Journal of Civil Engineering and Management
ISSN 1392-3730 / eISSN 1822-3605
2022 Volume 28 Issue 3: 166–176
https://doi.org/10.3846/jcem.2022.15777

IMPACT OF CONSUMER PREFERENCE ON THE DECISION-MAKING OF PREFABRICATED BUILDING DEVELOPERS

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Received 31 July 2020; accepted 31 July 2021

Abstract. Customers' preferences for prefabricated building or conventional cast-in-situ building directly affect the decision-making process for strategic selection of building developers. This study utilizes a Hotelling model integrating game theory, including the market share function, product price function, and profit function of duopoly building developers to contribute a new approach to assist decision makers in their selection of developers for their projects. By analyzing different strategy combinations and the income matrix, we obtained the strategy combinations of duopoly building developers and the income matrix strategies, market share, optimal price and maximum profit. Managerial implications were discussed for government and building developers. Finally, we presented the research contribution as well as future research direction.

Keywords: prefabricated construction, building developer, consumer preference, decision-making.

Introduction

Prefabricated construction has shown great potential for improving building quality, reducing the construction time, improving resource efficiency, reducing construction and demolition waste, contributing to health and safety requirements, enhancing performance, subject to achieving some soft, technical and economic prerequisites such as the economies of scale (Gan et al., 2017). The development of prefabricated construction has become one of the important solutions to transform the traditional construction industry and to overcome its shortcomings (Demiralp et al., 2012). In China, the development of prefabricated building has been proactively promoted since 2010 due to such constraints as labor shortage, resource scarcity and environmental concerns, and lengthy and costly construction cycles. Many kinds of policies have been developed to help extend and adopt the prefabricated construction methods by both central and local governments of China. One of central government's policies set a target of increasing the prefabricated building area ratio in all newly built area to 30% by 2025 (Central Committee of the Communist Party of China and the State Council, 2016). Despite such top-down policies, the prefabricated building in China reached 114 million square meters in 2016 which accounted for only 4.9% of all new building projects (Liu & Wang, 2017). Thus, there is a big gap between the reality and the goal in terms of the development of prefabricated building.

The existing studies are mainly carried out to discuss the causes and countermeasures of slow development of prefabricated building from the perspectives of barriers and their mutual relations, stakeholders' cooperation, supply chain integration, government role and so on (Blismas & Wakefield, 2008; Han & Wang, 2018; Pan et al., 2007; Cho et al., 2011; Mao et al., 2013). However, there is still a dearth of research on facilitating the spread of prefabricated building from the perspective of the consumer preference on decision-making of building developer. From the view of real estate economics, building developers and consumers, as supply and demand players of the building market respectively, play a major role to promote the prefabricated building development. Either traditional cast-in-situ construction or prefabricated construction is used to categorize the building products into traditional building or prefabricated building. From a long-term perspective, the traditional building and the prefabricated building will coexist and compete with each other. Considering

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prefabricated building's quality and safety, consumer preference on prefabricated building will result in the different payment willingness and the consuming function, which will influence the developer's decision making about developing the traditional building or prefabricated building.

There are many factors that affect consumers' purchasing behavior. Koklic and Vida (2011) developed a conceptual model of consumer strategic decision making and explored this model with regard to prefabricated house purchases. Kumar et al. (2020) employed the structural equation modeling to discover the factors influencing customer purchase intention towards solar water heaters. Factors such as assembly rate, product quality, safety, price, and energy efficiency will play an increasingly important role in influencing consumers' purchasing behavior. However, the prefabricated building development has "dual externalities" which not only have typical spillover effects but also generate external effects by reducing the products' external environmental costs (increased investment costs due to weak industrial foundation), resulting in great uncertainty risk. The profit level and risk resistance of building developer are closely related to consumers' preference for prefabricated buildings, because the proportion of consumers of prefabricated building products determines the mode selection of building developers and the profit level of related parties (Han et al., 2017). Therefore, it is important to study how the production and pricing decisions of developers are influenced by consumer preference. Given consumers' different preferences for prefabricated building and traditional building, this study developed the Hotelling model to compare and analyze the evolution of market share, optimal price, and maximum profit of duopoly building developers with consumers' different preferences. We also examined the impact of consumers' preferences on the strategic selection of building developers. Thus, the paper emphasized the role of consumers on the decision-making of building developers as well as broadened the theoretical research about facilitating the prefabricated building development.

The rest of the paper is organized as follows. Section 1 provides literature review. Section 2 presents the research methodology. Section 3 puts forward the modeling assumptions and the research model. Section 4 conducts a numerical simulation and discussion in terms of market share, optimal price, and maximum profit and suggests the managerial implications for promoting and developing prefabrication construction. Last section concludes the paper and proposes future research directions.

1. Literature review

1.1. Influencing factors for the development of prefabricated construction

Prefabricated construction methods seem to be a promising alternative to make a shift in the architecture, engineering and construction (AEC) industry to reduce the lead-in time in project delivery, cut cost, enhance performance, and lower the environmental impacts. However, the transition from traditional cast-in-situ construction to innovative prefabricated construction methods is not easy, especially as traditional construction approaches have been utilized for many years (Zhang & Skitmore, 2011). There have been many challenges identified and numerous solutions proposed to tackle problems for a successful shift. First, the identification of the factors inhibiting the adoption of prefabricated construction technologies is one of the main research directions (Li et al., 2014b). The high cost is one of the main constraints affecting the adoption of prefabricated construction methods in the UK, Australia, and China (Pan et al., 2008; Zhai et al., 2014). To promote the prefabricated construction application, Goulding et al. (2015) investigated people, process, and technology drivers for construction, manufacturing, and design, resulting in three levels of priority and timeframes to present a roadmap for future uptake. Second, researchers have shed lights on the strategic partnerships from different perspectives. For example, Shi et al. (2015) analyzed the coopertion problems between major modularized production suppliers. Nguyen et al. (2021) reviewed the stakeholder relationships in off-site construction via a systematic literature analysis. Yan et al. (2017) designed suppliers' incentive mechanism by applying a principal-agent/Stackelberg model. From the perspective of supply chain integration, Love et al. (2004) pointed out that supply chain management should relate the prefabricated production to construction plans. Tennant and Fernie (2014) investigated the complex relationships between different stakeholders and the methods for supply chain management. Third, many researchers have adopted real-time management tools and cloud computing to propose a technological solution to address some problems associated with the supply chain management, strategies, solution or technologies such as Just in Time (JIT), Personal Digital Assistant (PDA), Radio Frequency Identification Device (RFID), Building Information Modelling (BIM) and hybrid BIM system (Samaranayake & Toncich, 2007; Polat, 2010; Li et al., 2014a, 2018; Abedi et al., 2016; Kong et al., 2018; Ismail, 2020). Finally, considering the government's role, Wu et al. (2015) argued that the government's reasonable incentive policy is the most effective behavior. Cheng et al. (2020) developed a systematic and dynamic model to investigate and simulate the impacts of government incentive strategies on prefabricated construction by considering the evolutionary game process between the government and contractors. Osobajo et al. (2021) found the circular economy research in the construction industry mainly lies more on resource use and waste management and less on other areas of construction such as supply chain integration, building designs, policy. However, there is scarcely any research on the consumers' preference on the development of prefabricated construction, which provides impetus to growth and maturity of prefabricated building market. Although Rahimian et al. (2017) investigated that the low prevalence of off-site manufacturing in housing in Nigeria was influenced by many factors including negative local perception about OSM and client resistance, it still lacks of the in-depth study on how consumer preference impacts the prefabricated building spread.

