Research Article

Evolutionary Game Analysis of Green Building Development Dynamic System under Government Regulation: From the Perspective of the Contractor

Xiangjun Li

School of Management Engineering, Shandong Jianzhu University, Jinan 250101, China

Correspondence should be addressed to Xiangjun Li; xiangjun_li@sdjzu.edu.cn

Received 7 September 2022; Accepted 27 September 2022; Published 12 October 2022

Academic Editor: Lianhui Li

Copyright © 2022 Xiangjun Li. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

To speed up the development of green buildings (GB) and meet the requirements of low energy consumption, low carbon dioxide emissions, and green sustainable development, the key is to build a high-efficient green building dynamic system (GBDS). The government, the developer, and the contractor are the main power of GB promotion, and they are the main participants of GBDS. This paper aims to study how to improve the motivation of contractors’ investment and participation in GB under the government regulation measures, to make up for the gap of research on the contractor’s dynamic mechanism in the GBDS. In the research, evolutionary game theory was applied to build a dynamic model of the evolutionary game among the government, the developer, and the contractor, and the evolutionary laws and stability strategies of their game behaviors were analyzed. The research results show that the contractor’s motivation of building GBs depends on the sum of receipts after the mix of income from construction and government rewards and penalties. The higher the sum of receipts is, the more stable the contractor’s decision to participate in GBs is. When the government gives better incentive measures to the contractor, it is easier for the government, the developer, and the contractor to form an unanimous decision on the GB strategy, so the development dynamic system of GB is more stable.

1. Introduction

The direct impact of GBs on reducing energy consumption and carbon dioxide emissions has been widely recognized [1]. As a strategy to promote green, energy-saving, and the sustainable development of the construction industry [2], GB is not only recognized by academics engaged in theoretical research, but also welcomed and respected by the governments around the world. GB emphasizes the use of sustainable building technologies, materials, and equipment [3]. Compared with traditional buildings, GBs can be constructed through more technical improvements, such as the use of clean energy, material substitution, design iterations, energy efficiency modeling, and complex simulations, so as to achieve sustainability goals [4]. For the technical improvement and application of GB, not only the input and efforts of the contractor, but also the support of the developers and the cooperation of the designer are needed to break the technical barriers [5]. This means that the successful implementation of GB is the result of the efforts of all stakeholders. Through the discussion of failure cases, the differences of stakeholders’ values and their complex interactions will lead to obstacles in the implementation of GB [6, 7]. The interests of different stakeholders are heterogeneous, and they are interdependent with competition and cooperation [8]. Therefore, it is worth studying to build the dynamic system of GB development, balance the economic relationship between stakeholders, and promote the sustainable and healthy development of GB.

Historical experience has proved that the external force is an important agent to cause or accelerate industrial change, just as severe environmental pressure leads to the proposal of GB [9]. Government compulsion and economic incentive are considered to be the most important external motivation of GB promotion [10–12].
compulsion is reflected in the green building certification and evaluation standards issued in succession [13, 14]. Economic incentives are also implemented by the government, including laws and regulations, policy, and green building certification, and it is mainly for developers [15, 16]. The contractor participates in the developer’s GB plan and plays an irreplaceable role in the promotion of GB, but from the perspective of government economic incentives, the additional work required by the GB plan has almost no economic return [17]. The reason why the incentives for the contractor have not yet been discussed is that the contractor is still regarded as a passive party in GB construction, ignoring the value and significance of the contractor in promoting GBs [18]. Neglecting the value and role of contractors among stakeholders is not conducive to achieving the sustainability expectation of GB through professional and technical innovation [19], but also hinders the improvement of the performance level and functional quality of GB [20–23]. Therefore, the contractor is an indispensable part of the GBDS.

In this paper, the government, the developer, and the contractor of engineering projects are the main power of GB promotion, and they are the main participants of GBDS. Different from previous studies, this paper aims to study how to improve the motivation of contractors’ investment and participation in GB under the government regulation measures, to make up for the gap of research on the contractor’s dynamic mechanism in the GBDS. The research results will help to mobilize the enthusiasm and initiative of contractors to participate in the GB development plan and improve the incentive and restraint mechanism for the government to promote the green building development strategy. In the research, the evolutionary game theory was adopted to build a tripartite evolutionary game model among the government, the developer, and the contractor, and the behavioral strategy evolution of the participating actors in the GBDS was studied. This study is not only a reference to existing results, but also an extension and application of related theories such as evolutionary game theory, government regulation theory, and green building theory.

2. Literature Review

2.1. Government Regulation Measures of GB. Although GB has been widely valued, there are still many obstacles in its implementation. In the previous research, the factors affecting the implementation of GB such as high costs, lack of knowledge, and awareness of sustainable construction were listed [24]. The main obstacle to these factors is higher costs. Besides, many studies confirmed that the costs of GBs are much higher than those of traditional buildings. Kim et al. conducted a comprehensive cost comparison analysis of residential engineering projects [25]. The results of their research showed that, compared with traditional buildings, the GB systems with more energy-saving appliances and equipment have increased the construction cost of the project by 10.77%. Bartlett and Howard study showed that project construction costs of energy-saving and environment-friendly buildings were 5% to 15% higher than those of ordinary buildings [26]. The research data of Lapinski et al. showed that the installation of sustainable building equipment such as photovoltaics in GBs increased the delivery cost of GB projects [27]. In the course of promoting the development of GBs, whether or not more economic benefits can be obtained is the focus of many enterprises. All behaviors and decisions of enterprises are centered around the increase of benefits or income. Economic benefits can be regarded as the main driving factor for the promotion of GBs. Under the circumstances of fierce competition in the global property market, the initial high costs of GBs cause the developer to pause and ponder in the development and investment of GBs [28, 29]. Therefore, under the current situation, multiple incentive sources are needed to accelerate the development of GBs. Among those sources, government incentives and rewards have proved to be a good way to promote GBs [30, 31]. Meanwhile, some other scholars suggested that the government can force the developer and the contractor to construct GBs by setting standards, supervision, and enforcement [32, 33]. These views are consistent in understanding the necessity of using external incentive and constraint mechanism to promote the development of GB and are defined as the regulatory mechanism of governments.

