Research Article

Strategy of BIM Building Operation and Maintenance Management Based on LV-EG Model

Xiaojian Guo and Huan Hu
Jiangxi University of Science and Technology, Ganzhou, Jiangxi, China

Received 2 June 2020; Accepted 19 September 2020; Published 30 October 2020

Academic Editor: Eric Florentin

Copyright © 2020 Xiaojian Guo and Huan Hu. 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.

BIM technology can make building operation and maintenance (O&M) more efficient. This paper analyzes the evolution game (EG) of the three parties related to the O&M of the building. At the same time, it deduces the diffusion (LV) of the O&M management mode of the market in this condition by finding the evolutionary stable points under different conditions. Through the analysis of relevant conditions, the result of BIM-O&M diffusion is obtained as follows: complete market possession, partial market possession, and exit market three kinds of diffusion results, which provides a reference for the future development of BIM-O&M management in China.

1. Introduction

BIM (Building Information Modeling), as an emerging technology, is booming, which has attracted extensive attention from the construction industry at home and abroad. China’s 13th Five-Year Plan also clearly points out that the integrated application of building information model (BIM) technology in the whole process of planning, engineering survey and design, building operation, and maintenance (O&M) should be accelerated. In the whole life cycle of a construction project, the most expensive consumption is in the O&M phase of the building. According to the survey, the building consumes 30–40% of the world’s energy every year during the O&M period (Sisson et al. [1]). The use of BIM in the O&M phase can greatly reduce the cost of O&M management in the traditional sense. There are many researches on BIM technology abroad; Santos et al. [2] summarized the BIM research literature in recent years and clarified the development status and future prospect of BIM technology. Yilmaz et al. [3] studied eight models of BIM capability assessment and found that BIM-CALM could identify BIM capability of different AEC/FM processes. Ansah et al. [4] conducted an in-depth study and overview of BIM technology to promote the green building assessment plan and filled the research gap of combining BIM and green assessment plan. Poorang et al. [5] studied how integrated project delivery could promote the implementation of BIM technology, and the results showed that if the level of mutual trust among stakeholders could be improved and the obstacle of IPD implementation could be overcome, the application of BIM technology could be promoted well. Gao and Pishdad-Bozorgi [6] systematically review and analyze the latest BIM-related publications, including maintenance and repair, emergency management, energy management, change/relocation management, and safety analysis. The content analysis results show that the research on BIM oriented to O&M is still in its infancy, and the current research is mainly focused on energy management, which provides an abundant theoretical basis for researchers in related industries. At the present stage, the application of BIM in China has been in a critical period, and the application of BIM technology in the construction stage of the project has gradually matured. Zhang et al. [7] reviewed the history of the industrialization of China’s construction industry, then discussed the adoption of BIM in China’s construction industry in recent years and provided a good theoretical basis for modular design and industrial construction and installation under the support of BIM.
Technology, Liu et al. [1][8] defined and classified eight concepts that affect the development of BIM collaboration and divided BIM effect into three dimensions: technology, personnel, and process. The research results provide experience and insights about the collaborative nature of BIM construction projects and emphasize the important role of project team cooperation in BIM project delivery by discussing the understanding of project professionals on BIM implementation in collaborative design and construction and using grounded theory to analyze qualitative data. However, the research and application of BIM-O&M stage in China are still at a relatively low level. To promote the implementation of the application of BIM technology in O&M stage, all parties of the project need to jointly invest on the premise of guaranteeing the maximum benefits of all parties.

The evolution and competition effects of biological competition in ecology have been applied to various disciplines, and it is impossible to completely separate ecological and evolutionary effects. Evolutionary and ecological effects have nested interactions (Peter and Chaitanya [9]; Cressman and Garay [10]). This paper studies the asymmetric evolution game among building owners, operators, and managers, builds a model of the market diffusion applied by BIM technology in the project O&M stage, and finds out the stable point and the optimal state suitable for the current social development and accelerating the application of BIM technology in the O&M stage through the analysis of the two models.

