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Ecosystem Visualization and Analysis of Chinese Prefabricated Housing Industry

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Abstract

Prefabricated housing has proven to achieve high quality, reduce costs and improve housing environmental performance. While prefabricated housing has been widely constructed in many jurisdictions, it is still in its infancy in China. However, the prefabrication sector in China is in transition as the macro environment is changing and new participants are expected to enter architecture, engineering and construction (AEC) industry who will have to work cooperatively as well as competitively with the existed companies. Such changes and strategic activities have impacts on every participant within the ecosystem. A better understanding of the whole industry as well as the participants’ strategic positioning will help companies develop their survival strategies. This paper aims to establish the prefabricated housing ecosystem in China based on the business ecosystem theory and to analyze the interrelationships among the major participants. A conceptual model of the ecosystem is established through literature review. Subsequently, the social network analysis (SNA) approach is employed to quantitatively analyze the strategic relationships between property developers and contractors who have adopted prefabrication in their residential projects. Finally, Node XL software is used for visualization and data analysis. Through the SNA measurements, the top 3 property developers and contractors are identified and several clusters are uncovered, which suggests a cooperation tendency among local actors.

Keywords: prefabricated housing, business ecosystem, visualization, strategy

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1. Introduction

Construction is a key industry for many economies as it contributes largely to their GDP. In China, it accounted to 27.8% of the national GDP in 2014. However, the output and productivity data from the National Statistical Yearbook (2005-2014) shows that the construction industry has fallen behind other industries such as manufacturing in last decade in terms of productivity and efficiency. This has been blamed on the lack of technical innovation and fragmentation of the construction value chain [1]. Thus, there is a need for the construction sector to improve its efficiency by adopting an innovated technology such as prefabrication.

Prefabricated housing, otherwise known as prefabrication or offsite construction, offers substantial opportunities to improve project performance, both in terms of efficiency and quality. Moreover, it facilitates in reducing project costs and enhancing environmental performance [2-6]. This construction technique is well accepted and has been successfully implemented in many countries including Japan, Sweden and America. However, prefabricated housing still remains in its infancy in China.

In order to advance with this new technology, the Chinese government is currently sparing no effort to promote it nationwide. This effort on the part of the government has resulted in a radically changing policy environment for the prefabrication sector. Given that prefabricated housing requires much more cooperation among its major players [7] and that it often draws new entrants into the industry, the structure in which the industry functions is also set to transform. In such circumstances, dominant companies may lose their leadership whereas previously marginal ones may gain market advantage [8]. To remain competitive in this dynamic environment, developing effective strategies will be vital to the companies’ survival and growth. Moreover, companies may need to have a clear knowledge of their own strategic positioning, while they will also need to identify other firms with similar strategic positions in order to develop and implement their strategies [9-10]. Mapping the prefabricated housing ecosystem through a graph is one of the effective means that allow companies to gain knowledge regarding their position and the position of other firms as well as the relationships that exist between them.

Previous researches have examined several aspects of prefabrication in the housing sector, such as the constraints or the challenges it faces [5, 11], its decision making strategies [4] and policymaking [1]. However, there are only a limited number of studies that have investigated the subject area by viewing it as a reticular system or have examined the positioning of companies in the business ecosystem. Thus, the objectives of this paper were to establish the prefabricated housing ecosystem in China based on the theory of business ecosystem (BE) and to determine the positioning of major participants. Furthermore this paper also analyzed the interrelationships between the participants, particularly, between the contractors, property developers and customers.

This paper is presented in 7 sections. The next section, section 2, presents a review of previous research on prefabricated housing and business ecosystem. Section 3 of this paper describes the research methods employed in this research. Section 4 identifies the major participants and establishes the prefabricated housing ecosystem in China. Section 5 describes the data collection and analysis methods. Section 6 discusses the findings from the analysis and finally, section 7 draws the conclusions for this study.

2. Literature Review

2.1. Prefabrication

Prefabrication, also referred to as offsite construction or modular construction, is a construction process where building components are manufactured and assembled in a factory instead of the construction site before the final erection [12-14]. This modern method of construction has been well documented and is widely recognized to provide several benefits. The main reported benefits include its facilitation towards achieving high quality construction, reducing health and safety risks, improving in the planning, control and
innovation environments, as well as, facilitating organizations to be more successful [12, 15-16]. However, it has also been noted that these benefits can be able to support the generalization of prefabrication only when they are clearly acknowledged by all parties and are shared among the participants [16].