1.2. The impact of consumer preference on corporate decision-making

Consumer perception has become an important research topic for the product pricing (Hernandez, 2010; Guo et al., 2013). Kumar et al. (2019) validated that consumer buying behaviour in terms of purchasing solar water pumping system was significantly determined by cost, performance and government initiatives dimensions. Zhou et al. (2020) discussed the vehicle consumer consumption behavior from online perspective. Since the whole process of financing, marketing and sales work are different in the construction industry compared to other manufacturing industries regardless of their size or scale, consumer perception might or might not work in the construction market. Consumers' perception of product quality is an important factor for enterprises to make the production and operation decisions (Nie & Deng, 2014). This also applies to the AEC industry, but where such perceptions are systematically influenced by the previous performance of provider of the service, for instance one developer who may have a better reputation than their competitors for the buildings' quality. Analyzing consumers' risk perception of remanufactured product quality, Wang et al. (2018) found that consumers' quality perception plays an important role in product pricing. This is important especially for the construction industry where the dominating tendency is conservatively in favor of avoiding change in the existing practice unless it is absolutely necessary. Different consumers have indicated different willingness to pay for new products and remanufactured products (Gan et al., 2017). However, unlike other industries, the AEC industry is less inclined to spend on new remanufactured products as what counts at the end is the building where the sense of remanufacturing individual components may seem insignificant compared to the performance of the end product being the entire building. He and Yuan (2019) established a Hotelling model to study the impact of consumer quality perception on the production decision of building materials enterprises. Although the studies on and around the Hotelling model in manufacturing may not be few and far between, due to perceived differences, such studies are scarce, if at all they exist, in the AEC industry. With AEC industry moving along the line of other manufacturing industries in its adopted production strategies, solutions and processes due to more profound and sustained uptake of prefabricated manufacturing and construction methods, it has never been a better time to introduce models, theories or strategies which are known to be leading in manufacturing industries; hence this paper where we aim to apply the Hotelling model to the process of building developer's decision-making in the AEC industry.

With new concerns about climate change and our collective environmental impact and carbon footprint, one of the drivers which make reengineering or remanufacturing of products rather inevitable (as opposed to trendy or fashionable) if how our consumption can become more environmentally friendly through use of less impactful products and services. This may have some direct or indirect implications of which one with direct impact on the customers' decision outcome is the cost of the reengineering or remanufacturing new services or products with lower environmental impact. For the consumption impact of low-carbon products, Economides (1999) adopted the uniform distribution of [0,1] to reflect the consumer's marginal willingness to pay. Seyfang (2010) developed a function of consumer demand affected by low-carbon preference behaviors. This does not mean that customers are always prepared to pay a higher price for products with better environmental rankings. Consumer preference behavior has a significant impact on the production and operation strategies of enterprises as well as the cooperation and competition strategies among enterprises which may turn out to have a negative impact on the environment in long run (Chen et al., 2010). Ozaki and Sevastyanova (2011) concluded that the economic benefits related to transportation policies are the important factors affecting consumers' purchase of hybrid electric vehicles. Maniatis (2016) presented a structural construct to show how consumers weigh environmental and economic benefits while choosing green products. Hüttel et al. (2018) investigated consumer cognitive decision-making structures related to six distinct options for economically sustainable/non-sustainable consumption. Cohen and Vandenbergh (2012) discussed the impact of demand uncertainty on the green product manufacturers' decisions about production and price. Yet again, it is vital to note that it may not be possible to directly apply or prescribe what such studies in other manufacturing disciplines may have come up with to the AEC industry, and therefore, discipline-specific studies are needed. The market demand of low-carbon products and common products will be different because of the heterogeneity of consumers' choice behavior for manufacturing products and even more so in the AEC industry.

2. Methodology

2.1. Hotelling model

The Hotelling model is a classic model to study the spatial differences of products and services to reduce differentiation in the range of products or services offered. The main purpose of the Hotelling model is to solve the Bertrand paradox by introducing product differences with the principles of minimum differentiation in their offerings (Hotelling, 1929). Hotelling believed that the buyer's and the seller's market activities are scattered in different geographical spaces in the real world. Such geographical difference is an important source for manufacturers to gain market dominance where similarities between products can be increased to the level that it does not negatively affect the market share. Accordingly, the different transportation cost will weaken the market competition. In summary, the geographical dispersion and the resulting product differences are important determinants of market competition, which are the traditional Hotelling model's basic connotation.

The original Hotelling model utilizes the linear space to locate the enterprises' positions reflecting the degree of product difference. d'Aspremont et al. (1979) discussed the optimal location and price equilibrium of the Hotelling model under the linear transportation cost. Economides (1986) further studied the Hotelling model when the transportation cost is a power function $t(x) = bx^a$ ($a \geq 1$) and quadratic function $t(x) = ax + bx^2$, respectively. Tabuchi and Thisse (1995) studied the Hotelling model when the distribution density function of consumers is a trigonometric fold. Additionally, Harter (1996) analyzed the Hotelling model when consumers' preferences were non-uniform. Therefore, the model has been widely used in different research fields, such as industrial economy, regional economy, and environmental economy, etc. Furthermore, researchers have expanded the model from such aspects as product heterogeneity, consumer heterogeneous distribution, and internal transportation cost.

In this study, consumers' preference for prefabricated building products is the analogy of geographical difference in the traditional Hotelling model. In other words, consumers' preference for prefabricated building products are represented by their location differences. Based on this, it will conduct a study on the impact of the consumer preference on the building developers.

2.2. Game theory

Considered as a successful mathematical model, game theory can be utilized in many economic and other social circumstances (Trappey et al., 2013; Fudenberg & Levince, 2016; Samuelson, 2016). Usually, Nash equilibrium in games can be derived in different contexts in terms of incomplete preferences (Bade, 2005), random production output (Gorbachuk, 2007), and negotiation of on-site buffer stocks (Ng et al., 2008). Many researchers have further adopted game theory to study such business decision-making situations as land and property development negotiation (Samsura & Erwin, 2012), business negotiations (Peleckis, 2015), project management (Bockova et al., 2016), and unfriendly takeover of enterprises (Korolovych et al., 2019). In addition, game theory based evolutionary algorithms can be applied to solve structural engineering optimization (Greiner et al., 2017). Zhi et al. (2018) conducted cost-benefit analysis and behavior incentives for virtual water strategy using game theory. Furthermore, Abapour et al. (2018) defined three types of game theory in terms of cooperative game theory, dynamic game theory, and evolutionary game theory to facilitate decision-making process in power system problems.

This study will consider a duopoly market consisting of two building developers, which is consistent with the prefabricated building market situation at the early stage, as there are only a few big enterprises with strength is capable of and willing to take the lead to the high cost of inputs, because of the development cost of prefabricated buildings higher than that of the traditional cast-in-situ buildings currently. Accordingly, there is a competitive game relationship between the two building developers on the strategy of developing prefabricated buildings or traditional cast-in-situ buildings. Therefore, this study will adopt the Nash equilibrium theory to reveal the influence of consumer preference on the building developers through the related profit functions.