2. BIM Technology O&M Application

Diffusion Mechanism

In the building O&M management, the operation personnel’s choice of using BIM technology is not only influenced by their own development, but also by the asset owners and the management personnel recruited. If the building operator chooses to adopt BIM technology in the O&M of the building, the operator needs to invest a large amount of capital to achieve cost saving and efficient management in the O&M process, which is different from traditional building O&M methods. As the building leaseholder or seller, the building owner will choose to use BIM for O&M management and become a stakeholder. At the same time, the building operator will choose to share part of the cost of BIM-O&M input to gain the reputation of subsequent sales or leasing and greater profits. Operators who choose BIM-O&M technology, meanwhile, will need to recruit professional talents with relevant BIM-O&M technical skills or select the existing staff of BIM technology and BIM-related training of operations management and related management staff whether related technical level will directly on the operators can smoothly in the BIM-O&M management of building using BIM technology. When the above three-way strategy is generated, according to the ecological theory (Antai and Olson [11]; Sharma and Choudhury [12]), “natural selection, survival of the fittest,” and the competition and cooperation of biological populations will lead to the phenomenon of population diffusion, and the number of different populations will keep changing until it is stable. Analogous to BIM operations management, due to the shortage of the existing mode of traditional BIM-O&M management and BIM technology in building operations in the process of technical innovation, building owners, operators, and managers will change their own for BIM-O&M manner, especially as the principal part of the BIM-O&M of the process operators but also need to increase the focus on BIM operations, managing their own operations in the reform, and promote BIM operational technology diffusion in building operation management. However, as the traditional O&M management has been deeply rooted, it will hinder the diffusion of BIM-O&M, and different results will be generated under this background. On one hand, if the three parties of O&M increase their investment in BIM technology, the stakeholders of building O&M find that the greater the investment in BIM-O&M, the greater their own interests, and the whole social group will gradually abandon the traditional O&M management mode, and then choose BIM technology for O&M management, eventially leading to BIM-O&M completely replacing the traditional O&M mode. On the other hand, if the O&M three parties increase the investment related to BIM-O&M, but only some enterprises with considerable scale have the ability to use BIM Technology O&M, and the increased investment in BIM-O&M can not make the operation three parties obtain more benefits than the traditional O&M mode before and then the whole social group will choose not to use BIM Technology for building O&M management and continue to protect. With the traditional O&M management mode, BIM-O&M technology is finally abandoned. The above two situations are absolute. BIM-O&M or traditional O&M will take up a certain proportion in the evolution of real social architecture O&M. They will compete with each other and restrain each other.

To sum up, building owners, operators, and managers interact with each other, and all parties will choose appropriate strategies to maximize their own interests. According to the different strategies of the three parties, it will have different impacts on the diffusion of traditional O&M and BIM-O&M, and only one party will completely occupy the market or both parties will coexist. The specific results are shown in Figure 1. As different participants of building O&M, we need to fully understand the dynamic evolution of O&M process and choose our own strategies in time to ensure the direction and stability of the diffusion of building O&M management technology.

3. Construction and Analysis of BIM-O&M

Game Model (EG) and Diffusion Model (LV)

3.1. Basic Hypothesis and Model Construction of EG for BIM-O&M Promotion. Based on the above three parties of building O&M, the evolutionary game hypothesis is carried out:

Hypothesis 1: Without considering the influence of other factors, the participants in the evolutionary game model are the building owners, operators, and
managers, who are bounded rational and will only choose relevant strategies for their own maximum interests.

Hypothesis 2: All three parties of building O&M have two strategies to choose from. As the owner of the building, he can choose to support the O&M management of BIM technology of the existing building and make appropriate investment, or he can choose not to support it. The strategy set he chooses is (support, not support). Building operators can choose to adopt BIM technology for O&M management of buildings or choose to continue to choose traditional technology for O&M management instead of BIM technology. The strategy set they choose is (adopt, not adopt). As the manager employed by the operator, they can choose to learn BIM technology O&M skills by themselves, that is, they have relevant skills, or choose not to learn by themselves, that is, they do not have the relevant skills. The strategies they choose (possess, not possess).