The government regulation measures to promote GB summarized in the current research include law enforcement, economic incentives, and green certification promotion. Law and regulation drive means that the government promotes the investment and development of GBs by formulating and enacting laws and regulations related to mandatory GBs [34]. Economic incentive drive refers to the government’s use of various financial incentives [12, 35], such as direct appropriations, tax incentives, financial subsidies, rebates, and discount development administrative charges, so as to encourage the developer to actively invest and develop GBs. GB certification drive means that the government or related industry associations design and develop a scientific and comprehensive evaluation index system and a sound evaluation mechanism, which plays a guiding and standardizing role in the evaluation, construction, and implementation of GBs [36]. It also can attract the consumer’s attention to certified GBs and enhance the influence and status of GBs in the market [37, 38].

2.2. Green Building Dynamic System. The definition of GB has a wide range of connotations, including design and construction, energy and resource utilization, and environment and operation management [16]. Society, government, developers, designers, contractors, material and equipment manufacturers and suppliers, as well as home buyers can promote or hinder the promotion of GB [39]. However, the relationship between the above parties is too complex to be studied in an independent system [40]. In the research of GB’s driving forces, it is mainly static research from a one-sided or multi-party perspective; while dynamic research is usually conducted from the perspective of
bilateral cooperation, there is no dynamic research from the perspective of multi-party cooperation. Static research refers to the research based on questionnaire survey and interview [16, 39, 40], and it shows that high costs of the developer are the most serious obstacle to the promotion of GB [29, 41], and effective government supervision is the most effective measure to promote the popularization of GB [39]. Eliminating the factors restricting the application of green construction technology [42], such as the ability of project manager, coordination between the designer and the contractor, and designer support [43], can reduce the initial cost of GBs. The application of green construction technology can not only reduce the waste of nonrenewable resources [44], but also help to realize the best GB and increase its added value [45]. However, static research lacks analysis of behavior choice and strategic decision in the process of stakeholder cooperation.

The dynamic research in this paper is based on the dynamic theory, which studies the behavior choice and strategy decision-making of the participants over time. The dynamic research on the driving force of GB is mainly based on the evolutionary game method from two aspects. For example, Fan and Hui studied the interrelationship between the government and the developer through the evolutionary game method and proposed that the price premium, the degree of government incentives for green buildings, and the cost bearing capacity of developers are the critical factors for the decision-making of main participants [46]. Zhu et al. studied the evolutionary game problems of green construction behavior between the main contractor and the subcontractor in large-scale projects and proposed that there is an optimal subsidy allocation coefficient between the main contractor and the subcontractor, which can minimize the total probability of opportunistic behavior of the participants [1]. The dynamic research from the perspective of any two parties cannot cover all the main stakeholders.

The complexity of GB project delivery process needs to be realized through the joint efforts and sincere coordination of developers, designers, contractors, and other stakeholders [2]. According to the conclusion of static research, under the premise that the design is the contractor’s responsibility, this paper takes the government, the developer, and the contractor as the main stakeholders to build the GBDS. The GBDS is the system composed of the main stakeholders involved in the project that affect the promotion of GB, and it is the dynamic source to promote the development of GBs. In the system, the behavior choice of each member is influenced and restricted by other members.

2.3. Evolutionary Game Theory. Evolutionary game is a decision-making method based on dynamic theory, which is suitable for the study of cooperative behavior with conflict of interest. It uses mathematical models to analyze and judge the behavior choices and decisions of participants over time [46]. Evolutionary game theory is increasingly used in the research of government incentive and constraint mechanism and enterprise strategic management. For example, Zhao et al. used the evolutionary game model to study the potential reaction of main body to the implementation of incentive policies with regard to carbon emission reduction labeling plan, indicating that both direct subsidies and tax preferences have a positive impact on the implementation of carbon emission reduction labeling plan [47]. Fan et al. studied the optimal implementation strategy of government low-carbon subsidy measures, as well as the efficiency and stability of regulation [48]. Miao et al. analyzed optimal combination decision of manufacturer’s production output and product pricing under the carbon tax policy as well as quota and trading plan [49]. The results showed that carbon emission regulations issued by the government can reduce the demand for new products and promote the sales of remanufactured products. Cohen et al. analyzed the impedance to the development and rapidly spreading of GBs in Israel by using the method of game theory and proposed measures to overcome the obstacles [50]. The above research results show that evolutionary game theory can be applied to study the effect of government action on corporate behavior choice. Therefore, GBDS, as a complex system of corporate behavior selection under government regulation measures, can use evolutionary game theory to analyze its stability. Based on stakeholder theory, the relationship between project stakeholders is competition and cooperation [51–53]. The developer is reluctant to develop GBs because of its high costs, and the contractor is also reluctant to choose green construction strategies because of high costs and low benefits [29, 41]. Therefore, the government must actively guide the behavior of the developer and the contractor through positive incentive measures or negative restrictive measures [12, 35]. Influenced by government intervention and guidance, there is a conflict of interest between the government, developers, and contractors. Moreover, the evolution of the system is affected by government regulation measures and participant strategies. Evolutionary game theory can reduce the assumption of rational person and provide a good theoretical tool for the study of GBDS.

3. Research Hypotheses and the Model

The complete life cycle of GB project starts from investment decision, through engineering project design, then the construction process, and finally into project operation. As shown in Figure 1, the government is the maker and guide of GB development strategies or development plans, and it affects the decisions of the developer and the contractor through incentives and penalties. From the perspective of the developer, its decision-making and behavior are, respectively, affected by internal and external factors of the green building market. The internal factors include the economic benefits of the company, and the external factors mainly come from the constraints of policies and regulations issued by the government and the pressure of competition in the free market. For contractors in the system, it is affected by the internal factors, like its own economic benefits, as well as the external factors, like the government’s regulatory restrictions and incentive measures, and the competitive pressure of other enterprises in the market. Among the main
stakeholders of GB development and construction, the
developer is responsible for the decision and investment, but
GBs, as a construction product, are the result of the de-
veloper commissioning the contractor to design and con-
struct. Therefore, from the perspective of investment, de-
development, and construction of GBs, the government, the
developer, and the contractor are all major stakeholders. The
interdependence and cooperation between stakeholders
involved in the project are very important for the promotion
of GBs and are an important guarantee for the realization of
energy-saving effects of GBs [1].