In summary, the existing literature does not introduce the enterprises' development strategies and consumer preferences into the Hotelling model combining with game theory. More and more research is not limited to the difference in the geographical space. To improve production efficiency, reduce resources and materials waste, and reduce environmental impacts, the differences between prefabricated buildings and traditional buildings in terms of function, safety, and price affect the consumers' purchase preferences and further influence the building developers' decisions. Based on the Hotelling model and game theory, we mainly studied the impact of consumer preferences on the development strategy selection of the prefabricated building by considering consumers' needs and preferences.

3. Research model

3.1. Assumptions

Assumption 1: Assume the duopoly market has two building developers in a linear city with length = 1. Building developers are suppliers and consumers are buyers in the building market. R_1 represents developer 1 and R_2 represents developer 2. Strategy P is when the prefabricated buildings are developed; strategy T is when the traditional (cast-in-situ) buildings are developed. The development cost, sales price, market share, and profit for the building developer R_1 are c_i, p_i, q_i, and π_i, respectively, with $i = 1, 2$, and $\Delta c = c_1 - c_2 > 0$.

Assumption 2: Assume that the building market is a perfectly competitive market. Consumers' total demand is standardized as 1 (consumers have a unit demand). Only one unit of building product is purchased at a time. The total utility obtained by consumers' purchase of prefabricated building products is large enough to cover the entire market. The utility of consumers' purchase of prefabricated building products is $U = V + \eta v$ where V indicates the initial (reserved) utility of a consumer's purchase of prefabricated building products[1] and V is big enough;

[1] The maximum expected utility that one game player can get when he or she does not participate in the game (outside the game). Reservation utility is the opportunity cost for players to participate in the game.

v is the additional utility for consumers to buy prefabricated building products; η is the preference coefficient for consumers to obtain additional utility of prefabricated building products, $\eta \in [0,1]$. When η = 0, it indicates that the consumer won't accept the prefabricated building products; when η = 1, it indicates that consumers show strong preference for prefabricated building products. It can be predicted that consumers will increasingly accept the prefabricated building products with the labor force constraint and the promotion of environmental awareness.

Assumption 3: Consumers is uniformly distributed in linear cities [0,1]. The different consumers' position is used to reflect their preference for prefabricated building products. The location of construction developer 1 and developer 2 in the linear city is x_1 and x_2, respectively. Without losing generality, we assumed that the developer 1 is located at the left side of the developer 2, that is to say $0 < x_1 < x_2 < 1$. The consumer preference for prefabricated building products is x with purchasing prefabricated building product 1 and traditional cast-in-situ building product 2. Accordingly, the utility loss is $t(x_1 - x)^2$ and $t(x_2 - x)^2$, respectively, where the utility loss $t(t > 0)$ is the premium that consumers are willing to pay for maintaining their preference for building products.

Assumption 4: U_1 and U_2 represent the net residual utility of consumers obtained from purchasing building products from construction developers 1 and 2, respectively.

3.2. Research model

The strategy combinations of the two building developers' game are shown in Table 1. Scenario A (P, P): both building developers select strategy P.

The net residual utility of building products 1 and 2 purchased by consumers U_1 and U_2:

$$U_1 = V - p_1 - t\left(x_1 - x\right)^2; \quad (1)$$

$$U_2 = V - p_2 - t\left(x_2 - x\right)^2. \quad (2)$$

Set $\hat{x}$ is the position without different utility of building product 1 and building product 2, $\hat{x}$ satisfies the below equation:

$$V - p_1 - t(x_1 - \hat{x})^2 = V - p_2 - t(x_2 - \hat{x})^2. \quad (3)$$

Table 1. Strategy combinations of building developers' game

Developer 2 / Developer 1	Development of prefabricated buildings (strategy P)	Development of traditional cast-in-situ buildings (strategy T)
Development of prefabricated buildings (strategy P)	(P, P)	(P, T)
Development of traditional cast-in-situ buildings (strategy T)	(T, P)	(T, T)

Accordingly, we get the below result after solving the above equation:

$$\hat{x} = \frac{(p_2 - p_1)/t + (x_2 + x_1)(x_2 - x_1)}{2(x_2 - x_1)}. \quad (4)$$

Therefore, the market shares of developers 1 and 2 are as follows:

$$q_1 = \frac{(p_2 - p_1)/t + (x_2 + x_1)(x_2 - x_1)}{2(x_2 - x_1)}; \quad (5)$$

$$q_2 = 1 - \frac{(p_2 - p_1)/t + (x_2 + x_1)(x_2 - x_1)}{2(x_2 - x_1)}. \quad (6)$$

The profit functions of developers 1 and 2 are as follows:

$$\pi_1 = p_1\left(\frac{(p_2 - p_1)/t + (x_2 + x_1)(x_2 - x_1)}{2(x_2 - x_1)}\right); \quad (7)$$

$$\pi_2 = p_2\left(1 - \frac{(p_2 - p_1)/t + (x_2 + x_1)(x_2 - x_1)}{2(x_2 - x_1)}\right). \quad (8)$$

The profit functions π_1 and π_2 can be obtained by calculating the first derivative:

$$p_2 = 2p_1 - t(x_2 + x_1)(x_2 - x_1); \quad (9)$$

$$p_1 = 2p_2 + t(x_2 + x_1)(x_2 - x_1) - 2t(x_2 - x_1). \quad (10)$$

Thus, the optimal prices of developers 1 and 2 can be obtained as follows:

$$p_1^* = \frac{t(x_2 - x_1)(x_2 + x_1 + 2)}{3}; \quad (11)$$

$$p_2^* = \frac{t(x_2 - x_1)(4 - x_2 - x_1)}{3}. \quad (12)$$

Substitute Eqns (11) and (12) into Eqn (4), we got:

$$\hat{x} = \frac{x_2 + x_1 + 2}{6}. \quad (13)$$

By substituting (11) and (12) into profit functions (7) and (8), the maximum profits of developer 1 and 2 are:

$$\pi_1^* = \frac{t(x_2 - x_1)(x_2 + x_1 + 2)^2}{18}; \quad (14)$$

$$\pi_2^* = \frac{t(x_2 - x_1)(4 - x_2 - x_1)^2}{18}. \quad (15)$$

Similarly, consumers' net residual, indifferent position, optimal price, and maximum profit for scenario B (P, T), scenario C (T, P), and scenario D (T, T) are shown in Table 2.

Accordingly, the income matrix of construction developers 1 and 2 is shown in Table 3.

3.3. Model analysis

Based on Table 3, the equilibrium achieved by developers 1 and 2 is dominant equilibrium as well as Nash equilibrium. No matter what strategy one developer chooses, the best strategy the other developer chooses is unique.