Hypothesis 3: Different strategies adopted by the three parties of building O&M all require different costs. If the building owner chooses to support the O&M management of BIM technology, the investment cost required is $C_1$. Meanwhile, if the building operator chooses to adopt the O&M management of BIM technology, the O&M investment of BIM technology required is $C_2$. At this time, if the relevant manager hired has BIM technology O&M ability, the salary of the manager needs to be paid is $W$; if not, the training fee needs to be paid is $T$. If the building operator chooses not to adopt BIM technology for O&M management but adopts the traditional O&M management method, due to the asymmetry of information, the building owner will still choose to invest capital, but due to insufficient feedback from the operator, only $C_0$ will be invested, and $0 < C_0 < C_1 < C_2$. If the building manager wants to own the corresponding BIM-O&M management ability, the cost shall be $G$.

Hypothesis 4: Different strategies adopted by the three parties of building O&M can also achieve different benefits. If the owners do not support the operation and management of BIM technology, they will get the income of lease or sales expenses $S_1$. If the owners support it, in addition to the sales and lease income, they will also gain potential industry status and good reputation; it quantifies these benefits, as $S_0'$ and $S_0$. At this time, if the operator does not choose to use BIM but uses the traditional O&M method, the profit that the operator can obtain by using the traditional O&M method is $S_2$, but the building owner will obtain part of the reputation and public praise for supporting the operator to use BIM, which is $S_0'$. If the operator adopts BIM technology for O&M management, the net income the operator gains will be more than the traditional way, the extra part is $S_0'$, and the building owner will get all the fame and status, is $S_0$, for supporting the operator to use BIM, and $0 < S_0' < S_0$. When the operator intends to adopt BIM technology for O&M management, if the manager hired by the operator has BIM-O&M management ability, the profit will be $W$; if not, the profit will be $T$.

According to the above four hypotheses, suppose that the probability of the building owner supporting the O&M using BIM technology is $x$, the probability of the operator adopting BIM for O&M management is $y$, and the probability of the manager having BIM-O&M ability is $z$, and the payoff matrix of the three-party game of building O&M is shown in Table 1.

According to the game strategy selection(Xie [13]) in Table 1, it can be concluded that the expected revenue when the building owner chooses “support” strategy, the expected revenue and the average expected revenue when the building owner chooses “not support” strategy are, respectively, $V_{11}$, $V_{12}$, $V_1$.

\[
V_{11} = yz(S_1 - C_1 + S_0) + y(1 - z)(S_1 - C_1 + S_0) + (1 - y)z(S_1 - C_0 + S_0) + (1 - y)(1 - z)(S_1 - C_0 + S_0)
\]

\[
= y(C_0 - C_1) + S_1 - C_0 + S_0, \quad (1)
\]

\[
V_{12} = yzS_1 + y(1 - z)S_1 + (1 - y)zS_1 + (1 - y)(1 - z)S_1 = yS_0' + S_1, \quad (2)
\]

\[
V_1 = xV_{11} + (1 - x)V_{12}. \quad (3)
\]
The expected return of the operator when choosing “adopt” strategy, the expected return of the operator when choosing “not adopt” strategy and the average expected return are, respectively, $V_{21}, V_{22}, \overline{V}_2$.

\begin{equation}
V_{21} = xz(S_2 - C_2 + C_1 - W + S_3) + x(1 - z)(S_2 - C_2 + C_1 - T + S_3) + (1 - x)z(S_2 - C_2 + S_3 - W) + (1 - x)(1 - z)(S_2 - C_2 + S_3 - T) = xc_1 + z(T - W) + S_2 - C_2 + S_3 - T,
\end{equation}

\begin{equation}
V_{22} = xz(S_2 + C_0 - W) + x(1 - z)(S_2 + C_0) + (1 - x)z(S_2 - W) + (1 - x)(1 - z)S_2 = xc_0 - zW + S_2,
\end{equation}

\begin{equation}
\overline{V}_2 = yV_{21} + (1 - y)V_{22}.
\end{equation}

The expected return of the manager when choosing “possess” strategy, the expected return of the manager when choosing “not possess” strategy, and the average expected return are, respectively, $V_{31}, V_{32}, \overline{V}_3$.

