supplier | 10 | 6.0 |
| | Subcontractor | 5 | 3.0 |
| | End users | 5 | 3.0 |
| | Government | 3 | 1.8 |
| | Facility management company | 2 | 1.2 |
| | Industry organization | 2 | 1.2 |
| OSC-related working years | Less than 3 years | 59 | 35.3 |
| | 3–5 years | 42 | 25.1 |
| | 6–10 years | 42 | 25.1 |
| | Over 10 years | 24 | 14.4 |
| Main responsibilities | Construction management | 33 | 19.8 |
| | Design management | 27 | 16.2 |
| | Overall project management | 24 | 14.4 |
| | Cost management | 24 | 14.4 |
| | Modular manufacturing and supply management | 18 | 10.8 |
| | Supervision | 18 | 10.8 |
| | Contract management | 11 | 6.6 |
| | Investment development | 7 | 4.2 |
| | Project installation management | 1 | 0.6 |
| | Others | 4 | 2.4 |

## *4.2. 2D Stakeholder Mapping*

Five power–interest matrices at different stages of OSC project delivery were developed (Figures 4–8). It can be seen that the majority of OSC stakeholders can be classified into the two categories of Key players and Minimal effort at the different stages of project implementation. More specifically, the key players include the client, government, designer, main contractor, modular manufacturer, supplier, end users, subcontractor, and supervision company at the "conceptual design and feasibility study" stage (Figure 4). Comparing the power and interest attribute scores of stakeholder groups at this stage with the overall average scores across the five stages, the most significant difference observed is the change in the government's scores. The government's power score at this stage is 4.07, and its interest score is 3.63. In contrast, the overall average scores across all five stages are 3.47 for power and 3.30 for interest. Therefore, compared to other stages, the government shows greater interest in the social effects of OSC and has a more significant influence on its implementation during the "conceptual design and feasibility study" stage.

At the "detailed design" stage (Figure 5), the key players include client, government, designer, main contractor, modular manufacturer, supplier, and subcontractor. Comparing the power and interest attribute scores of the stakeholder groups at this stage with the overall average scores across the five stages, it can be found that the biggest difference is the change in the designer's position. The designer's power score is 4.04 and the interest score is 3.89. Across all five stages, the total average score for power is 3.41, and the total average score for interest is 3.47. The increase in power and interest scores indicate the designer's rise from a mid-level key player to a high-influence key player. This change in attribute score is expected to some extent, as during the detailed design stage, designers assume the critical responsibility of ensuring the accuracy and feasibility of the design, which is essential for the successful implementation of the entire project.

Building on the previous stage, the supervision company was added as a key player at the "prefabrication and construction" stage (Figure 6). Comparing the stakeholder group attribute scores at this stage with the overall average scores, the main differences lie in the main contractor, modular manufacturer, supplier, and subcontractor. Based on the analysis of these attribute score changes, the supervision company has shifted from minimal effort to key player. This shift is driven by their need to provide real-time oversight of the construction process, which significantly increases their influence at this stage. The rising influence of the modular manufacturer and supplier can be attributed to the fact that the materials they produce or provide during the prefabrication stage will directly impact the overall success of the project. For the main contractor, this involves their focus on ensuring the quality, progress, and final outcomes of the construction.

The key players identified in the "completion" stage are consistent with those determined in the first stage (Figure 7). When comparing the stakeholder group scores in the fourth stage with the overall average scores, the greatest variation is observed in the supervision company. With a power score of 3.16 and an interest score of 3.36, both significantly exceeding the overall average, the supervision company's elevated influence is evident. This is attributed to their crucial responsibility of organizing the preliminary acceptance of the unit project during the completion phase.

At the last stage of "operation and maintenance" (Figure 8), the key players include the client, end users, main contractor, facility management company, government, designer, and modular manufacturer. Using the same comparative analysis method as in the previous stage, the primary distinction identified is the role of the facility management company. The facility management company is responsible for ensuring the normal operation, maintenance, and management of the entire OSC project during the operation and maintenance phase. Their duties encompass regular inspections, repairs, and upgrades, all aimed at ensuring the facility's long-term service life and safety.

In terms of the Minimal effort group, its members include the industry organizations, facility management company, and the public at the "conceptual design and feasibility study" stage (Figure 4). The Minimal effort group members are the same at the "detailed design" stage (Figure 5) and the "prefabrication and construction" stage (Figure 6). At the "completion" stage (Figure 7), these include the industry organizations, facility management company, and the public. At the stage of "operation and maintenance" (Figure 8), the Minimal effort stakeholders include the subcontractor, industry organizations, the public, and supervision company.