In recent years, researchers in this particular area have directed their focus on the participants involved in prefabricated construction. For example, Jeong, Hastak & Syal identified four main participants in the prefabrication supply chain and analyzed their material, information and capital flows to develop a combined conceptual supply chain model [17]. Steinhardt et al. provided an overview of the prefabrication industry where they perceived prefabrication as an open innovation system involving multiple interacting parties. More importantly, they argued that increased openness and cooperation among actors leads to increased innovation [18].

Even though, these previous studies have suggested that the cooperation between the participants are important for the efficiency and effectiveness of the entire industry, there have been only a few researchers that have done a detailed investigation on these relationships along with the competitive strategies of participants. This gap however, can be fulfilled by utilizing ecosystem visualization and analysis since the recent changes in the industry and the complexity of its structure call for a new approach to analyze it rather than simple value chain analysis.

2.2. Business ecosystem

Business ecosystem is a dynamic structure which consists of an interconnected population of organizations [19]. Inter-firm relationships make up the fiber of the value creation process in a BE. Generally, companies are interdependent and share a common fate; however, by forming a loose network, they can either affect and/or are affected by their offers as well as the macro environment. This can be explained through an example of Microsoft Corporation, where its success resulted from the platform it provided for its business partners and by encouraging interdependency between each other. On the other hand, the example of Webvan.com demonstrates failure in terms of their strategy regarding business expansion which resulted in the company’s bankruptcy during the boom years of the Internet [20]. In both of the cases, the business partners shared the success of Microsoft or suffered from the failure of Webvan concomitantly. In other words, any company in a BE can influence and can be influenced by the actions of other companies. This can be interpreted as co-evolution, which is defined as “a process in which independent species evolve in an endless reciprocal cycle – in which changes in species A, set the stage for the natural selection of changes in species B – and vice versa” [8]. Thus, if a company would like to enter and survive in a new ecosystem, it’s vital for them to understand the ecosystem well and to have knowledge of the other companies in the ecosystem [21].

BE is regarded as a strategy analyzing tool for researchers, both at a theoretical and practical level. Iansiti and Levien proposed the keystone strategy classifying the players in an ecosystem into three categories: the keystone, the dominator, and the niche player, where each one has a unique surviving strategy [20]. The keystone companies are the ones who care about the whole ecosystem and offer physical or intellectual platform for the other companies for improving the competency of the whole industry. The dominators on the other hand, are the ones who only care about their own benefits, and thus, are a danger to the industry. The Niches refers to small companies that use the platform provided by keystones and focus on the technology innovation to obtain a core and unique technical competency.

Taking into account, the effects of consumers and the network itself, Vaz et al. suggested a platform-mediated network visualization and investigation tool, which graphs the ecosystem and offers a new way to analyze the relationships among participants [9]. By doing so, companies are able to have a better understanding of the ecosystem and identify potential alliance with those that have similar competition positioning. In addition, Battistella et al., proposed a method for modelling, analyzing and foresighting a business ecosystem, which was validated to be valuable with the case of Italia telecom ecosystem.
3. Research method

To establish the prefabricated housing ecosystem and analyze the interrelationships between the major participants, a mixed methods approach combining literature review and social network analysis (SNA) was adopted in the current study. Primarily, a literature review was conducted to qualitatively identify the major participants in the prefabricated housing ecosystem and to establish the conceptual ecosystem model. Subsequently, SNA was used to quantitatively determine the interrelationships between property developers, contractors and customers. Data was collected for the research using Baidu, an online search engine. Subsequently, Node XL software was used for data analysis.

4. Establishing the prefabricated housing ecosystem

The key elements for understanding a business ecosystem are the vertex and the edge. A vertex is a node standing for a group or a class of companies while an edge represents the connection between them [9]. Thus identifying the participants and their interrelationships is essential work for establishment of an ecosystem.