\begin{equation}
V_{31} = xy(W - G) + x(1 - y)(W - G) + (1 - x)y(W - G) + (1 - x)(1 - y)(W - G) = W - G,
\end{equation}

\begin{equation}
V_{32} = xyT + x(1 - y)0 + (1 - x)yT + (1 - x)(1 - y)0 = yT,
\end{equation}

\begin{equation}
\overline{V}_3 = zV_{31} + (1 - z)V_{32}.
\end{equation}

### 3.2. BIM Building O&M Diffusion Model (LV) Construction

When BIM technology comes into being and can be applied to building O&M management, there are two choices of operators in the market, that is, to adopt or not to adopt BIM technology for O&M management. The market shares of the two options are $Y_1$ and $Y_2$ respectively. Lotka-Volterra diffusion model is a collaborative dynamic model proposed by Lotka and Volterra [14] to simulate the population dynamic competitive relationship, which is an extension of the logistic model. According to the collaborative dynamics model of Lotka-Volterra diffusion, the diffusion model of BIM technology in O&M management can be expressed as follows (Cressman et al. [15]):

$$
\begin{align*}
\frac{dy_1}{dt} &= r_1 y_1 \left(1 - \frac{y_1}{K_1} - \lambda_{12} \frac{y_2}{K_2}\right), \\
\frac{dy_2}{dt} &= r_2 y_2 \left(1 - \frac{y_2}{K_2} - \lambda_{21} \frac{y_1}{K_1}\right).
\end{align*}
$$

Including $r_1, r_2$ for society when there is only one way to O&M management of the natural growth rate, $K_1, K_2$, respectively, two kinds of O&M management one of the biggest environmental bearing capacity, $\lambda_{12}$ said the inhibitory effect of maintaining traditional O&M management on the adoption of BIM technology for O&M management, $\lambda_{21}$ said BIM technology is adopted to improve the O&M management of traditional inhibition of O&M management, according to the building owners and managers about the attitudes of BIM-O&M management and the corresponding selection strategy for change, and $\lambda_{12}, \lambda_{21} > 0$, said the new technology and maintained a competitive relationship with the traditional technology. Since the maximum capacity of the market is not easy to determine, let $y_1 = (Y_1/K_1), y_2 = (Y_2/K_2)$ represent the proportion of the two O&M management modes for their respective maximum capacity. Here, equation (10) can be transformed into

$$
\begin{align*}
\frac{dy_1}{dt} &= r_1 y_1 (1 - y_1 - \lambda_{12} y_2), \\
\frac{dy_2}{dt} &= r_2 y_2 (1 - y_2 - \lambda_{21} y_1).
\end{align*}
$$

---

**Table 1: Gain matrix of tripartite game of building O&M.**

| Tripartite game strategy choice | Relevant strategic benefits |
|--------------------------------|-----------------------------|
| (Support, adoption, possess) | $(S_1 - C_1 + S_0, S_2 - C_2 + C_1 - W + S_3, W - G)$ |
| (Support, Adoption, Not possess) | $(S_1 - C_1 + S_0, S_2 + C_0 - W, W - G)$ |
| (Support, not adoption, possess) | $(S_1 - C_0 + S_0, S_2 + C_0 - W, W - G)$ |
| (Support, Not Adoption, Not possess) | $(S_1 + S_0, S_2 - C_2 + C_1 - T, T)$ |
| (Not support, adoption, possess) | $(S_1 + S_0, S_2 - C_2 + C_1 - T + S_3, T)$ |
| (Not support, Adoption, Not possess) | $(S_1 + S_0, S_2 - C_2 + S_3 - W, W - G)$ |
| (Not support, not adoption, possess) | $(S_1, S_2 - W, W - G)$ |
| (Not support, not adoption, not possess) | $(S_1, S_2 - W, W - G)$ |
3.3. Analysis of the Diffusion Stability of BIM Building O&M.
Due to building O&M between the three parties of information asymmetry, building operations parties would know information such as income and investment to choose their own benefit maximization and show the three sides of asymmetric game replication dynamic process. According to the formulas (1)–(9), the building owners, operators, and managers of replicated dynamic equation are (Friedman [16]; Yin et al. [17])