In order to build an effective GBDS and promote the
development of GBs, the evolutionary trajectory of the
behavioral strategies of the government, the developer,
and the contractor in the GBDS was studied without loss of
generality. The following hypotheses were made:

Hypothesis 1. The government, the developer, and the
contractor are three game players in the market. Based on
stakeholder theory, government’s incentive, and supervi-
sion, the developers’ investment and the contractors
technology realization constitute the dynamic system of
promoting and realizing GBs [2, 6, 7]. For the three parties,
driven by interests and threatened by opportunism [8, 54],
you have bounded rationality in the process of deregulation
and realization of building.

Hypothesis 2. The government may adopt different strate-
gies due to the influence of its own financial capacity and
governance costs, as well as the pressure of different energy
conservation and environmental protection supervision
indicators [55, 56]. According to the two different measures
of positive guidance and negative restriction, the govern-
ment regulation can be divided into positive and negative
behaviors [30–33]. So, its strategy set is \{developing
green buildings, developing ordinary buildings\}. The
probability of the developer developing GBs is \( y \); its prob-
ability of developing ordinary buildings is \( 1 - y \) and
\( y \in [0, 1] \). In the context of the government’s positive
actions, the government subsidy that the developer can get for
developing GBs is \( H \). If the subsidy has been obtained, but in
the government’s supervision and evaluation, the developer
does not meet the corresponding GB evaluation index, the
government will give the developer the penalty of \( F \), and
\( F > H \).

Based on stakeholder theory, when the objectives and
cooperation strategies of project stakeholders are consistent,
it is conducive to the realization of common interests and
individual interests [51–53]. On the contrary, it is difficult to
guarantee the common interests and individual interests.
Under the premise that the contractor implements a green
construction strategy, when the developer chooses to de-
velop a GB development strategy, its return is \( \sigma_1 \); when
the developer chooses to develop an ordinary building strategy,
its return is \( \sigma'_1 \), and \( \sigma_1 > \sigma'_1 \). In the context of the contractor
implementing a traditional construction strategy, when the
developer chooses to develop a GB strategy, its return is \( \sigma_2 \); when
the developer chooses to develop an ordinary building

\[
\begin{align*}
\sigma_1 &= \text{Return of developing GBs} \\
\sigma'_1 &= \text{Return of developing ordinary buildings} \\
\sigma_2 &= \text{Return of developing ordinary buildings} \\
\sigma'_2 &= \text{Return of developing practical buildings}
\end{align*}
\]

\[z \in [0, 1].\] Negative action means that no subsidy incentive
measures have been taken, but the implementation of project
energy-saving standards is still evaluated, and punitive
measures are taken if the evaluation fails. The government
supervision or third-party supervision entails supervision
costs, which are recorded as \( c \). When the government takes
positive actions, additional benefits can be obtained from
GBs, including local environment improvement, energy
consumption reduction, citizen satisfaction improvement,
and high-efficient local government administration [57, 58],
which are recorded as \( m \); when the government is inactive,
the extra benefits from GBs are less than that under positive
actions, which are recorded as \( n \).

Hypothesis 3. Driven by economic benefits, developers’ GB
investment and development strategies are influenced by
whether the cost of GB can bear [25, 28] and consumers’
purchase intention [59]. So, its strategy set is \{developing
green buildings, developing ordinary buildings\}. The
probability of the developer developing GBs is \( y \); its prob-
ability of developing ordinary buildings is \( 1 - y \) and
\( y \in [0, 1] \). In the context of the government’s positive
actions, the government subsidy that the developer can get for
developing GBs is \( H \). If the subsidy has been obtained, but in
the government’s supervision and evaluation, the developer
does not meet the corresponding GB evaluation index, the
government will give the developer the penalty of \( F \), and
\( F > H \).

Based on stakeholder theory, when the objectives and
cooperation strategies of project stakeholders are consistent,
it is conducive to the realization of common interests and
individual interests [51–53]. On the contrary, it is difficult to
guarantee the common interests and individual interests.
Under the premise that the contractor implements a green
construction strategy, when the developer chooses to de-
velop a GB development strategy, its return is \( \sigma_1 \); when
the developer chooses to develop an ordinary building strategy,
its return is \( \sigma'_1 \), and \( \sigma_1 > \sigma'_1 \). In the context of the contractor
implementing a traditional construction strategy, when the
developer chooses to develop a GB strategy, its return is \( \sigma_2 \); when
the developer chooses to develop an ordinary building

\[
\begin{align*}
\sigma_1 &= \text{Return of developing GBs} \\
\sigma'_1 &= \text{Return of developing ordinary buildings} \\
\sigma_2 &= \text{Return of developing ordinary buildings} \\
\sigma'_2 &= \text{Return of developing practical buildings}
\end{align*}
\]

\[z \in [0, 1].\] Negative action means that no subsidy incentive
measures have been taken, but the implementation of project
energy-saving standards is still evaluated, and punitive
measures are taken if the evaluation fails. The government
supervision or third-party supervision entails supervision
costs, which are recorded as \( c \). When the government takes
positive actions, additional benefits can be obtained from
GBs, including local environment improvement, energy
consumption reduction, citizen satisfaction improvement,
and high-efficient local government administration [57, 58],
which are recorded as \( m \); when the government is inactive,
the extra benefits from GBs are less than that under positive
actions, which are recorded as \( n \).

Hypothesis 3. Driven by economic benefits, developers’ GB
investment and development strategies are influenced by
whether the cost of GB can bear [25, 28] and consumers’
purchase intention [59]. So, its strategy set is \{developing
green buildings, developing ordinary buildings\}. The
probability of the developer developing GBs is \( y \); its prob-
ability of developing ordinary buildings is \( 1 - y \) and
\( y \in [0, 1] \). In the context of the government’s positive
actions, the government subsidy that the developer can get for
developing GBs is \( H \). If the subsidy has been obtained, but in
the government’s supervision and evaluation, the developer
does not meet the corresponding GB evaluation index, the
government will give the developer the penalty of \( F \), and
\( F > H \).