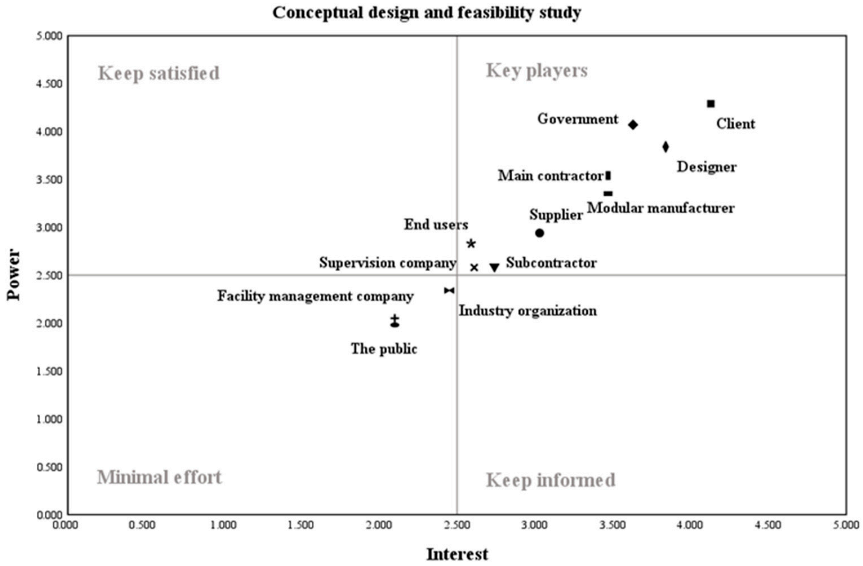


**Figure 4.** The power–interest matrix at the conceptual design and feasibility study stage.

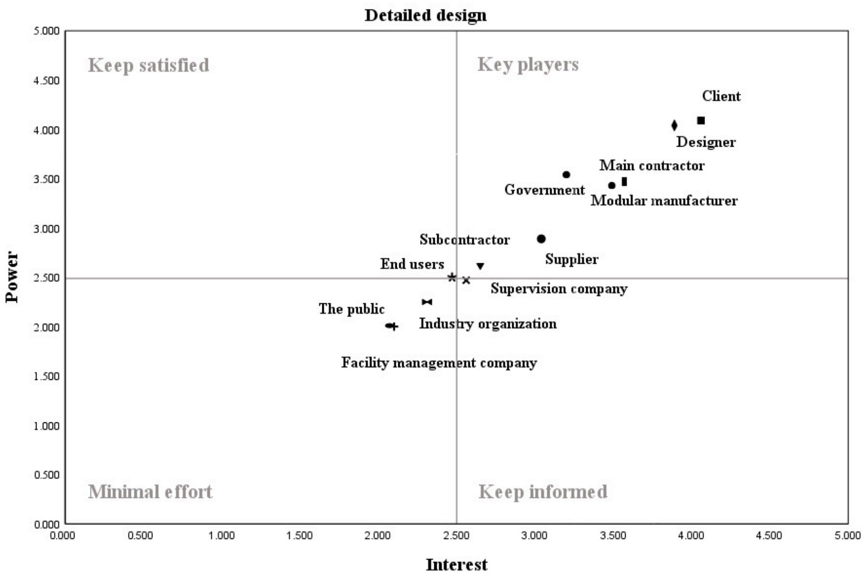


**Figure 5.** The power–interest matrix at the detailed design stage.

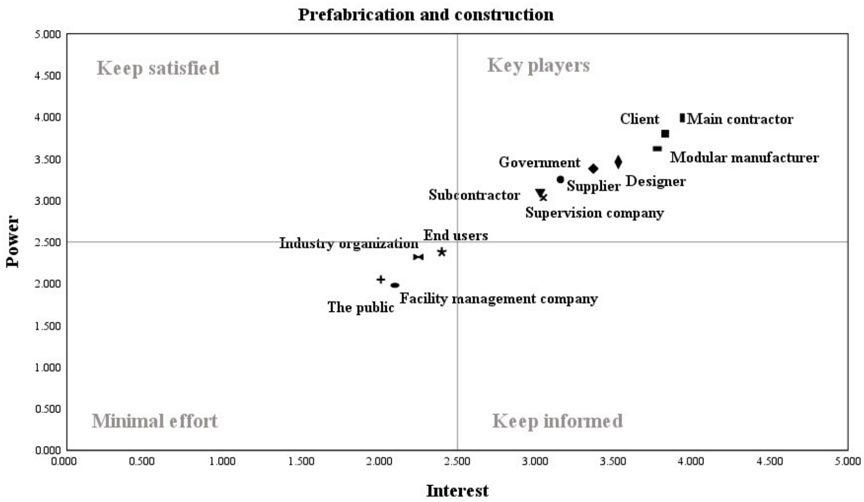


**Figure 6.** The power–interest matrix at the prefabrication and construction stage.

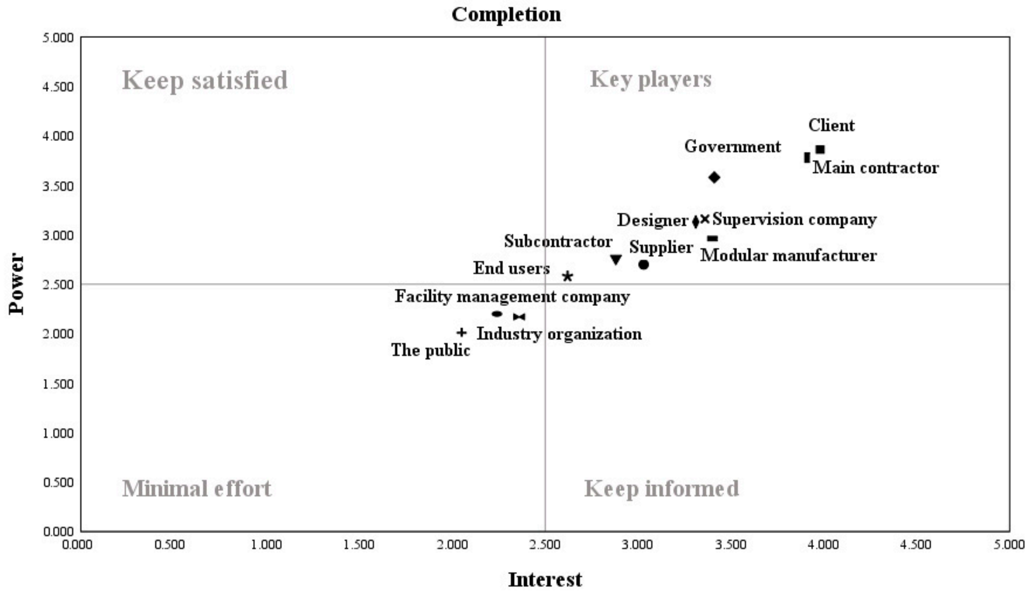


**Figure 7.** The power–interest matrix at the completion stage.

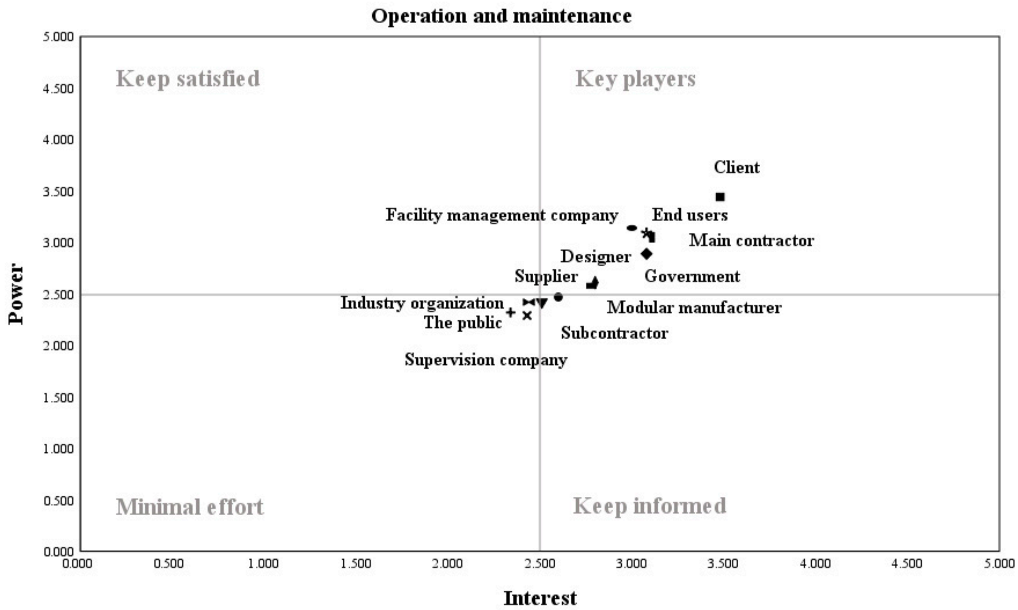


**Figure 8.** The power–interest matrix at the operation and maintenance stage.

### *4.3. 3D Stakeholder Mapping*

Only the key players in the delivery of OSC projects were involved in the 3D stakeholder mapping analysis in this study. Five 3D decision surfaces were developed for the different stages of OSC project delivery (Figures 9–13). Overall, although these stakeholders were identified as key players at the different stages, the levels of their salience were different. A further analysis of Figures 9–13 identified the key players placed in both the flat area and the acute slope at the different stages (Table 3).