\[
F(x) = \frac{dx}{dt} = x(V_{11} - \nabla_1) = x(1-x)[y(C_0 - C_1 - S_0') + S_0 - C_0],
\]

\[
F(y) = \frac{dy}{dt} = y(V_{21} - \nabla_2) = y(1-y)[x(C_1 - C_0) + zT - C_2 + S_2 - T],
\]

\[
F(z) = \frac{dz}{dt} = z(V_{31} - \nabla_3) = z(1-z)(W - G - yT).
\]

According to the formulas (12)–(14), we can know the dynamic process of strategy selection of three parties in the building O&M under finite rationality. When the strategy becomes stable gradually, the Nash equilibrium point of three parties in the game is found. According to the method proposed by Friedman [18], the evolutionary stability strategy (ESS) of the differential equation system can be obtained from the local stability analysis of the Jacobian matrix of the system. According to the above theory, the Jacobian matrix of the system is

\[
J = \begin{bmatrix}
(1 - 2x)[y(C_0 - C_1 - S_0') + S_0 - C_0] & x(1-x)(C_0 - C_1 - S_0') & 0 \\
y(1-y)(C_1 - C_0) & (1-2y)[x(C_1 - C_0) + zT - C_2 + S_2 - T] & y(1-y)T \\
0 & z(1-z)(-T) & (1-2z)(W - G - yT)
\end{bmatrix}
\]

At the same time, if \( F(x) = F(y) = F(z) = 0 \), the local equilibrium points of the available system are \((1, 1, 1), (1, 1, 0), (1, 0, 1), (0, 1, 1), (0, 1, 0), (0, 1, 0), (0, 0, 1) (0, 0, 0)\). According to the evolutionary game theory, the equilibrium point satisfying that all eigenvalues of the Jacobian matrix are nonpositive is the evolutionary stability point (ESS) of the system. Eight local equilibrium points are, respectively, brought in the Jacobian matrix of the system, and the results are shown in Table 2.

At this time, in order to judge the stable equilibrium state of the BIM-O&M diffusion model, let equation (11) be 0, and the four equilibrium points of the system can be obtained at \((0, 0), (1, 1), (0, 1), \) and \( P((1 - \lambda_{12}/1 - \lambda_{12}\lambda_{21}), (1 - \lambda_{21}/1 - \lambda_{12}\lambda_{21})) \). When BIM-O&M management spreads and gradually stabilizes, that is, it is in a saturated state, there are two curves \( M, N \):

\[
\begin{align*}
M(y_1, y_2) &= 1 - y_1 - \lambda_{12}y_2, \\
N(y_1, y_2) &= 1 - y_2 - \lambda_{21}y_1.
\end{align*}
\]

When \( \lambda \) value is different, the stable result of the O&M market is different. According to the size of \( \lambda \), it can be divided into four situations:

1. When \( \lambda_{12} > 1, 0 < \lambda_{21} < 1 \), it can be seen that the traditional O&M management mode has a strong inhibitory effect on the BIM operation and management mode for the operator, and the BIM operation and management mode has a weak inhibitory effect on the traditional O&M management mode. At this time, both the building owner and the building manager adopt a negative attitude towards BIM-O&M management. The change of the O&M management mode of the building operator is shown in Figure 2.

From the perspective of the change and stability of O&M management in the market, at this time, the traditional O&M mode is flooding the whole market while the BIM-O&M management mode is bleak. In the whole society, building operators will only adopt one O&M management mode of traditional O&M, that is, \( y = 0 \). According to the conditions of the stable point of the evolutionary game and the stable point of the evolutionary game, the stable point of the choice of the three parties of the game is \(( _, 0, _ )\), that is, the choice strategy is \(( xx, not adopted, xx )\); thus, there are four conditions for choice:

1. When the game three parties adopt the strategy of \((0, 0, 0), S_0 < C_0, S_3 < C_2 + T, \) and \( W < G \) can be obtained. At this time, the cost of the operator choosing BIM-O&M investment is far greater than the income, and the building owner's support for the O&M personnel will not make the income of the operator higher than the
When the strategy of the game three parties is (1, 0, 1), \( S_0 > C_0, C_1 + S_1 < C_0 + C_2 \), and \( W > G \) can be obtained. At this time, the cost of the operator choosing BIM-O&M investment is far greater than the benefit, but the building owner’s support for the operator will also increase its own reputation and improve its net benefit. At the same time, the benefit of the manager’s own BIM-O&M management technology is also greater than the cost required by the technology.