Based on stakeholder theory, when the objectives and
cooperation strategies of project stakeholders are consistent,
it is conducive to the realization of common interests and
individual interests [51–53]. On the contrary, it is difficult to
guarantee the common interests and individual interests.
Under the premise that the contractor implements a green
construction strategy, when the developer chooses to de-
velop a GB development strategy, its return is \( \sigma_1 \); when
the developer chooses to develop an ordinary building strategy,
its return is \( \sigma'_1 \), and \( \sigma_1 > \sigma'_1 \). In the context of the contractor
implementing a traditional construction strategy, when the
developer chooses to develop a GB strategy, its return is \( \sigma_2 \); when
the developer chooses to develop an ordinary building

\[
\begin{align*}
\sigma_1 &= \text{Return of developing GBs} \\
\sigma'_1 &= \text{Return of developing ordinary buildings} \\
\sigma_2 &= \text{Return of developing ordinary buildings} \\
\sigma'_2 &= \text{Return of developing practical buildings}
\end{align*}
\]

\[z \in [0, 1].\] Negative action means that no subsidy incentive
measures have been taken, but the implementation of project
energy-saving standards is still evaluated, and punitive
measures are taken if the evaluation fails. The government
supervision or third-party supervision entails supervision
costs, which are recorded as \( c \). When the government takes
positive actions, additional benefits can be obtained from
GBs, including local environment improvement, energy
consumption reduction, citizen satisfaction improvement,
and high-efficient local government administration [57, 58],
which are recorded as \( m \); when the government is inactive,
the extra benefits from GBs are less than that under positive
actions, which are recorded as \( n \).
strategy, its return is $\sigma'_1$, and $\sigma'_2 > \sigma_2$. Among them, $\sigma_1 > \sigma'_1 > \sigma'_2 > \sigma_2$. Hypothesis 4. The contractor is affected by its own GB design technology, construction technology, and cost, so its selectable strategy set is [green construction, traditional construction] [24, 44]. The probability of the contractor choosing green construction is $x$, while the probability of choosing traditional construction is $1 - x$ and $x \in [0, 1]$. In the context of the government’s positive actions, if the contractor obtains the subsidy has been obtained, but in the government’s supervision and evaluation, the contractor does not meet the corresponding green building evaluation index, the government will give the contractor the penalty of $f$, and $f > h$.

Similarly, based on stakeholder theory, the following assumptions can be made [51–53]. In the case where the developer chooses to develop green buildings, when the contractor’s decision is a green construction strategy, its return is $\pi'_1$; when the contractor’s decision is a traditional construction strategy, its return is $\pi'_3$; and $\pi'_1 > \pi'_3$. In the case where the developer chooses to develop ordinary buildings, when the contractor’s decision is a green construction strategy, its return is $\pi'_2$; when the contractor’s decision is a traditional construction strategy, its return is $\pi'_4$, and $\pi'_2 > \pi'_4$. Among them, $\pi_1 > \pi'_1 > \pi'_2 > \pi_2$.

3.1. Evolutionary Game Model of GBDS. In view of the above hypotheses, a three-party game return matrix for the government, the developer, and the contractor in the green building dynamic system is constructed, as shown in Table 1.

When positive actions are taken, the government’s expected returns are

$$f_{D1} = zH + \sigma_2 + x(\sigma_1 - \sigma_2).$$

The developer’s expected returns for developing ordinary buildings are

$$f_{D2} = \sigma'_2 - F + x(\sigma'_1 - \sigma'_2).$$

The developer’s replicated dynamic equation is

$$U (Y) = y(1 - y)[zH + \sigma_2 + x(\sigma_1 - \sigma_2) - \sigma'_2 + F - x(\sigma'_1 - \sigma'_2)]]$$.

The contractor’s expected returns from green construction are

$$f_{C1} = zH + \pi'_2 + y(\pi'_1 - \pi'_2).$$

The contractor’s expected returns from traditional construction are

$$f_{C2} = y(\pi'_1 - \pi'_2) + \pi'_2 - f.$$

The contractor’s replicated dynamic equation is

$$UX = x(1 - x)[zH + \pi'_2 + y(\pi'_1 - \pi'_2) - y(\pi'_1 - \pi'_2) - \pi'_2 + f].$$

$$U (Y) = y(1 - y)[zH + \pi'_1 + z(\sigma_1 - \sigma_2) + \pi'_2 - F - x(\sigma'_1 - \sigma'_2)]$$.

Friedman pointed out that the evolutionary stable equilibrium solution of the replicated dynamic system can be obtained by the local stability analysis of Jacobi matrix of the system [60], so Jacobi matrix of green building replicated dynamic system is shown in equation (11). In the green building replicated dynamic system (equation (10)), if each replicated dynamic equation is set to zero, 9 stable equilibrium points of the GB replicated dynamic system can be obtained. According to the evolutionary game theory [61], the evolutionary stability sets (ESS) of the GB replicated dynamic system that obeys Jacobi matrix eigenvalues are all negative conditions. The eigenvalues of the Jacobi matrix are shown in Table 2.
Table 2: Jacobi matrix eigenvalues of the replicated dynamic system.

| Equilibrium point | Eigenvalue $\lambda_1$ | Eigenvalue $\lambda_2$ | Eigenvalue $\lambda_3$ |
|-------------------|-------------------------|-------------------------|-------------------------|
| $E_1 (0, 0, 0)$   | $\pi_2 - \pi'_1 + f$   | $\sigma_2 - \sigma'_2 + F$ | 0                       |
| $E_2 (0, 0, 1)$   | $h + \pi_2 - \pi'_1 + f$ | $H + \sigma_2 - \sigma'_2 + F$ | 0                       |
| $E_3 (0, 1, 1)$   | $h + \pi_1 - \pi'_1 + f$ | $-H + \sigma_2 - \sigma'_2 + F$ | $-H$                    |
| $E_4 (1, 0, 0)$   | $\pi_1 - \pi'_1 + f$   | $-\sigma_2 + \sigma'_2 - F$ | $h$                     |
| $E_5 (1, 0, 1)$   | $-h - \pi_2 + \pi'_1 + f$ | $-H - \sigma_2 + \sigma'_2 - F$ | $-h$                    |
| $E_6 (1, 1, 0)$   | $-\pi_1 + \pi'_1 - f$   | $-\sigma_2 + \sigma'_2 - F$ | $h - H$                 |
| $E_7 (1, 1, 1)$   | $-h - \pi_1 + \pi'_1 - f$ | $-H - \sigma_2 + \sigma'_2 - F$ | $-h + H$               |
| $E_8 (x^*, y^*, z^*)$ | Saddle point | Unsatisfactory | Stability |