Given that prefabricated construction is mainly applied to residential projects in China and particularly in affordable housing construction, the ecosystem established in this study focused on the prefabricated housing industry. In a mature prefabrication housing ecosystem, the major participants that constitute to the core of the ecosystem can be divided into four categories: customers, retailers, manufacturers and suppliers [17]. Customers purchase the prefabricated houses and are the end users of the product. Retailers play a mediating role between the manufacturers and the customers to transfer the houses that are produced by the manufacturers to the customers. The property developers generally take on this role in China. Manufacturers on the other hand, are responsible for the designing, engineering, producing and delivering of houses. In China, the contractors perform these works which are related to the assembly, testing and the delivery of the prefabricated products. The suppliers produce or supply the different building materials to the manufacturers. Apart from the four main categories of participants, the government, R&D authorities and other intermediaries are also involved in the ecosystem. They form the auxiliary level of the ecosystem and offer relevant services or support for the core. Basically, all their activities take place within the policy, technic and economic environment, which is called the environmental level of the ecosystem (Figure 1).

![Figure1. The Simplified Conceptual Model of Prefabricated Housing Ecosystem](image_url)
However, it has to be noted that transforming the complex interrelations to an easy to understand graph for the prefabrication sector is not an easy task. Ecosystem visualization needs to have a balance between detail, abstraction, accuracy, efficiency, perceptual tension and aesthetics [22]. Moreover, trying to depict the relationship between all the participants in ecosystem visualization can be complicated and more importantly, difficult to comprehend. Thus, in order to keep the graph simple and easily comprehensible, this paper focused on illustrating the relationship between the two main actors, the contractors (represented by a solid diamond) and property developers (represented by a sphere) shown over the period of past 8 years. Once a contractor provides a house to the property developer, the connection (an edge) is established. Furthermore, the number of customers can reflect the efficiency of their collaboration and further suggests the possibility of potential collaborations. Thus, the customers were also considered (represented by black points).

5. Data

5.1. Data collection

The profiles of the property developers and contractors that have used prefabrication in their residential projects were investigated based on publicly available information. Baidu, a web based search engine was used as the primary tool for data collection, where the keywords used to search for information included terms like prefabrication, off-site manufacturing, combined with the terms like housing, homes and apartments. Data from the residential projects involving both public and private developments in the past 8 years were recorded. Data was collected on the identified projects in regards to the building area, participants involved and the sales status. Collecting data using the Baidu was considered more appropriate compared to sources such as published academic literature because the status of the prefabricated housing industry is constantly changing and online search engines was believed to offer more current data in the context of this study.

5.2. Data analysis and ecosystem visualization

The collected data regarding the companies was categorized by separating the property developers with the contractors. Subsequently, the relationships between the subsidiaries and their parent companies were analyzed. Furthermore, customers were also included in the analysis and these three parties made up the vertexes of the ecosystem.

When the data showed that a house was built by a contractor for a property developer, a connection line was drawn between the two participants. It was further assumed that a single sale is correspondent to a single customer, since it generally not common for the same customer to buy two houses from the same property developer within a short period of time. By doing so, each group of actors in the ecosystem was connected.

One thousand customers were grouped as one node. This was done because the total number of customers was too large to be assessed independently. For instance, if a contractor provided 3,000 sets of houses, there would be 3 consumer nodes connected to the contractor and to the respective property developers. Since every edge has the same weight of 1000 sales, the more connections a property developer and a contractor have, the closer they are pulled together.

Another point that was considered was the graph direction. In a directed graph, an edge connecting point A to point B is different from an edge that connects point B to point A [9]. Since the relations studied are bi-directional, the graph is undirected.

To visualize the ecosystem, NodeXL was used. NodeXL is an open source software for Microsoft Excel which is available for free download. Data was inserted in an Excel sheet and imported into NodeXL for possessing. The request is that the connected nodes should be inserted in adjacent columns [9]. Indicates that reflect if the participants were closely connected were calculated by the software.
6. Results

From the 99 identified projects, 44 property developers and 32 contractors were initially listed. Among these identified companies, only the ones involved in more than 1000 sales and with a building area of over 1000 square meters were considered. This was done in order to simplify the visualization as well as to strengthen the accuracy of the data. Thus, 23 property developers and 21 contractors were analyzed and visualized, as is shown in figure 2.