(2) When \( \lambda_{21} > 1, 0 < \lambda_{12} < 1 \), it can be seen that for operators, BIM-O&M mode has a strong inhibition on traditional O&M management mode, and traditional O&M management mode has a weak inhibition on BIM operation and management mode. At this time, building owners and building managers take a positive attitude towards BIM-O&M management. The change of O&M management mode of building operators is shown in Figure 3.

From the perspective of the change and stability of O&M management in the market, BIM-O&M mode gradually fills the whole market and completely replaces the traditional O&M management mode. There is only one O&M mode of Bim in the whole society. According to the conditions of the evolutionary game stability point and the evolutionary stability point of the game, the evolutionary stability point of the three parties is (_, 1, _), that is, the selection strategy is (XX, Using, XX), we can see that there are four options:

⑤ When the strategy adopted by the three parties is (1, 1, 1), \( S_0' < S_0 - C_1, S_3 + C_1 > C_0 + C_2 \), and \( W - G > T \). At this time, the income of the operator’s choice of BIM-O&M investment is far greater than the cost, and the building owner’s support for the O&M operator will make its own reputation and other net income the largest, and the income of the manager’s own BIM-O&M management technology is also greater.

⑥ When the strategy adopted by the three parties in the game is (1, 1, 0), \( S_0' < S_0 - C_1, S_3 + C_1 > C_0 + T + C_2 \), and \( W - G < T \) can be obtained. At this time, the profit of the operator choosing BIM-O&M investment is far greater than the cost, and the support of the building owner to the operator will also make the operator the most profitable, but the profit of the manager possessing the corresponding

| Equilibrium point | Eigenvalue 1 | Eigenvalue 2 | Eigenvalue 3 |
|-------------------|-------------|-------------|-------------|
| (1, 1, 1)         | (-1) \((-C_1 - C_0 - C_2 - S_1)\) | (-1) \((-C_1 - C_0 - C_2 - S_3 + S_2)\) | \((-1)(W - G - T)\) |
| (1, 1, 0)         | (-1) \((-C_1 - C_0 - C_2 - S_3)\) | (-1) \((-C_1 - C_0 - C_2 - S_3 - T)\) | \(W - G - T\) |
| (1, 0, 1)         | (-1) \((-C_0 - C_0)\) | (-1) \((-C_1 - C_0 - C_2 + S_3 - T)\) | \(G - W\) |
| (1, 0, 0)         | (-1) \((-C_0 - C_0)\) | (-1) \((-C_1 - C_0 - C_2 + S_3 - T)\) | \(W - G\) |
| (0, 1, 1)         | \(-C_1 - S_0 + S_0\) | (-1) \((-C_2 + S_1)\) | \((-1)(W - G - T)\) |
| (0, 1, 0)         | \(-C_1 - S_0 + S_0\) | (-1) \((-C_2 + S_1 - T)\) | \(W - G - T\) |
| (0, 0, 1)         | \(S_0 - C_0\) | \(-C_2 + S_1\) | \(G - W\) |
| (0, 0, 0)         | \(S_0 - C_0\) | \(-C_2 + S_1 - T\) | \(W - G\) |
technology of BIM-O&M management is less than the profit that does not possess.

⑦ When the strategy adopted by the three parties in the game is \((0, 1, 1)\), \(S_0 > S_0 - C_1\), \(S_3 > C_2\), and \(W - G > T\) can be obtained. At this time, the profit of operators choosing BIM-O&M investment is far greater than the cost, and the profit of managers having BIM-O&M management corresponding technologies is also greater, but the support of building owners to operators will not make the profit brought by their reputation greater than the investment cost.