Table 3: Stability of the replicated dynamic system.

| Equilibrium point | $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | Asymptotically stable condition | Stability |
|-------------------|-------------|-------------|-------------|---------------------------------|-----------|
| $E_1 (0, 0, 0)$   | Uncertain  | Uncertain  | 0           | \(\vdash\)                      | Unstable  |
| $E_2 (0, 0, 1)$   | Uncertain  | Uncertain  | 0           | \(\vdash\)                      | Unstable  |
| $E_3 (0, 1, 1)$   | +          | +          | +           | $H + \sigma_2 + F < \sigma'_2$  | Saddle point |
| $E_4 (0, 1, 0)$   | +          | -          | Uncertain   | \(\vdash\)                      | Unstable  |
| $E_5 (1, 0, 0)$   | +          | +          | +           | $\pi_2 + f < \pi'_2$            | Saddle point |
| $E_6 (1, 0, 1)$   | -          | -          | -           | $h + \pi_2 + f < \pi'_2$        | Unstable  |
| $E_7 (1, 1, 0)$   | -          | -          | +           | \(h < H\)                       | Stable    |
| $E_8 (1, 1, 1)$   | -          | -          | +           | \(h > H\)                       | Stable    |

\[f = \begin{bmatrix}
1 - 2x \left[ z h + \pi_2 + y \left( \pi_1 - \pi_2 \right) - y \left( \pi'_1 - \pi'_2 \right) - \pi'_2 + f \right] \\
y \left( 1 - y \right) \left( \sigma_1 - \sigma_2 - \sigma'_1 + \sigma'_2 \right) \\
z \left( 1 - z \right) h
\end{bmatrix}
\begin{bmatrix}
x \left( 1 - x \right) \left( \pi_1 - \pi_2 - \pi'_1 + \pi'_2 \right) \\
\left( 1 - 2y \right) \left[ z H + \sigma_2 + x \left( \sigma_1 - \sigma_2 - \sigma'_1 + F - x \left( \sigma'_1 - \sigma'_2 \right) \right] - z \left( 1 - z \right) H \\
\left( 1 - 2z \right) \left( h x - H y \right)
\end{bmatrix}.

As can be seen from Table 3, except $E_6 (1, 0, 1), E_7 (1, 1, 0),$ and $E_8 (1, 1, 1),$ the other points cannot be determined because whether some of its eigenvalues are positive cannot be determined.

**Case 1.** Without changing the external initial conditions, the stability of the three-party evolutionary game cannot be judged because whether some of its eigenvalues are positive cannot be determined.

**Case 2.** If the external initial conditions change, the following stable evolution strategy can be obtained:

1. If $h + \pi_2 + f > \pi'_2,$ then all the eigenvalues corresponding to the equilibrium point $E_6 (1,0,1)$ are negative; that is, (green construction, developing ordinary buildings, positive government action) is an evolutionary stability strategy.

2. If $h < H,$ all the eigenvalues corresponding to the equilibrium point $E_7 (1,1,0)$ are negative; that is, (green construction, developing green buildings, negative government action) is an evolutionary stability strategy.

3. If $h > H,$ all the eigenvalues corresponding to the equilibrium point $E_8 (1,1,1)$ are negative; that is, (green construction, developing green buildings, positive government action) is an evolutionary stability strategy.

The phase diagram of the model in Case 2 is shown in Figures 2–4.

3.3. GBDS Evolution Simulation. In order to intuitively depict the impact of the government’s positive and negative regulatory measures on the strategy evolution of the
3.4. The Government Adopts Positive Regulation Measures. It is assumed that the government’s economic subsidy for green construction of the contractor is 130, i.e., \( h = 130 \), which only satisfies the constraint condition of \( h + \pi_2 + f > \pi_2' \). The behavior strategy evolution trajectory of the three parties in GBDS is shown in Figure 5.

However, when the government’s economic subsidy for green construction of the contractor is 230, i.e., \( h = 230 \), the constraint conditions of \( h > H \) and \( h + \pi_2 + f > \pi_2' \) are met at the same time. The behavior strategy evolution trajectory of the three parties in GBDS is shown in Figure 6.

When the government adopts positive regulation measures on the developer and the contractor at the same time, i.e., \( H > 0 \), \( h > 0 \), according to the tripartite evolutionary game stability process shown in Figures 5 and 6, it shows that in order to promote their efficiency in GB development and construction, the government takes positive actions such as motivating and punishing the developer and the contractor. If the sum of the contractor’s green construction income \( \pi_2 \) and the government subsidy \( h \) is greater than the difference between the contractor’s ordinary construction income \( \pi_2' \) and the government penalty \( f \), as time goes on, the contractor’s choice of strategy is green construction. Figure 6 shows that when the government adopts positive actions, if the government’s incentive \( h \) for the contractor’s green construction behavior is greater than its incentive \( H \) for the developer’s development of GB behavior, the evolutionary game among the three parties will stabilize at the point of \( E_8 \) (1,1,1); that is, (green construction, developing green buildings, positive government action) is an evolutionary stability strategy. The evolution of these two strategies is consistent with the theoretical analysis. If the incentive and punishment measures taken by the government to the contractor can only make the contractor not suffer economic loss due to the green construction strategy, it can make the contractor tend to choose the green construction strategy. However, it cannot make the developer choose green building strategy. Only when the government’s incentive measures to the contractor can achieve the purpose of reducing the investment of the developer by reducing the cost of the contractor, can the green building strategy selection of the developer and the contractor be consistent.

3.5. The Government Adopts Negative Regulatory Measures. When the government only adopts negative regulation measures, let \( H = 0 \), \( h = 0 \), and only satisfy the evolution stability condition of \( E_7 \). The behavior strategy evolution trajectory of the three parties in GBDS is shown in Figure 7.