**Table 3.** The key players placed in both the flat area and the acute slope at the different stages.

| Stages | Key Players Placed in the Flat Area of the Decision Surface | Key Players Placed in the Acute Slope of the Decision Surface |
|---|---|---|
| Conceptual design and feasibility study | Client, Designer | Government, Main contractor, Modular manufacturer, and Supplier |
| Detailed design | Client, Designer | Modular manufacturer, Subcontractor, Government, Main contractor, and Supplier |
| Prefabrication and construction | Client, Modular manufacturer, and Main contractor | Designer, Supplier, Government, Subcontractor, and Supervision company |
| Completion | Client, Main contractor | Government, Designer, Modular manufacturer, Supervision company, Supplier, End users, and Subcontractor |
| Operation and maintenance | Client | End users, Main contractor, Facility management company, Designer, Government, and Modular manufacturer |

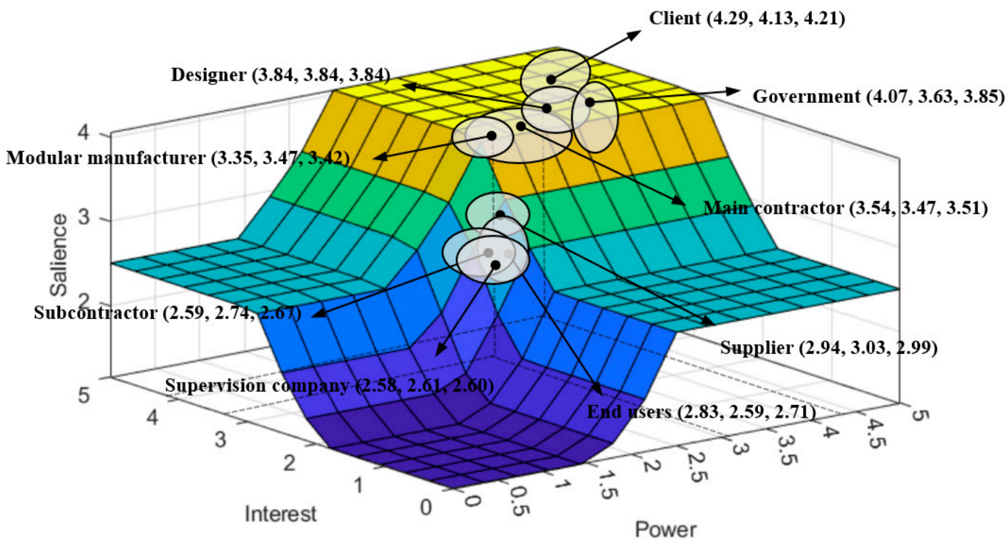