Table 2. Consumers' net residual, indifferent position, optimal price, and maximum profit of construction developers under different game strategies

Index \ Scenario	Scenario B (P, T)	Scenario C (T, P)	Scenario D (T, T)
Consumers' net residual	$U_1 = V + \eta v - p_1 - t(x_1 - x)^2$	$U_1 = V - p_1 - t(x_1 - x)^2$	$U_1 = V + \eta v - p_1 - t(x_1 - x)^2$
	$U_2 = V + \eta v - p_2 - t(x_2 - x)^2$	$U_2 = V + \eta v - p_1 - t(x_2 - x)^2$	$U_2 = V + \eta v - p_1 - t(x_1 - x)^2$
Indifferent position	$\hat{x} = \frac{t(x_2 - x_1)(x_2 + x_1 + 2) + \eta v - \Delta c}{6t(x_2 - x_1)}$	$\hat{x} = \frac{t(x_2 - x_1)(x_2 + x_1 + 2) - \eta v + \Delta c}{6t(x_2 - x_1)}$	$\hat{x} = \frac{x_2 + x_1 + 2}{6}$
Optimal price	$p_1^* = \frac{t(x_2 - x_1)(x_2 + x_1 + 2) + \eta v + 2\Delta c}{3}$	$p_1^* = \frac{t(x_2 - x_1)(x_2 + x_1 + 2) - \eta v + \Delta c}{3}$	$p_1^* = \frac{t(x_2 - x_1)(x_2 + x_1 + 2)}{3} + \Delta c$
	$p_2^* = \frac{t(x_2 - x_1)(4 - x_2 - x_1) - \eta v + \Delta c}{3}$	$p_2^* = \frac{t(x_2 - x_1)(4 - x_2 - x_1) + \eta v + 2\Delta c}{3}$	$p_2^* = \frac{t(x_2 - x_1)(4 - x_2 - x_1)}{3} + \Delta c$
Maximum profit	$\pi_1^* = \frac{\left(t(x_2 - x_1)(x_2 + x_1 + 2) + \eta v - \Delta c\right)^2}{18t(x_2 - x_1)}$	$\pi_1^* = \frac{\left(t(x_2 - x_1)(x_2 + x_1 + 2) - \eta v + \Delta c\right)^2}{18t(x_2 - x_1)}$	$\pi_1^* = \frac{t(x_2 - x_1)(x_2 + x_1 + 2)^2}{18}$
	$\pi_2^* = \frac{\left(t(x_2 - x_1)(4 - x_2 - x_1) - \eta v + \Delta c\right)^2}{18t(x_2 - x_1)}$	$\pi_2^* = \frac{\left(t(x_2 - x_1)(4 - x_2 - x_1) + \eta v - \Delta c\right)^2}{18t(x_2 - x_1)}$	$\pi_2^* = \frac{t(x_2 - x_1)(4 - x_2 - x_1)^2}{18}$

Table 3. Income matrix of Game 1 and 2 of construction developers under different strategy combinations

Developer 1 \ Developer 2	Development of prefabricated buildings (Strategy P)	Development of traditional cast-in-situ buildings (Strategy T)
Development of prefabricated buildings (Strategy P)	$\left(\frac{t(x_2 - x_1)(x_2 + x_1 + 2)^2}{18}, \frac{t(x_2 - x_1)(4 - x_2 - x_1)^2}{18}\right)$	$\left(\frac{\left(t(x_2 - x_1)(x_2 + x_1 + 2) + (\eta v - \Delta c)\right)^2}{18t(x_2 - x_1)}, \frac{\left(t(x_2 - x_1)(4 - x_2 - x_1) - (\eta v - \Delta c)\right)^2}{18t(x_2 - x_1)}\right)$
Development of traditional cast-in-situ buildings (Strategy P)	$\left(\frac{\left(t(x_2 - x_1)(x_2 + x_1 + 2) - (\eta v - \Delta c)\right)^2}{18t(x_2 - x_1)}, \frac{\left(t(x_2 - x_1)(4 - x_2 - x_1) + (\eta v - \Delta c)\right)^2}{18t(x_2 - x_1)}\right)$	$\left(\frac{t(x_2 - x_1)(x_2 + x_1 + 2)^2}{18}, \frac{t(x_2 - x_1)(4 - x_2 - x_1)^2}{18}\right)$

The degree of consumers' preference for prefabricated buildings determines these two building developers' income, thus affecting the final game equilibrium results. We discussed the below two situations by setting $\mu = \eta v - \Delta c$.

1) When $\mu = \eta v - \Delta c < 0$, then $\eta < \frac{\Delta c}{v}$. When consumers have a low preference for prefabricated buildings, the equilibrium strategy combination chosen by building developers 1 and 2 is (T, T). Thus, both developers will develop traditional cast-in-situ buildings.
2) When $\mu = \eta v - \Delta c > 0$, then $\eta > \frac{\Delta c}{v}$. When consumers have a high preference for prefabricated buildings, the equilibrium strategy combination chosen by building developers 1 and 2 is (P, P). Thus, both developers will develop prefabricated buildings.

Conclusion 1: When building developers 1 and 2 reach the game equilibrium, the indifferent position for their market share is $\frac{x_1 + x_2 + 2}{6}$. Specifically, building developer 1's market share is $q_1 = \frac{x_1 + x_2 + 2}{6}$ and building developer 2's market share is $q_2 = 1 - q_1 = 1 - \frac{x_1 + x_2 + 2}{6} = \frac{4 - (x_1 + x_2)}{6}$. That is to say, two building developers' market share is related to $x_1 + x_2$, when $0 < x_1 < x_2 < 1$, then $0 < x_1 + x_2 < 2$; when $0 < x_1 + x_2 < 1$, then $q_1 < q_2$; when $1 < x_1 + x_2 < 2$, then $q_1 > q_2$.

Conclusion 2: When $\eta < \frac{\Delta c}{v}$, both building developers 1 and 2 will develop traditional cast-in-situ buildings, the optimal prices are $p_1^* = \frac{t(x_2 - x_1)(x_2 + x_1 + 2)}{3}$, $p_2^* = \frac{t(x_2 - x_1)(4 - x_2 - x_1)}{3}$, respectively.

$p_1^* - p_2^* = \frac{2t(x_2 - x_1)(x_2 + x_1 + 2)}{3}$, since $0 < x_1 < x_2 < 1$, when $0 < x_1 + x_2 < 1$, then $p_1^* - p_2^* = \frac{2t(x_2 - x_1)(x_2 + x_1 + 2)}{3} < 0$, thus, $p_1^* < p_2^*$; when $1 < x_1 + x_2 < 2$, then $p_1^* - p_2^* = \frac{2t(x_2 - x_1)(x_2 + x_1 + 2)}{3} > 0$, thus, $p_1^* > p_2^*$.

Conclusion 3: When $\eta > \frac{\Delta c}{v}$, both building developers 1 and 2 will develop prefabricated buildings. Similarly, when $0 < x_1 + x_2 < 1$, then $p_1^* < p_2^*$; when $1 < x_1 + x_2 < 2$, then $p_1^* > p_2^*$.

Conclusion 4: When $\eta < \frac{\Delta c}{v}$, both building developers 1 and 2 will develop traditional cast-in-situ buildings, the maximum profits $\pi_1^* = \frac{t(x_2 - x_1)(x_2 + x_1 + 2)^2}{18}$ and $\pi_2^* = \frac{t(x_2 - x_1)(4 - x_2 - x_1)^2}{18}$, $\pi_1^* - \pi_2^* = \frac{2t(x_2 - x_1)(x_2 + x_1 - 1)}{3}$, since $0 < x_1 < x_2 < 1$, when $0 < x_1 + x_2 < 1$, then $\pi_1^* - \pi_2^* = \frac{2t(x_2 - x_1)(x_2 + x_1 - 1)}{3} < 0$, thus, $\pi_1^* < \pi_2^*$; when $1 < x_1 + x_2 < 2$, then $\pi_1^* - \pi_2^* = \frac{2t(x_2 - x_1)(x_2 + x_1 - 1)}{3} > 0$, thus, $\pi_1^* > \pi_2^*$.