In the visualization, the spheres denote property developers, among which all the red ones represent Vanke Group. The solid diamonds denote contractors and every black point equals 1000 customers. The size of the spheres and solid diamonds are proportionally represented for the building area of the property developers and contractors respectively.

The graph clearly illustrates that Shenyang Metro Real Estate Development, Blue Harbor Real Estate Development and Hefei Construction Authority of Key Projects had the largest building area in the market. In terms of contractors, Broad Homes, Baoye Construction and Zhongnan Construction produced the most building area for property developers. Among these contractors, Shenyang Metro and Hefei Construction Authority both have cooperated with Baoye Construction, whereas, Blue Harbor seems to have chosen Broad Homes as the only partner. As for Zhongnan Consturction, it was seen that they mostly build houses for Zhongnan Real Estate Development, which provided the fourth largest building area for the market and both these companies belonged to the same parent company, the Zhongnan Group. In addition, several clusters were found, such as Hefei Xin City State Asset Management Limited, Hefei Construction Authority of Key Projects and Baoye Construction, which suggest that there is a tendency for the property developers to select local contractors.

Graph density is a metric that calculates the sum of existing edges divided by the number of all possible edges. High graph density suggests a closely connected network. The graph density of the prefabrication industry is 0.018, which is very low. It means that the companies are not closely connected. Table 1 and Table 2 show the 5 property developers and 5 contractors that have the highest vertex degree. The result mostly validates the analysis of building area. Vertex degree measures the connections a node has. Having highest vertex degree means the company holds the most number of direct connections with others. Such companies occupy relatively advantageous positions in the ecosystem and have strong impact on others.

Figure 2. The Visualization of Network of Property Developers and Contractors
Table 1. Property developers with top 5 vertex degree

<table>
<thead>
<tr>
<th>Vertex</th>
<th>Vertex degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shenyang Metro Real Estate Development</td>
<td>30</td>
</tr>
<tr>
<td>Blue Harbor Real Estate Development</td>
<td>16</td>
</tr>
<tr>
<td>Hefei Construction Authority of Key Projects</td>
<td>10</td>
</tr>
<tr>
<td>Shenzhen Vanke</td>
<td>9</td>
</tr>
<tr>
<td>Beijing Public Housing Center</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 2. Contractors with top 5 degree

<table>
<thead>
<tr>
<th>Vertex</th>
<th>Vertex degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad Homes</td>
<td>17</td>
</tr>
<tr>
<td>Baoye Construction</td>
<td>12</td>
</tr>
<tr>
<td>Shanghai Construction</td>
<td>9</td>
</tr>
<tr>
<td>Shenyang North Construction</td>
<td>9</td>
</tr>
<tr>
<td>China State Construction International Investments</td>
<td>9</td>
</tr>
</tbody>
</table>

7. Conclusions

This study established the Chinese prefabricated housing ecosystem based on the business ecosystem theory and provided a brief analysis of its business network. These results can offer guidance for companies in developing strategies in the future. For instance, big contractors who have had no experience with prefabrication but hold an interest to enter the prefabricated housing market may find it more effective to partner with a more experienced company like Shenzhen Vanke or Broad Homes. They may also identify firms which occupy similar strategic positioning and try a merger or an alliance to improve synergies, especially with companies such as Hefei Construction Authority of Key Projects and Beijing Public Housing Center which provide affordable housing.

But there are also limitations in this study. The visualization depends on the accuracy of data obtained. As of yet, there is no official list of companies involved in prefabricated housing and such project information is not provided by the government. Thus, there is a possibility that some companies or connections may not have been captured in this study. Also, the study only analyzed three parties and other industry participants such as suppliers, government, R&D authorities and other intermediaries were not considered. Finally, some companies or groups such as the filiales of Vanke group that showed the regional impact on the business connections, was not considered as a whole in this study. Future research may attempt to incorporate all the various participants to develop a more robust business ecosystem for the prefabrication sector.

This study provides several further directions for future research. For instance, a comparison study can be done by including the suppliers into the system to examine how it changes the positioning of other players as well as analyze cluster evolution. Moreover, single and multi-factors analysis can be carried out by including key contextual factors such as policy, technical factors, economy and the market, to identify their impact on the stability of the ecosystem. Additionally, the evolution of the ecosystem can be further investigated.

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