When the government takes negative regulation measures on the developer and the contractor, according to the stable process of tripartite evolutionary game shown in Figure 7, we can see that when the government adopts negative actions, the value of the contractor’s income from its traditional construction behavior \( \pi_2' \) minus the government’s penalty \( f \) for the traditional construction behavior is less than the contractor’s income from its green construction behavior \( \pi_2 \); the developer’s return from developing GBs \( \sigma_1 \) is greater than the developer’s return on the development of...
Figure 5: $h=130$ stable process of tripartite evolutionary game.

Figure 6: $h=230$ stable process of tripartite evolutionary game.
ordinary buildings $\sigma_1^\prime$ minus the penalty $F$. As time goes on, the evolutionary game among the three parties will stabilize at the point of $E_7 (1,1,0)$; that is, (green construction, developing green buildings, negative government action) is an evolutionary stability strategy. The above data analysis shows that with a single punishment regulation measure, the developer and the contractor can also reach an agreement on green building strategy choice because of fear of economic losses caused by punishment.

It can be seen that for the contractor, there are two external sources of motivation for its green construction behavior. One is that the government encourages the green construction behavior of the contractor through positive actions, and that the government’s incentives for the contractor are higher than those for the developer can promote the consistency of the developer and the contractor in their strategies of GBs and green construction. The second is that the government takes negative actions on the developer and the contractor’s decisions in GBs and green construction, so the developer and the contractor can only reach an agreement on GB and green construction strategies through economic benefits.

4. Conclusions and Implication

In view of the dynamic system of GB development under the government regulation, this paper discusses the different GB strategy combinations of the developer and the contractor under the government’s positive incentives and negative actions through the evolutionary game analysis among the government, the developer, and the contractor from the perspective of the contractor. Compared with the incentive measures given to the developer, when the government makes better incentive measures for the contractor, it is easier for the three parties to reach an agreement on the GB strategy, and the GBDS is more stable. The government’s positive incentive behavior for the developer and the contractor can achieve better results than those for the developer alone, which is more conducive to the development and promotion of GBs. It shows that the current government only aims at the incentive measures for the developer, which results in that the contractor cannot benefit from the incentive measures and provide a strong promoting force for the development of GB. Therefore, the government needs to directly encourage the contractor to maintain the stability of the GBDS.

Based on the purpose of better promoting the popularization of GBs and building an effective corresponding dynamic system, according to the research conclusions of this paper, the following implications can be obtained: (1) the government usually adopts financial subsidies, tax incentives, and other incentive measures. Keeping the total incentive amount unchanged, when the incentive for the contractor is stronger than that for the developer, it will be more conducive for them to reach an agreement on promoting GB development strategy. The short-term effect of

\[ \begin{align*}
\text{Figure 7: } & H = 0 \ h = 0 \ \text{stable process of tripartite evolutionary game.}
\end{align*} \]
direct incentive is that the contractor chooses green environment-friendly and energy-saving materials and equipment in the project, and the contractor’s costs can be partly shared due to the government’s incentive measures. As a result, the contractor’s profit in the project remains unchanged. If the contractor guarantees the project profit through government incentive, the contract price of the project will not be increased, and the pressure of increasing investment caused by GB can be relieved. The long-term effect is that the government’s direct incentive to the contractor can stimulate and support the latter to make GB technology innovation, which can accelerate the maturity of GB technology and reduce the costs of GB technology. The cost reduction of GB technology can solve the problem of high costs of GB. In the long-term development process, the developer and the contractor can reach an agreement on GB development strategy. (2) When the government takes negative measures such as supervision and punishment, as long as the adverse consequences that the developer and the contractor need to bear are greater than the additional costs in the GB strategy, then the developer and the contractor will turn to the GB strategy. Therefore, it is necessary to strictly implement the national standards of GB through the third party and comprehensively carry out the green construction evaluation mechanism. At the same time, matching economic punishment measures should be implemented to force the developer to develop GBs and the contractor to conduct green construction. The action-forcing measures for contractors to save energy and reduce emissions can enable the EPC contractor to increase the R & D investment in green design, popularize the application of green construction technique, and promote the research and promotion of relevant energy-saving equipment and environmental protection materials. The introduction of third-party methods can reduce the increased expenditure required by the government’s own supervision or expand the scope of management services and improve the efficiency of management services without increasing government expenditure. In the current market environment, if we want to improve the initiative of relevant enterprises to develop GBs and green construction, we must recognize that whether the enterprise has design capability, green construction capability is the basic condition for competition and survival in the long-term market. The government should guide the developer and the contractor to actively participate in the sustainable development of engineering construction through regulations, policies, and market regulation, and clearly convey to the market, enterprises, and consumers that GBs and green construction are a signal of long-term mechanism.

In the research, the evolutionary game model is applied to study all potential strategic combination of the government, the developer, and the contractor in the GBDS. Through the stability analysis of evolutionary game model, the corresponding research conclusions are obtained, which supplement the theory of government regulation and management of GBs. However, only three stakeholders are included in the GBDS. Therefore, the follow-up research is to add other stakeholders to the three parties of the existing research and study the choice and decision-making of all stakeholders in GBDS.

**Data Availability**

The data used to support the findings of this study can be obtained from the author upon request.

**Conflicts of Interest**

The author declares that there are no conflicts of interest regarding the publication of this paper.

**References**

[1] J. Zhu, M. Fang, Q. Shi, P. Wang, and Q. Li, “Contractor cooperation mechanism and evolution of the green supply chain in mega projects,” *Sustainability*, vol. 10, no. 11, p. 4306, 2018.

[2] J. Zhang, H. Li, A. O. Olanike, and L. Bai, “A successful delivery process of green buildings: the project owners’ view, motivation and commitment,” *Renewable Energy*, vol. 138, pp. 651–658, 2019.

[3] E. Ojo, C. Mbowa, and E. T. Akinlabi, “Barriers in implementing green supply chain management in construction industry,” in *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Bali, Indonesia, January 2014.

[4] M. Rekola, T. Mäkeläinen, and T. Häkkinen, “The role of design management in the sustainable building process,” *Architectural Engineering and Design Management*, vol. 8, no. 2, pp. 78–89, 2012.

[5] L. B. Robichaud and V. S. Anantatmula, “Greening project management practices for sustainable construction,” *Journal of Management in Engineering*, vol. 27, no. 1, pp. 48–57, 2011.