Conclusion 5: When $\eta > \frac{\Delta c}{v}$, both building developers 1 and 2 will develop prefabricated buildings. Similarly, when $0 < x_1 + x_2 < 1$, then $\pi_1^* < \pi_2^*$; when $1 < x_1 + x_2 < 2$, then $\pi_1^* > \pi_2^*$.

4. Numerical analysis and discussion

Set $t = 160$, $\Delta c = 40$, $v = 50$, Python was used to compare and analyze building developers' market share, optimal price, and maximum profit.

4.1. Market share comparison

The market share of developers 1 and 2 is mainly related to $x_1 + x_2$ whose value ranges from 0 to 2. If $x_1 + x_2$ increases, then developer 1's market share is gradually increasing and developer 2's market share is gradually decreasing. When $0 < x_1 + x_2 < 1$, the market share of developer 1 is less than the market share of developer 2; when $1 < x_1 + x_2 < 2$, the market share of developer 1 is greater than the market share of developer 2. When $x_1 + x_2 = 1$, the two developers have equal market shares. Therefore, the market share of duopoly building developers is directly related to consumers' preference for prefabricated building products. The evolution of the market share of developers 1 and 2 is shown in Figure 1.

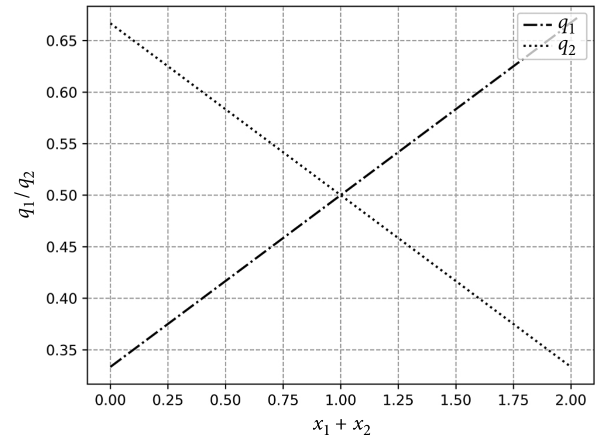

Figure 1. Evolution of market share gained by developers 1 and 2

4.2. Optimal price comparison

In the first case, when $\eta < \frac{\Delta c}{v}$, set $\eta = 0.2$.That is, when there is a higher proportion of the difference value between the development cost of prefabricated buildings and traditional buildings to the additional utility gained from consumers, both building developers 1 and 2 will develop the traditional cast-in-situ buildings. The evolution process of the optimal price is shown in Figure 2.

As shown in Figure 2, when $0 < x_1 + x_2 < 1$, the optimal price of developer 1 is less than developer 2; when $1 < x_1 + x_2 < 2$, the optimal price of developer 1 is higher than developer 2.

In the second case, when $\eta > \frac{\Delta c}{v}$, set $\eta = 0.8$. That is, when there is a lower proportion of the difference value between the development cost of prefabricated buildings and traditional buildings to the additional utility gained from consumers, both building developers 1 and 2 will develop the prefabricated building. The evolution process of the optimal price is shown in Figure 3.

As shown in Figure 3, when $0 < x_1 + x_2 < 1$, the optimal price of developer 1 is less than developer 2; when $1 < x_1 + x_2 < 2$, the optimal price of developer 1 is higher than developer 2.

By comparing the two above-mentioned cases we can get the following two findings. The first one is that whether to develop traditional cast-in-situ building or prefabricated building is mainly determined by the proportion of the difference value between the development cost of prefabricated buildings and traditional buildings to the additional utility gained from consumers. For the moment, the previous studies showed that the cost of developing prefabricated buildings is higher than that of developing traditional building. If the increased cost can be made up by the additional utility gained from consumers, it is economical to develop prefabricated buildings. If not, it is proper to develop traditional buildings. Secondly, the optimal price of duopoly building developers is directly related to consumers' preference ($x_1 + x_2$) for prefabricated building products, with no relationship with traditional and prefabricated construction methods. According to Figure 2 and Figure 3, consumers are willing to pay a higher price when they have a higher preference for prefabricated buildings. Thus, consumers' preference on prefabricated building is a crucial element for enlarging the real estate market. How to enhance the consumers' preference should be on consideration.

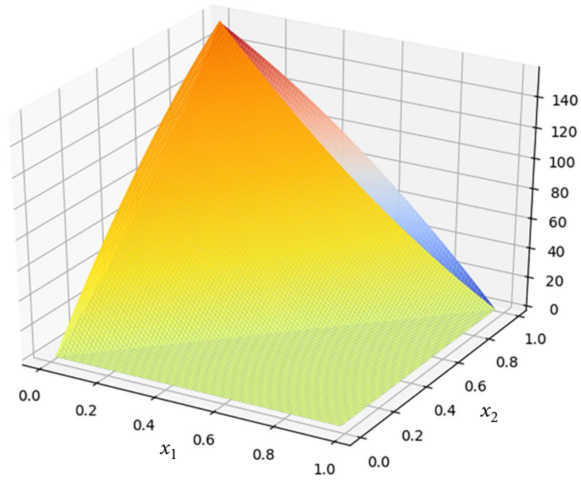

Figure 2. The evolution process of the optimal price of building developers 1 and 2 when η = 0.2 (x_1 and x_2 is the consumer's preference on prefabricated building product 1 and traditional cast-in-situ building product 2, respectively)

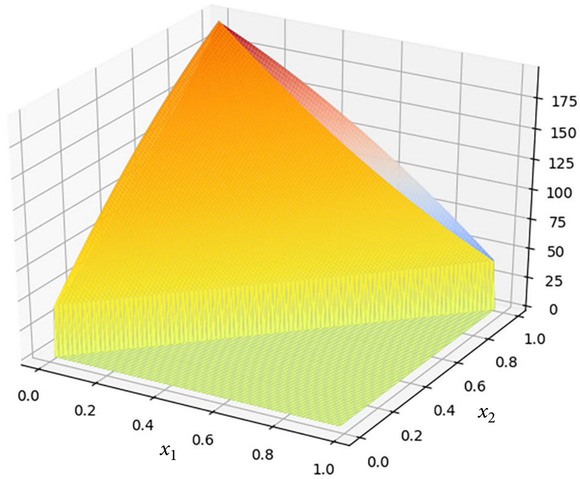

Figure 3. The evolution process of the optimal price of building developers 1 and 2 when η = 0.8 (x_1 and x_2 is the consumer's preference on prefabricated building product 1 and traditional cast-in-situ building product 2, respectively)

4.3. Maximum profit comparison

When both building developers 1 and 2 develop either traditional cast-in-situ buildings or prefabricated buildings to achieve the game equilibrium, the evolution process of their maximum profits is shown in Figure 4.

As shown in Figure 4, when $0 < x_1 + x_2 < 1$, the maximum profit of developer 1 is less than developer 2; when $1 < x_1 + x_2 < 2$, the maximum profit of developer 1 is greater than developer 2. In summary, the maximum profit of duopoly building developers is directly related to consumers' preference for prefabricated building products, with no relationship with the proportion of the difference value between the development cost of prefabricated buildings and traditional buildings to the additional utility gained from consumers. The value of $x_1 + x_2$ is the only one factor influencing the maximum profit of building developers.