**Figure 9.** The 3D decision surface at the conceptual design and feasibility study stage.

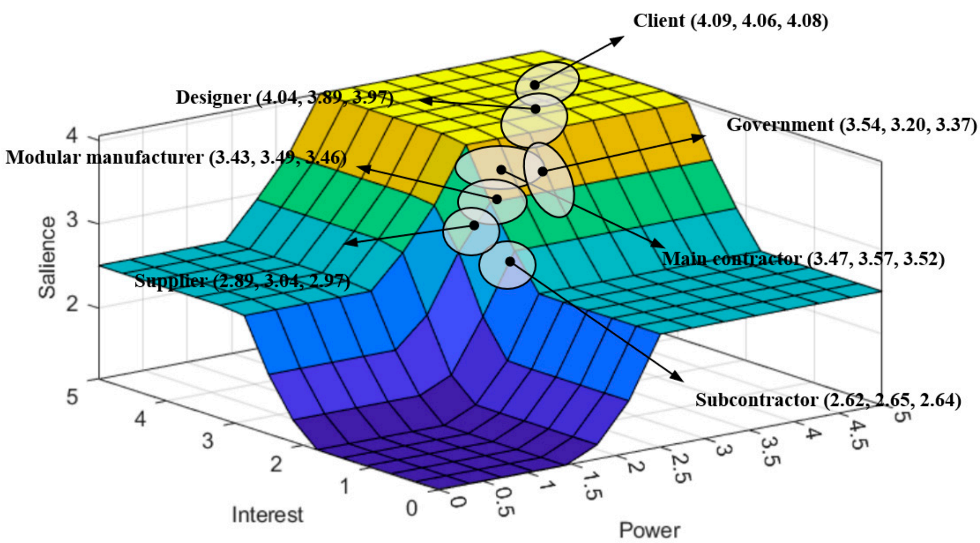


**Figure 10.** The 3D decision surface at the detailed design stage.

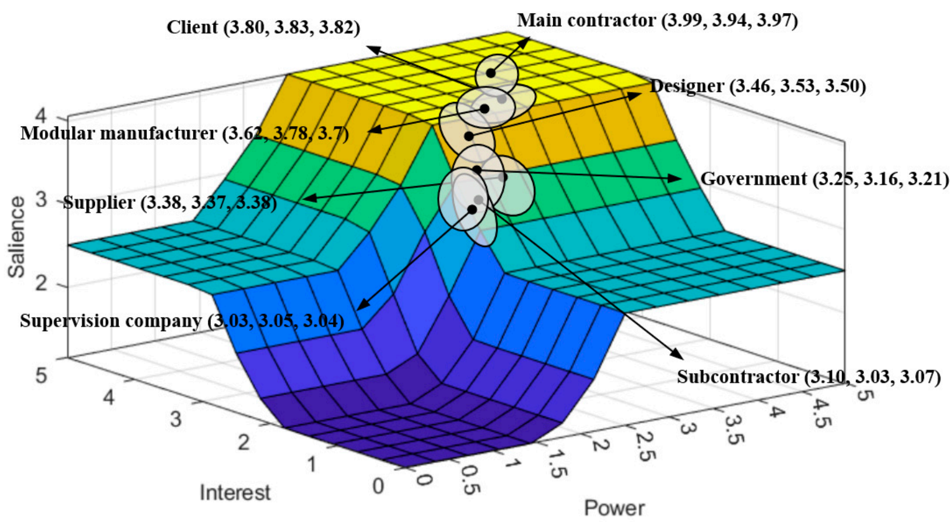


**Figure 11.** The 3D decision surface at the prefabrication and construction stage.

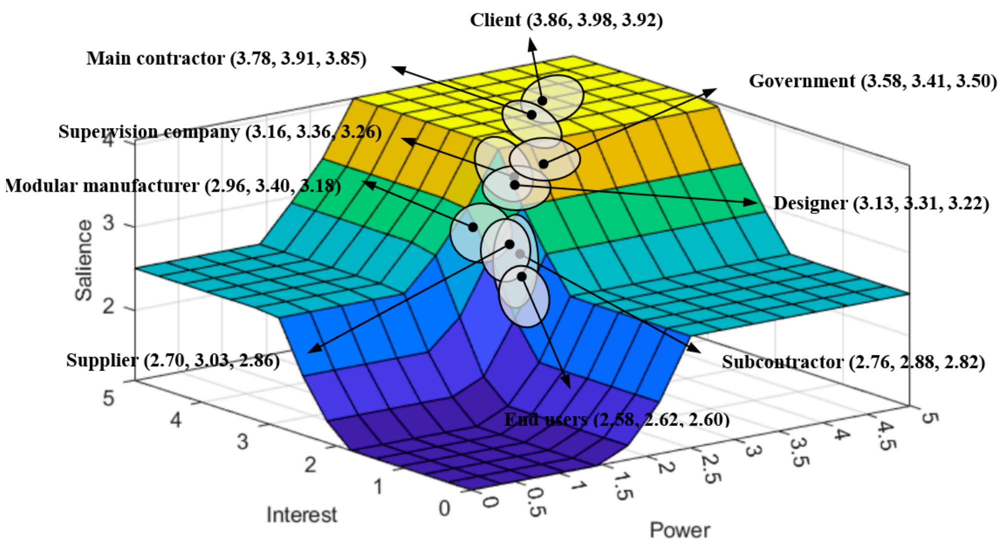


**Figure 12.** The 3D decision surface at the completion stage.

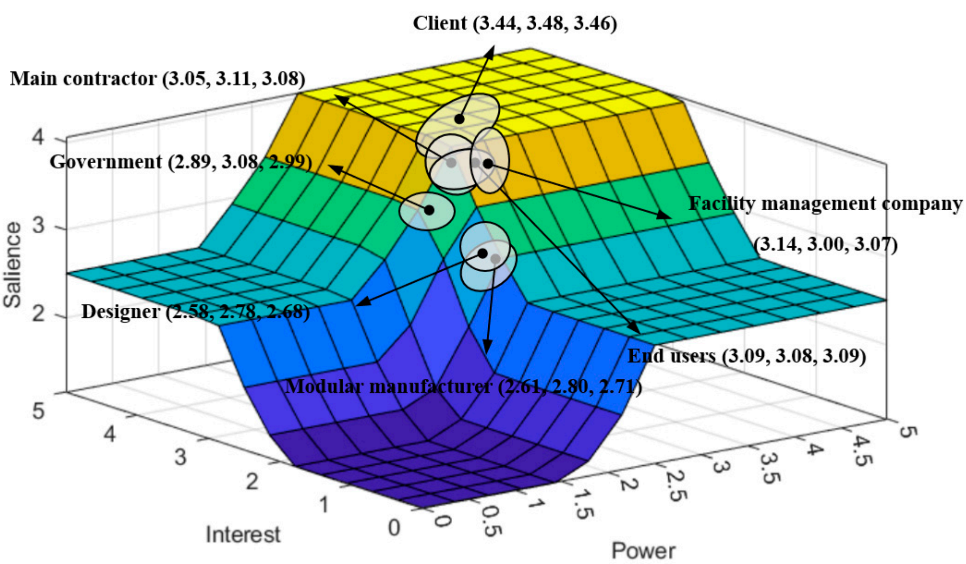


**Figure 13.** The 3D decision surface at the operation and maintenance stage.

#### 4.3.1. Conceptual Design and Feasibility Study Stage

In this stage, the client and designer are placed in the flat area of the decision surface, which indicates their stable dominating roles at this stage (Figure 9). On the contrary, other key players are placed in the acute slope of the decision surface (Figure 9), which means that these stakeholders can quickly change their salience.