[6] K. Stephan and C. C. Menassa, “Modeling the effect of building stakeholder interactions on value perception of sustainable retrofits,” *Journal of Computing in Civil Engineering*, vol. 29, no. 4, 2015.

[7] R. J. Yang, P. X. W. Zou, and J. Wang, “Modelling stakeholder-associated risk networks in green building projects,” *International Journal of Project Management*, vol. 34, no. 1, pp. 66–81, 2016.

[8] M. S. Dator, “Green building regulations: extending mandates to the residential sector,” *Boston College Environmental Affairs Law Review*, vol. 37, pp. 393–424, 2010.

[9] J. Iwaro and A. Mwasha, “The impact of sustainable building envelope design on building sustainability using Integrated Performance Model,” *International Journal of Sustainable Built Environment*, vol. 2, no. 2, pp. 153–171, 2013.

[10] M. R. Pitt, M. Tucker, M. Riley, and J. A. Longden, “Towards sustainable construction: promotion and best practices,” *Construction Innovation*, vol. 9, no. 2, pp. 201–224, 2009.

[11] G. Salvalai, G. Masera, and M. M. Sesana, “Italian local codes for energy efficiency of buildings: theoretical definition and experimental application to a residential case study,” *Renewable and Sustainable Energy Reviews*, vol. 42, pp. 1245–1259, 2015.

[12] E. H. W. Chan, Q. K. Qian, and P. T. I. Lam, “The market for green building in developed Asian cities—the perspectives of building designers,” *Energy Policy*, vol. 37, no. 8, pp. 3061–3070, 2009.
[13] Z. Ding, Z. Fan, V. W. Y. Tam et al., “Green building evaluation system implementation,” Building and Environment, vol. 133, pp. 32–40, 2018.
[14] Y. Zhang, J. Wang, F. Hu, and Y. Wang, “Comparison of evaluation standards for green building in China, Britain, United States,” Renewable and Sustainable Energy Reviews, vol. 66, pp. 262–271, 2017.
[15] B. He, L. Jiao, X. Song, L. Shen, and B. Xiong, “Country review on the main building energy-efficiency policy instrument,” in Proceedings of the 19th International Symposium on Advancement of Construction Management and Real Estate, pp. 379–396, Springer, Berlin, Heidelberg, July 2015.
[16] Z. Yas and K. Jaafer, “Factors influencing the spread of green building projects in the UAE,” Journal of Building Engineering, vol. 27, Article ID 100894, 2020.
[17] J. Zuo, B. Read, S. Pullen, and Q. Shi, “Carbon-neutral commercial building development,” Journal of Management in Engineering, vol. 29, no. 1, pp. 95–102, 2013.
[18] E. Bartlett and N. Howard, “Informing the decision makers on the cost and value of green building,” Building Research & Information, vol. 28, no. 5–6, pp. 315–324, 2000.
[19] A. R. Lapinski, M. J. Horman, and D. R. Riley, “Lean processes for sustainable project delivery,” Journal of Construction Engineering and Management, vol. 132, no. 10, pp. 1083–1091, 2006.

[20] J. Ying Liu, S. Pheng Low, and X. He, “Green practices in the Chinese building industry-drivers and impediments,” Journal of Technology Management in China, vol. 7, no. 1, pp. 50–63, 2012.
[21] H. Wallbaum, L. Silva, C. D. Plessis, R. Cole, A. Hoballah, and S. Kranke, “Motivating stakeholders to deliver change,” in Proceedings of the 3rd International Holcim Forum for Sustainable Construction—Reinventing Construction, Universidad Iberoamericana, Mexico City, North America, December 2010.

[22] Y. Y. Li, P. H. Chen, D. A. S. Chen, C. C. Teo, and R. G. Ding, “Critical project management factors of AEC firms for delivering green building projects in Singapore,” Habitat International, vol. 41, pp. 229–235, 2014.
[23] X. Zhang, A. Platten, and L. Shen, “Green property development practice in China: costs and barriers,” Building and Environment, vol. 46, no. 11, pp. 2153–2160, 2011.
[24] Y. Y. Li, P. H. Chen, D. A. S. Chen, C. C. Teo, and R. G. Ding, “Critical project management factors of AEC firms for delivering green building projects in Singapore,” Journal of Construction Engineering and Management, vol. 137, no. 12, pp. 1153–1163, 2011.
[25] J. Zuo, B. Read, S. Pullen, and Q. Shi, “Carbon-neutral commercial building development,” Journal of Management in Engineering, vol. 29, no. 1, pp. 95–102, 2013.
[26] E. Mills, “Building commissioning: a golden opportunity for reducing energy costs and greenhouse gas emissions in the United States,” Energy Efficiency, vol. 4, no. 2, pp. 145–173, 2011.
[27] W. Wang, S. Zhang, and C. Pasquire, “Factors for the adoption of green building specifications in China,” International Journal of Building Pathology and Adaptation, vol. 36, no. 3, pp. 254–267, 2018.
[28] J. L. Kim, M. Greene, and S. Kim, “Cost comparative analysis of a new green building code for residential project development,” Journal of Construction Engineering and Management, vol. 140, no. 5, Article ID 0504002, 2014.
[29] G. Y. Qi, L. Y. Shen, S. X. Zeng, and O. J. Jorge, “The drivers for contractors’ green innovation: an industry perspective,” Journal of Cleaner Production, vol. 18, no. 14, pp. 1358–1365, 2010.
[30] N. Ghodrati, M. Samari, and M. M. W. Shafieei, “Investigation on government financial incentives to simulate green homes purchase,” World Applied Sciences Journal, vol. 20, no. 6, pp. 832–841, 2012.
[31] S. Pheng Low, S. Gao, and W. Lin Tay, “Comparative study of project management and critical success factors of greening new and existing buildings in Singapore,” Structural Survey, vol. 32, no. 5, pp. 413–433, 2014.