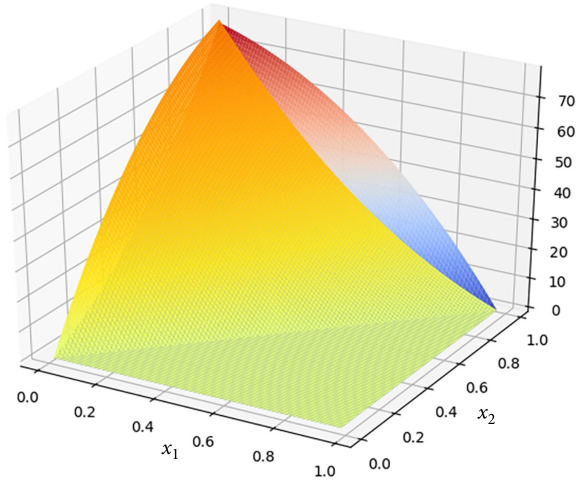

Figure 4. The evolution process of the maximum profit of building developers when the game equilibrium is reached (x_1 and x_2 is the consumer's preference on prefabricated building product 1 and traditional cast-in-situ building product 2, respectively)

4.4. Managerial implications

This study built on a premise that two building developers have the option to opt for either cast-in-situ construction method or a prefabricated one while having to deal with their product variation, the customer and market behavior. The strategy for selection of developing prefabricated buildings or traditional cast-in-situ building construction method mainly comes from consumers' willingness to pay higher prices for prefabricated buildings (which entail remanufacturing/reengineering of a set of products with higher performance specifications and possibly lower environmental impact). Thus, evidently the market demand for prefabricated buildings is the fundamental drive for more sustainable development of prefabricated building industry, it should not go unnoticed that the mechanisms through with the market demand can be managed in the AEC industry are by no means comparable or even close to those of other manufacturing industries. This means different strategies will be needed and more centralized supports will be needed to mobilize the market in favor of prefabricated construction methods. This may be in form of, government planning, policies, regulatory and monetary incentives to effectively improve consumers' recognition of, and boost their willingness to proactively accept prefabricated building products.

The government will need to design the optimal policies for extended subsidies and tax incentives in the early stages of prefabricated building development to boost consumers' awareness and to ensure higher efficiency in quality of the product and the price for customers and end users. Although the total social welfare might be perceived to work out negative in short term, the building developers' profit will be increased while better end-products are delivered to customers and end users with lower environmental impacts, lower maintenance costs and better performance specifications in long term. Furthermore, the economic and social welfare will be improved if the scale of prefabricated buildings is increased. Therefore, it is necessary to track and analyze consumers' preference for prefabricated building and provide reasonable economic subsidies for purchasing prefabricated buildings.

For building developers, one more incentive to adopt prefabricated building systems remains to be the health and safety of their workforce together with the quality of their end product while provide highly cost-effective buildings to the market; what is, by default, what prefabricated construction can achieve. This remains subject to further investigation with respect what this paper aspired to and did deliver using the application of Hotelling model. Needless to say, that the role of proactive marketing to enhance the customers' perception of prefabricated systems and to increase the level of acceptance of such systems is of paramount importance. When consumers have a low preference for prefabricated buildings, they should be actively encouraged to cooperate with suppliers, contractors, developers and other project partners to help them realize the benefits of such systems and help all parties to collectively work to reduce the upfront cost and lead-time associated with prefabricated systems, resulting in extended value of the final product for both clients and end-users.

Conclusions

We constructed a Hotelling model that includes the market share function, product price function, and profit function of duopoly building developers. Different strategy combinations and their income matrix were analyzed to understand the strategy selection, income matrix strategies, market share, optimal price, and maximum profit of duopoly building developers.

This paper mainly discussed the short-term equilibrium problem of the prefabricated building market at the initial stage. The main characteristics of this stage is limited number of large companies dominating the market, incomplete market infrastructure, and lack of supporting industries. With the increase of the market demand and the expansion of the market size, more and more enterprises will participate in the prefabricated building development, resulting in the industrial structure and organizational mode change. Therefore, it is necessary to establish a more practical model based on the real situation of the prefabricated building market. In addition, the decision to manufacture the prefabricated component in house (in case the construction company has acquired the facilities, technology, knowledge and skills to do so) or to outsource it will result in different transaction costs for the large contractor, which could be further explored in the future. Last, in light of our uniquely developed approach, in the near future, we may also identify and study the specific factors affecting consumers' preference for prefabricated buildings.

Acknowledgements

This research is jointly supported by the Key Research and Development Program of Shaanxi (Grant No. 2021SF-522), the Fundamental Research Funds for the Central Universities (Grant No. 300102239621, and 300102230616) and Science and Technology Planning Program of Xi'an (Grant No. 2021-0014). Their support is gratefully acknowledged. The authors would like to thank the editors, reviewers and experts for their time and constructive comments.

References

Abapour, S., Nazari-Heris, M., Mohammadi-Ivatloo, B., & Mehrdad, T. H. (2018). Game theory approaches for the solution of power system problems: A comprehensive review. *Archives of Computational Methods in Engineering*, *27*, 81–103. https://doi.org/10.1007/s11831-018-9299-7

Abedi, M., Fathi, M. S., Mirasa, A. K., & Rawai, N. M. (2016). Integrated collaborative tools for precast supply chain management. *Scientia Iranica*, *23*, 429–448. https://doi.org/10.24200/sci.2016.2129

Bade, S. (2005). Nash equilibrium in games with incomplete preferences. *Economic Theory*, *26*(2), 309–332. https://doi.org/10.1007/s00199-004-0541-1

Blismas, N., & Wakefield, R. (2008). Drivers, constraints and the future of off-site manufacture in Australia. *Construction Innovation*, *9*(1), 72–83. https://doi.org/10.1108/14714170910931552

Bockova, K. H., Slavikova, G., & Porubcanova, D. (2016). Game theory as a tool of conflict and cooperation solution between intelligent rational decision-makers in project management. *International Journal of Economic Perspectives*, *10*(4), 147–156.

Central Committee of the Communist Party of China and the State Council. (2016). *Several opinions on further strengthening the management of urban planning and construction*. http://www.gov.cn/zhengce/2016-02/21/content_5044367.htm

Chen, Y., Okudan, G. E., & Riley, D. R. (2010). Decision support for construction method selection in concrete buildings: Prefabrication adoption and optimization. *Automation in Construction*, *19*(6), 665–675. https://doi.org/10.1016/j.autcon.2010.02.011

Cheng, B., Wei, Y., Zhang, W., Zhou, X., Chen, H., Huang, L., Huang, J., & Kang, X. (2020). Evolutionary game simulation on government incentive strategies of prefabricated construction: a system dynamics approach. *Complexity*, 8861146. https://doi.org/10.1155/2020/8861146

Cho, C.-Y., Kwon, S., Shin, T.-H., Chin, S., & Kim, Y.-S. (2011). A development of next generation intelligent construction liftcar toolkit for vertical material movement management. *Automation in Construction*, *20*(1), 14–27. https://doi.org/10.1016/j.autcon.2010.07.008