#### 4.3.2. Detailed Design Stage

In Figure 10, it is evident that the client continues to occupy a relatively flat area, indicating a stable level of influence throughout the project stages. Conversely, the positional importance of designers has notably increased, suggesting their growing influence as the project progresses. Meanwhile, the main contractor, government, modular manufacturer, supplier, and subcontractor are situated on the steeper side of the mapping. Although they are categorized as key players, they are likely to experience significant changes.

#### 4.3.3. Prefabrication and Construction Stage

By analyzing the 3D decision surface, it is evident that during the prefabrication and construction stage, the positions of the main contractor and modular manufacturer undergo significant changes, with both shifting from the steep area in the previous stage to the flat area (Figure 11). Meanwhile, the influence of designers gradually diminishes, shifting progressively towards the steep area.

#### 4.3.4. Completion Stage

At this stage, the main contractor and client remain in the flat areas of the 3D decision surface, while the remaining stakeholders (supervision company, government, designer, modular manufacturer, supplier, end users, subcontractor) are positioned in the steep areas of the surface (Figure 12).

#### 4.3.5. Operation and Maintenance

During the operation and maintenance stage, apart from the client, all other key players identified in the 2D phase (main contractor, government, facility management company, end users, designer, modular manufacturer) are positioned on the steep surface (Figure 13). It is noteworthy that the client transitions from a stable state to a relatively variable state for the first time, while the score of the end users shows a significant increase compared to other stages.

## 5. Discussions

### *5.1. Key Players of OSC Projects*

The research findings reveal that different stakeholders are identified as key players at the different stages of OSC project implementation. This preliminary result is consistent with the general proposition that different stakeholders have different influences on construction projects, and they express varied interests in the decisions at the different stages of construction projects [10,46]. Despite this, our study found that the client, modular manufacturer, main contractor, government, and designer are identified as key players at all stages of OSC project implementation, with the supervision, supplier and subcontractor also being key players during certain stages. This result extends the current proposition that key project participants should be engaged in all stages of OSC projects [30], particularly for the close interactions of these key stakeholders in fostering a collaborative and supportive environment during project implementation.

For an in-depth understanding of stakeholder management in OSC projects, the client has the power to strongly influence the implementation of OSC projects and shows high interest in decisions at the different stages of OSC projects. For instance, the cost performance of OSC projects has long been criticized for being generally higher than that of traditional construction projects [49,50]. The client's interest in cost-related decisions at different project stages will help them to be kept informed about cost management-related activities and propose appropriate cost management action, which is an effective way of managing cost during the implementation of OSC projects. Given the importance of the client in the implementation of OSC projects, it has been expected that the client should be actively involved in the life cycle of OSC project implementation [6]. In the 3D decision surface, the client consistently remains in a relatively stable area, reflecting their steady influence and involvement across all stages of the project.

In addition, the modular manufacturer is another key player identified at all stages of implementing OSC projects, and their engagement into the different stages of an OSC project is of great importance. As suggested by Hu, et al. [8], the modular manufacturer should work as a decision supporter, producer, and coordinator in the implementation of OSC projects. At the early stages of an OSC project, the modular manufacturer will influence the implementation of OSC projects based on their advice to other stakeholders (e.g., the client, designer, contractor) about project designability and buildability. It has been suggested that the modular manufacturer should be integrated into the early stages of an OSC project, as this early engagement can bring various benefits to the project, such as improved prefabrication feasibility and enhanced collaboration of different stakeholders [51,52]. During the prefabrication, construction, and completion stages of an OSC project, the modular manufacturer will influence the implementation of OSC projects based on the quality of the supplied modular components and their on-site installation. In the process, it is important that the modular manufacturer collaborates with other stakeholders and coordinate on-site construction and off-site production activities [8,53]. At the operation and maintenance stage, the modular manufacturer influences OSC projects by supporting the operation and maintenance of modular components, in collaborating with other stakeholders, especially the client and facility management company. It should be noted that the modular manufacturer is a key player placed in the acute slope of the decision surfaces of all stages, which means that the modular manufacturer can quickly change their salience. Consequently, the modular manufacturer should be closely engaged and monitored, as even small changes in their attributes can significantly influence the delivery of an OSC project.