[32] S. Meysam Khoshnava, R. Rostami, M. Ismail, and H. B. Lamli, “Obstacles and drivers in steering IBS towards green and sustainability,” Research Journal of Applied Sciences, Engineering and Technology, vol. 8, no. 14, pp. 1639–1647, 2014.
[33] N. K. M. Isa, A. Alias, and Z. A. Samad, “Sustainability integration into building projects: Malaysian construction stakeholders’ perspectives,” The Macrotheme Review, vol. 3, no. 3, pp. 14–34, 2014.
[34] Q. K. Qian and E. H. W. Chan, “Policies for promoting building energy efficiency (BEE): a comparative study between Mainland China and some developed countries,” The International Journal of Interdisciplinary Social Sciences: Annual Review, vol. 4, no. 5, pp. 45–64, 2009.
[35] H. Meryman and R. Silman, “Sustainable engineering – using specifications to make it happen,” Structural Engineering International, vol. 14, no. 3, pp. 216–219, 2004.
[36] J. Sarkis, L. M. Meade, and A. R. Presley, “Incorporating sustainability into contractor evaluation and team formation in the built environment,” Journal of Cleaner Production, vol. 31, no. 12, pp. 40–53, 2012.
[37] X. Li, V. Strezov, and M. Amati, “A qualitative study of motivation and influences for academic green building developments in Australian universities,” Journal of Green Building, vol. 8, no. 3, pp. 166–183, 2013.
[38] X. Li, Y. Liu, S. Wilkinson, and T. Liu, “Driving forces influencing the uptake of sustainable housing in New Zealand,” Engineering Construction and Architectural Management, vol. 26, no. 1, pp. 46–65, 2019.
[39] J. Yang and Z. Yang, “Critical factors affecting the implementation of sustainable housing in Australia,” Journal of Housing and the Built Environment, vol. 30, no. 2, pp. 275–292, 2015.
[40] J. Liu, Y. S. Liu, and Y. Shi, “Research on the incentive and restraint mechanism of large scale development of green building based on evolutionary game theory,” Science and Technology Management Research, vol. 36, pp. 239–257, 2016.
[41] Y. Kang, C. Kim, H. Son, S. Lee, and C. Lim sawad, “Comparison of preproject planning for green and conventional buildings,” Journal of Construction Engineering and Management, vol. 139, no. 11, Article ID 4013018, 2013.
[42] B. G. Hwang and W. J. Ng, “Project management knowledge and skills for green construction: overcoming challenges,” International Journal of Project Management, vol. 31, no. 2, pp. 272–284, 2013.
[43] C. Koranda, W. K. Chong, C. Kim, J. S. Chou, and C. Kim, “An investigation of the applicability of sustainability and lean concepts to small construction projects,” KSCE Journal of Civil Engineering, vol. 16, no. 5, pp. 699–707, 2012.
[45] M. J. Horman, D. R. Riley, A. R. Lapinski et al., “Delivering green buildings: process improvements for sustainable construction,” *Journal of Green Building*, vol. 1, no. 1, pp. 123–140, 2006.

[46] K. Fan and E. C. M. Hui, “Evolutionary game theory analysis for understanding the decision-making mechanisms of governments and developers on green building incentives,” *Building and Environment*, vol. 179, Article ID 106972, 2020.

[47] R. Zhao, X. Zhou, J. Han, and C. Liu, "For the sustainable performance of the carbon reduction labeling policies under an evolutionary game simulation," *Technological Forecasting and Social Change*, vol. 112, pp. 262–274, 2016.

[48] R. Fan, L. Dong, W. Yang, and J. Sun, "Study on the optimal supervision strategy of government low-carbon subsidy and the corresponding efficiency and stability in the small-world network context," *Journal of Cleaner Production*, vol. 168, pp. 536–550, 2017.

[49] Z. Miao, H. Mao, K. Fu, and Y. Wang, "Remanufacturing with trade-ins under carbon regulations," *Computers & Operations Research*, vol. 89, pp. 253–268, 2018.

[50] C. Cohen, D. Pearlmutter, and M. Schwartz, "Promoting green building in Israel: a game theory-based analysis," *Building and Environment*, vol. 163, Article ID 106227, 2019.

[51] R. Kowalczyk and W. Kucharska, "Corporate social responsibility practices incomes and outcomes: stakeholders’ pressure, culture, employee commitment, corporate reputation, and brand performance. A Polish-German cross-country study,” *Corporate Social Responsibility and Environmental Management*, vol. 27, no. 2, pp. 595–615, 2019.

[52] S. Schaltegger, J. Hörisch, and R. E. Freeman, "Business cases for sustainability: a stakeholder theory perspective," *Organization & Environment*, vol. 32, no. 3, pp. 191–212, 2019.

[53] S. L. Berman and M. E. Johnson-Cramer, "Stakeholder theory: seeing the field through the forest," *Business & Society*, vol. 58, no. 7, pp. 1358–1375, 2019.

[54] P. Lu, L. Qian, Z. Chu, and X. Xu, "Role of opportunism and trust in construction projects: empirical evidence from China," *Journal of Management in Engineering*, vol. 32, no. 2, Article ID 05015007, 2016.

[55] Y. H. Ahn, A. R. Pearce, Y. Wang, and G. Wang, "Drivers and barriers of sustainable design and construction: the perception of green building experience,” *International Journal of Sustainable Building Technology and Urban Development*, vol. 4, no. 1, pp. 35–45, 2013.

[56] X. Huo and A. T. W. Yu, "Analytical review of green building development studies,” *Journal of Green Building*, vol. 12, no. 2, pp. 130–148, 2017.

[57] N. Z. Abidin, "Sustainable construction in Malaysia developers’ awareness,” *Proceedings of World Academy of Science, Engineering and Technology*, vol. 3, pp. 480–487, 2009.

[58] Y. Liu, X. Guo, and F. Hu, "Cost-benefit analysis on green building energy efficiency technology application: a case in China,” *Energy and Buildings*, vol. 82, pp. 37–46, 2014.

[59] B. A. Portnov, T. Trop, A. Svechkina, S. Ofek, S. Akron, and A. Ghermandi, "Factors affecting homebuyers’ willingness to pay green building price premium: evidence from a nationwide survey in Israel,” *Building and Environment*, vol. 137, pp. 280–291, 2018.

[60] D. Friedman, “Evolutionary games in economics,” *Econometrica*, vol. 59, no. 3, pp. 637–666, 1991.

[61] K. Ritzberger and J. W. Weibull, "Evolutionary selection in normal form games,” *Econometrica*, vol. 63, no. 6, pp. 1371–1399, 1995.