Cohen, M. A., & Vandenbergh, M. P. (2012). The potential role of carbon labeling in a green economy. *Energy Economics*, *34*(Supplement 1), S53–S63. https://doi.org/10.1016/j.eneco.2012.08.032

d'Aspremont, C., Gabszewicz, J. J., & Thisse, J. F. (1979). On Hotelling's "Stability in Competition". *Econometrica*, *47*, 1145–1150. https://doi.org/10.2307/1911955

Demiralp, G., Guven, G., & Ergen, E. (2012). Analyzing the benefits of RFID technology for cost sharing in construction supply chains: a case study on prefabricated precast components. *Automation in Construction*, *24*, 120–129. https://doi.org/10.1016/j.autneu.2012.02.005

Economides, N. (1986). Minimal and maximal product differentiation in Hotelling's duopoly. *Economics Letters*, *21*(1), 67–71. https://doi.org/10.1016/0165-1765(86)90124-2

Economides, N. (1999). Quality choice and vertical integration. *International Journal of Industrial Organization*, *17*(6), 903–914. https://doi.org/10.1016/S0167-7187(97)00063-5

Fudenberg, D., & Levine, D. K. (2016). Whither game theory? Towards a theory of learning in games. *The Journal of Economic Perspectives*, *30*(4), 151–170. https://doi.org/10.1257/jep.30.4.151

Gan, S.-S., Pujawan, I. N., & Widodo, B. (2017). Pricing decision for new and remanufactured product in a closed-loop supply chain with separate sales-channel. *International Journal of Production Economics*, *190*, 120–132. https://doi.org/10.1016/j.ijpe.2016.08.016

Gorbachuk, V. M. (2007). An asymmetric cournot-nash equilibrium under uncertainty as a generalized cournot-stackelberg-nash equilibrium. *Cybernetics and Systems Analysis*, *43*(4), 471. https://doi.org/10.1007/s10559-007-0073-3

Goulding, J. S., Rahimian, F. P., Arif, M., & Sharp, M. D. (2015). New offsite production and business models in construction: priorities for the future research agenda. *Architectural Engineering and Design Management*, *11*(3/4), 163–184. https://doi.org/10.1080/17452007.2014.891501

Greiner, D., Periaux, J., Emperador, J. M., Galván, B., & Winter, G. (2017). Game theory based evolutionary algorithms: A review with nash applications in structural engineering optimization problems. *Archives of Computational Methods in Engineering*, *24*(4), 703–750. https://doi.org/10.1007/s11831-016-9187-y

Guo, J. H., Li, B. Y., & Ni, M. (2013). Remanufacturing into decision making under WTP differential. *China Science of Management*, *21*(01), 149–156. https://doi.org/10.16381/j.cnki.issn1003-207x.2013.01.021

Han, Y. H., & Wang, L. F. (2018). Identifying barriers to off-site construction using grey DEMATEL approach: case of China. *Journal of Civil Engineering and Management*, *24*(5), 364–377. https://doi.org/10.3846/jcem.2018.5181

Han, Y., Skibniewski M., & Wang L. (2017). A market equilibrium supply chain model for supporting self-Manufacturing or outsourcing decisions in prefabricated construction. *Sustainability*, *9*(11), 2069. https://doi.org/10.3390/su9112069

Harter, J. F. R. (1996). When technology and preferences differ in Hotelling's competition. *Journal of Economics*, *22*(2), 97–100.

He, L. L., & Yuan, H. P. (2019). A study on the decision making of recycled manufacturing materials enterprises considering consumer perception of quality. *Industrial Engineering and Management*, *1*, 19. https://doi.org/10.19495/j.cnki.1007-5429.2019.01.019

Hernandez, M. A. (2010). Nonlinear pricing and competition intensity in a Hotelling-type model with discrete product and consumer types. *Economics Letters*, *110*(3), 174–177. https://doi.org/10.1016/j.econlet.2010.11.031

Hotelling, H. (1929). Stability in competition. *Economic Journal*, *39*, 41–57. https://doi.org/10.2307/2224214

Hüttel, A., Ziesemer, F., Peyer, M., & Balderjahn, I. (2018). To purchase or not? Why consumers make economically (non-)sustainable consumption choices. *Journal of Cleaner Production*, *174*, 827–836. https://doi.org/10.1016/j.jclepro.2017.11.019

Ismail, Z.-A. (2020). Maintenance management practices for green building projects: towards hybrid BIM system. *Smart and Sustainable Built Environment*. https://doi.org/10.1108/SASBE-03-2019-0029

Koklic, M. K., & Vida, I. (2011). Consumer strategic decision making and choice process: prefabricated house purchase. *International Journal of Consumer Studies*, *35*(6), 634–643. https://doi.org/10.1111/j.1470-6431.2010.00953.x

Kong, L. L., Li, H., Luo, H. B., et al. (2018). Sustainable performance of just-in-time (JIT) management in time-dependent batch delivery scheduling of precast construction. *Journal of Cleaner Production*, *193*, 684–701. https://doi.org/10.1016/j.jclepro.2018.05.037

Korolovych, O., Chabaniuk, O., Ostapiuk, N., Kotviakovskyi, Y., & Gut, N. (2019). Effective decisions for individualized assessment and minimization of the risk of unfriendly takeover of enterprises: The features of the game theory application. *Problems and Perspectives in Management*, *17*(1), 370–379. https://doi.org/10.21511/ppm.17(1).2019.32

Kumar, V., Hundal, B. S., & Kaur, K. (2019). Factors affecting consumer buying behaviour of solar water pumping system. *Smart and Sustainable Built Environment*, *8*(4), 351–364. https://doi.org/10.1108/SASBE-10-2018-0052

Kumar, V., Syan, A. S., & Kaur, K. (2020). A structural equation modeling analysis of factors driving customer purchase intention towards solar water heater. *Smart and Sustainable Built Environment*. https://doi.org/10.1108/SASBE-05-2020-0069

Li, Y. G., Qiu, K. N., Wei, Y. H., & Zeng, T. (2014a). Study of digital lean construction platform for precast components. In *Proceedings of 2014 International Conference on Computing in Civil and Building Engineering* (pp. 480–487), Orlando, Florida, United States. https://doi.org/10.1061/9780784413616.060

Li, Z., Shen, G. Q., & Xue, X. (2014b). Critical review of the research on the management of prefabricated construction. *Habitat International*, *43*, 240–249. https://doi.org/10.1016/j.habitatint.2014.04.001

Li, C. Z., Xue, F., Li, X., Hong, J., & Shen, G. Q. (2018). An Internet of Things-enabled BIM platform for on-site assembly services in prefabricated construction. *Automation in Construction*, *89*, 146–161. https://doi.org/10.1016/j.autcon.2018.01.001

Liu, M. X., & Wang, J. N. (2017). Research on the road map for the progressive promotion of prefabricated building zoning. *China Engineering & Consulting*, *9*, 44–49. https://doi.org/10.3969/j.issn.1006-9607.2017.09.019

Love, P. E. D., Irani, Z., & Edwards, D. J. (2004). A seamless supply chain management model for construction. *Supply Chain Management*, *9*(1), 43–56. https://doi.org/10.1108/13598540410517575

Mao, C., Shen, Q., Shen, L., & Tang, L. (2013). Comparative study of greenhouse gas emissions between off-site prefabrication and conventional construction methods: Two case studies of residential projects. *Energy and Building*, *66*(1), 165–176. https://doi.org/10.1016/j.enbuild.2013.07.033