The main contractor is also a key player at all stages of implementing OSC projects and they profoundly influence the implementation of OSC projects in various ways. Similar to the modular manufacturer, the main contractor should also be integrated into the early stages of OSC projects to collaborate with other stakeholders (e.g., the client, designer, modular manufacturer), which positively influences project performance such as in improved project constructability [52,54]. The research findings also reveal that the main contractor shows high interest in decisions at different project stages. For instance, the main contractor focuses on the decisions from the client and the designer at the early stages of implementing OSC projects. Based on this, they can better understand the requirements of the client, which is the foundation of project success [30]. During the prefabrication, construction, and completion stages of OSC projects, the main contractor monitors the decisions from other stakeholders (e.g., the modular manufacturer, subcontractor, client) and takes corresponding action to ensure the project is on the right track [53]. At the operation and maintenance stage, the main contractor assists in the operation and maintenance activities based on understanding the decisions and action of the facility management company. It should be noted that the dominant roles of the main contractor are relatively stable at the three stages of "detailed design", "prefabrication and construction", and "completion". At other stages, the main contractor should be closely monitored, as their salience can change quickly due to change in attributes.

The government and designer have also been identified as key stakeholders throughout the OSC project stage. The government mainly uses policies to influence the OSC project implementation process [55,56]. It is also important to monitor the government, as its salience can change quickly at different stages of OSC project delivery. In the Chinese construction industry, although the government has imposed various incentive polices to promote the adoption of OSC, the effectiveness of some policies did not achieve their expected results [57]. The government also shows high interest in the decisions of different stakeholders in the implementation of OSC projects, ensuring that these decisions comply with the legal requirements to protect the interest of the public [58]. The government's power remains high throughout all stages of the OSC project, allowing it to effectively regulate and guide the project. Its strong influence helps ensure that stakeholder decisions comply with legal standards and protect public interests. However, the effectiveness of some government policies has varied, highlighting the need for ongoing evaluation and adjustment. In terms of the designer, they influence the implementation of OSC projects through providing design proposals and documents based on understanding the client's requirements and collaborating with other stakeholders (especially the contractor and modular manufacturer) in the delivery of OSC projects [36]. The designer also has high interest in the decisions of stakeholders in the delivery of OSC projects, such as understanding the client's decisions to better grasp their requirements and demands and comprehending the contractor's decisions to better manage the project delivery process. The 3D stakeholder mapping results indicated that the dominate roles of the designer are stable at the two stages of "conceptual design and feasibility study" and "detailed design". This stability shows that their consistent role is essential for guiding the project's direction and maintaining design quality throughout these critical stages.

Apart from that, there are some other key players identified during some stages of the implementation of OSC projects, such as the supervision, supplier, and subcontractor. These stakeholders play crucial roles in ensuring the success of OSC projects at different stages. The supervision company, for instance, is vital during the prefabrication and construction stage, where their expertise and oversight ensure that on-site installation aligns with the required quality and regulatory standards [30]. Suppliers are critical throughout the supply chain, particularly during the "detailed design" and "prefabrication and construction" stages, where effective coordination with architects and construction teams is necessary to maintain project timelines, meet specifications, and mitigate risks. Subcontractors, especially those involved in on-site assembly, are essential in the final integration of prefabricated components, ensuring that the modules are installed correctly and that the project progresses smoothly [36]. The involvement and effective management of these key players at the right stages are critical for the overall success of OSC projects, contributing to a seamless transition from off-site manufacturing to on-site assembly. In the 3D decision surface, these stakeholders are often on steeper parts of the curve, showing noticeable changes. This aligns with the conclusion that they are not key participants in certain stages. As the project moves through different stages, their influence may decrease, supporting the idea that they are less critical at those times. This dynamic is clearly reflected in the 3D analysis.

### *5.2. Stakeholders with Minimal Effort or Involvement*

The research findings reveal that some stakeholders are identified as participants with minimal effort or involvement due to their limited power and interest in decisions during the project implementation process. In particular, the public and industry organizations are such stakeholders at all stages of implementing OSC projects.

The public has been identified as a crucial stakeholder in the implementation of construction projects, and they influence the project delivery process in various ways [59]. Nevertheless, the findings of this study revealed that the public has been largely ignored in the delivery of OSC projects. This result is consistent with the findings of some recently published OSC stakeholder related studies, where the public is not well-considered [60]. The same issue was reported in the construction industry of the United Kingdom years ago, as the public was excluded from the strategies of OSC housebuilders [61]. In fact, the public can impact the implementation of OSC projects significantly. For instance, public awareness (e.g., the knowledge and understanding of the public on OSC) is a crucial factor influencing the adoption of OSC in construction projects in China, and the positive attitudes and sufficient understanding of the public promote OSC transformation [62,63]. The public shows interest in project decisions when these decisions influence their community and/or individual interests. This can be reflected in the reported community protest campaigns against some projects due to the negative impacts of these projects on communities [64]. It should also be noted that as the current attention of the public on OSC is rising in the Chinese construction market, there is a possibility of increased dissatisfactions or complaints from the public, especially given that the OSC implementation process may negatively influence communities (e.g., the environmental pollution issue resulting from the transportation of modular components) [62,65].