Maniatis, P. (2016). Investigating factors influencing consumer decision-making while choosing green products. *Journal of Cleaner Production*, *132*, 215–228. https://doi.org/10.1016/j.jclepro.2015.02.067

Ng, S. T., Fang, Y., & Skitmore, R. M. (2008). Negotiation of on-site buffer stocks: A fuzzy non-structural fuzzy decision support system approach. *Construction Innovation*, *8*(3), 202–217. https://doi.org/10.1108/14714170810888967

Nguyen, B. N., London, K., & Zhang, P. (2021). Stakeholder relationships in off-site construction: A systematic literature review. *Smart and Sustainable Built Environment*. https://doi.org/10.1108/SASBE-11-2020-0169

Nie, J. J., & Deng, D. F. (2014). Effects of remanufacturing product quality on recovery channel in closed-loop supply chain. *Industrial Engineering and Management*, *19*, 1–7. https://doi.org/10.19495/j.cnki.1007-5429.2014.01.001

Osobajo, O. A., Oke, A., Omotayo, T., & Obi, L. I. (2021). A systematic review of circular economy research in the construction industry. *Smart and Sustainable Built Environment*. https://doi.org/10.1108/SASBE-04-2020-0034

Ozaki, R., & Sevastyanova, K. (2011). Going hybrid: An analysis of consumer purchase motivations. *Energy Policy*, *39*(5), 2217–2227. https://doi.org/10.1016/j.enpol.2010.04.024

Pan, W., Gibb, A. G. F., & Dainty, A. R. J. (2007). Perspectives of UK housebuilders on the use of offsite modern methods of construction. *Construction Management and Economics*, *25*(2), 183–194. https://doi.org/10.1080/01446190600827058

Pan, W., Gibb, A. G. F., & Dainty, A. R. J. (2008). Leading UK housebuilders' utilization of offsite construction methods. *Building Research & Information*, *36*(1), 56–67. https://doi.org/10.1080/09613210701204013

Peleckis, K. (2015). The use of game theory for making rational decisions in business negotiations: A conceptual model. *Entrepreneurial Business and Economics Review*, *3*(4), 105–121. https://doi.org/10.15678/EBER.2015.030407

Polat, G. (2010). Precast concrete systems in developing vs. industrialized countries. *Journal of Civil Engineering and Management*, *16*, 85–94. https://doi.org/10.3846/jcem.2010.08

Rahimian, F. P., Goulding, J., Akintoye, A., & Kolo, S. (2017). Review of motivations, success factors, and barriers to the adoption of offsite manufacturing in Nigeria. *Procedia Engineering*, *196*, 512–519. https://doi.org/10.1016/j.proeng.2017.07.232

Samaranayake, P., & Toncich, D. (2007). Integration of production planning, project management and logistics systems for supply chain management. *International Journal of Production Research*, *45*(22), 5417–5447. https://doi.org/10.1080/00207540600810077

Samsura, A. A., & Erwin, D. K. (2012). Negotiating land and property development: A game theoretical approach to value capturing. *Journal of European Real Estate Research*, *5*(1), 48–65. https://doi.org/10.1108/17539261211216003

Samuelson, L. (2016). Game theory in economics and beyond. *The Journal of Economic Perspectives*, *30*(4), 107–130. https://doi.org/10.1257/jep.30.4.107

Seyfang, G. (2010). Community action for sustainable housing: Building a low-carbon future. *Energy Policy*, *38*(12), 7624–7633. https://doi.org/10.1016/j.enpol.2009.10.027

Shi, X. X., Zhu, J. B., & Sheng, Z. H. (2015). Research on supplier cooperation mechanism of key components in major engineering. *Soft Science*, *29*(11), 124–129. https://doi.org/10.13956/j.ss.1001-8409.2015.11.27

Tabuchi, T., & Thisse, T. F. (1995). Asymmetric equilibrium in spatial competition. *International Journal of Industrial Organization*, *13*(2), 213–227. https://doi.org/10.1016/0167-7187(94)00449-C

Tennant, S., & Fernie, S. (2014). Theory to practice: A typology of supply chain management in construction. *International Journal of Construction Management*, *14*(1), 56–66. https://doi.org/10.1080/15623599.2013.875268

Trappey, A. J. C., Trappey, C. V., & Ni, W. (2013). A multi-agent collaborative maintenance platform applying game theory negotiation strategies. *Journal of Intelligent Manufacturing*, *24*(3), 613–623. https://doi.org/10.1007/s10845-011-0606-5

Wang, Y. C., Huscroft, J. R., Hazen, B. T., & Zhang, M. Y. (2018). Green information, green certification and consumer perceptions of remanufactured automobile parts. *Resources, Conservation and Recycling*, *128*, 187–196. https://doi.org/10.1016/j.resconrec.2016.07.015

Wu, H. J., Mao, C., & Liu, G. W. (2015). Market expectations of government's measures to promote off-site construction in mainland China: developers' perspective. In *Proceedings of the 19th International Symposium on Advancement of Construction Management and Real Estate* (pp. 1053–1063). Springer.

Yan, D. J., Zeng, W., & Wang H. W. (2017). Analysis on incentive mechanism of major engineering supplier cultivation under risk aversion. *Journal of Systems Engineering*, *32*(3), 325–334. https://doi.org/10.13383/j.cnki.jse.2017.03.004

Zhai, X. L., Reed, R., & Mills, A. (2014). Factors impeding the offsite production of housing construction in China: an investigation of current practice. *Construction Management and Economics*, *32*(1–2), 40–52. https://doi.org/10.1080/01446193.2013.787491

Zhang, X., & Skitmore, M. (2011). Industrialized housing in China: a coin with two sides. *International Journal of Strategic Property Management*, *16*, 143–157. https://doi.org/10.3846/1648715X.2011.638945

Zhi, Y., Hamilton, P. B., Wang, X., Zhang, Z., & Liang, L. (2018). Game theory analysis of the virtual water strategy. *Water Resources Management*, *32*(14), 4747–4761. https://doi.org/10.1007/s11269-018-2081-7

Zhou, F., Lim, M.K., He, Y., & Pratap, S. (2020). What attracts vehicle consumers' buying: A Saaty scale-based VIKOR (SSC-VIKOR) approach from after-sales textual perspective? *Industrial Management & Data Systems*, *120*(1), 57–78. https://doi.org/10.1108/IMDS-01-2019-0034

APPENDIX

Summary of Notations

Notation	Meaning	Notation	Meaning
π_s^z	Profit of Component Supplier S under self-manufacturing decision	π_s^w	Profit of Component Supplier S under outsourcing decision
π_A^z	Profit of Contractor A under self-manufacturing decision	π_A^w	Profit of Contractor A under outsourcing decision
π_B^z	Profit of Contractor B under self-manufacturing decision	π_B^z	Profit of Contractor B under outsourcing decision
q_A	Production quantity of Contractor A	a	Market size
q_B	Production quantity of Contractor B	p	Market equilibrium price, $p = a - q_A - q_B$
C_A	Assembly cost of Contractor A	C_S	Unit production cost of Component Supplier S
C_B	Assembly cost of Contractor B	C_Z	Unit self-manufacturing cost of Contractor A
P_z	Unit purchase price of Contractor B under self-manufacturing decision	P_i^w	Unit purchase price of Contractor A and B under outsourcing decision, $i = A, B$