The industry organizations (e.g., unions, associations) are another identified stakeholder with minimal effort or involvement at all stages of implementing OSC projects in China. The industry organizations in China have less power to influence the construction industry and projects compared with those in some other countries such as the United States. For instance, Said [53] revealed that labor unions in the United States are a crucial consideration of contractors in the implementation of OSC projects as labor unions may constrain contractors' use of OSC due to the reduced number of construction workers at construction sites. The industry organizations in China also have less interest in OSC stakeholders' decisions at different stages, as their decisions will have very limited or no impact on the business activities of industry organizations.

### *5.3. Other Stakeholders*

The research findings revealed that a few stakeholders are classified into other groups during the implementation of OSC projects. The end users are grouped into the "keep satisfied" group at the designer stage. The end users are the consumers of OSC projects and have the power to influence the early stages of OSC project implementation mainly through impacting the demand for the final industrialized products [6]. It is important to note that the final products should keep them satisfied as this will determine the success of OSC projects from a commercial perspective. At the detailed design stage, the supervision company shows a relatively high level of interest in stakeholders' decisions due to its responsibility to ensure that the project meets the required standards and regulations. However, despite this interest, the supervision company holds a neutral position in terms of power to influence project implementation, indicating that it does not have sufficient authority to lead or enforce major changes. This positioning reflects the role of the supervision company as an observer and overseer, whose primary task is to ensure that decisions made during the design stage align with established quality and safety requirements, rather than directly influencing the project's design direction. The study findings also reveal that at the operation and maintenance stage, the subcontractor and modular manufacturer should be kept informed. For instance, regular communication with the subcontractor helps quickly address maintenance issues, while keeping the modular manufacturer updated ensures they can provide necessary support to maintain the quality and performance of the project.

## 6. Conclusions

Various stakeholders have different levels of power to influence OSC project implementation at the different stages of OSC projects. They also show varied interest in project decisions. In existing research, challenges in understanding and analyzing stakeholders still persist, and there is limited literature evaluating the prioritization of stakeholders at different stages of the entire OSC project lifecycle. To effectively manage OSC stakeholders, it is of great importance to understand their attributes. To achieve this, stakeholder mapping models were developed to analyze the attributes of OSC stakeholders (e.g., power, interest, and salience) at the different stages of project implementation. Using visualization tools to generate the 2D power–interest matrix and 3D surface has enhanced our understanding of various project stakeholders. The results indicate that the majority of OSC stakeholders can be classified into the two categories of key players and minimal effort. Interestingly, the client, modular manufacturer, main contractor, government, and designer are identified as key players, while the public and the industry organizations are stakeholders requiring minimal effort at all stages of OSC project implementation. Meanwhile, some stakeholders are identified as key players during specific stages, such as the supervision company, supplier, and subcontractor. At the detailed design stage, the end users are categorized as "keep satisfied", while the supervision company is categorized as "keep informed". During the operation and maintenance stages, the subcontractor and modular manufacturer are also classified as "keep informed". This study also revealed that the levels of key players' salience were varied at different stages of OSC projects. The client consistently occupies a flat area of the decision surface across all project stages, while other stakeholders, such as the modular manufacturer, designer, and main contractor, tend to be on the acute slope at different stages, leading to shifts in their influence and involvement.

The theoretical contributions of this research are multifaceted and advance the field of stakeholder management in OSC projects in several ways. Firstly, the research findings have enriched current stakeholder management knowledge by using stakeholder mapping methods to explore stakeholder issues in the OSC field. For instance, the 3D decision surface reveals dynamic stakeholder mapping, which can improve the decision-making process through the clarified patterns of stakeholders' attribute changes at different stages of OSC projects. The knowledge contribution would support strategic stakeholder management in the OSC field. Additionally, this study highlights the varying levels of key players' salience across different project stages, providing a deep understanding of stakeholder influence over time. This knowledge contribution supports strategic stakeholder management in the OSC field and offers a framework for future studies to further investigate stakeholder dynamics in construction projects.

In practical application, the findings provide an in-depth understanding of stakeholders' attributes at the different stages of OSC projects from the perspectives of power, interest, and salience. In particular, their influences have been clarified during the whole lifecycle of OSC projects, which can optimize the allocation of limited management resources for effective stakeholder management. Nevertheless, this study also has some limitations. The questionnaire survey may lead to relatively subjective research results. In addition, as the research was conducted in the Chinese construction industry, its findings may be restricted in their use in other countries. Future research should address these limitations by using case studies from different countries for more comprehensive results. Another limitation of this study is the use of convenience sampling due to practical constraints, which may introduce bias and limit generalizability. Future research should use more rigorous sampling methods, like stratified random sampling, to improve representativeness and reliability.

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