⑧ When the game three parties adopt the strategy of \((0, 1, 0)\), \(S_0' > S_0 - C_1\), \(S_3 > C_2 + T\), and \(W - G < T\) can be obtained. At this time, the operator chooses BIM-O&M investment, and the income is far greater than the cost. However, the building owner’s support for the O&M operator will not make its income higher than the cost of investment, and the manager’s own income from the corresponding technology of BIM-O&M management is less than the income that it does not possess.

(3) When \(0 < \lambda_{31} < 1, 0 < \lambda_{12} < 1\) (Figure 4) or \(\lambda_{31} > 1, \lambda_{12} > 1\) (Figure 5), the inhibition effect of BIM operation management mode on the traditional O&M management mode and the inhibition effect of traditional O&M management mode on BIM-O&M mode are both strong or weak for the operator. If the inhibition of both parties is weak, the inhibition of both parties reaches a relatively stable state (point \(p\) in Figure 4). If the inhibition of both parties is strong, the game parties will change the income and cost according to the difference of initial values and their own reforms so as to reach the absolute stability conditions of (1) and (2). At this time, the cost and income conditions of the O&M game parties are at an interval other than the conditions of ①–⑧. In this interval, the evolution of the O&M three-party game is in an unstable state and there is no evolutionary stability point (ESS).

(4) To sum up, according to the different costs and benefits of the three parties in the O&M management game, the choice of strategy will be different. The choice of BIM-O&M in the O&M management market of the whole society will also change the mutual inhibition coefficient of both parties according to the different costs and benefits of the three parties in the game to stabilize in the above three cases, namely, complete diffusion, partial diffusion and extinction.
4. Analog Simulation

In order to directly reflect the spread of BIM-O&M management in the social market in the way of three-parties strategy selection of O&M, MATLAB is used to simulate and analyze the above three situations. Assuming that the initial values of x, y, and z are 0.5, r₁ = r₂ = 0.5, y₁, y₂ are all any value in [0.3, 0.6, 0.9], and t is large enough; the specific simulation situation is as follows:

(1) Taking S₀ = 8, C₀ = 9, S₁ = 20, C₁ = 16, T = 7, W = 5, G = 6, S₀ = 4, C₁ = 10 to satisfy the condition ①, S₀ = 8, C₀ = 9, S₁ = 20, C₁ = 10 to satisfy the condition ②, S₀ = 9, C₀ = 8, S₁ = 20, C₁ = 16, T = 7, W = 5, G = 6, S₀ = 4, C₁ = 10 to satisfy the condition ②, and S₀ = 9, C₀ = 8, S₁ = 13, C₁ = 16, T = 7, W = 6, G = 5, S₀ = 4, C₁ = 10 to satisfy the condition ②. The simulation situation of three-party game simulation at this time is shown in Figure 6. Letting λ₁₂ = 1.2, λ₂₁ = 0.8 in the diffusion equation and the simulation situation of O&M management diffusion at this time is shown in Figure 7.

It can be seen from the figure that under the conditions ①–③, the proportion of BIM-O&M management in the social market will first increase to a certain value and then decrease rapidly or directly to 0, which makes BIM-O&M management "ephemeral," while the traditional O&M management mode will be replaced by BIM-O&M and then increase rapidly or BIM-O&M will not affect the continuous increase of the traditional O&M management mode. Finally, the traditional O&M management mode completely occupies the market.

(2) Taking S₀ = 9, C₀ = 3, S₁ = 20, C₁ = 16, T = 6, W = 12, G = 4, S₀ = 4, C₁ = 4 to satisfy the condition ③, S₀ = 9, C₀ = 3, S₁ = 20, C₁ = 16, T = 6, W = 12, G = 4, S₀ = 6, C₁ = 4 to satisfy the condition ④, and S₀ = 9, C₀ = 3, S₁ = 20, C₁ = 16, T = 6, W = 12, G = 4, S₀ = 6, C₁ = 4 to satisfy the condition ⑤. The simulation situation of three-party game simulation at this time is shown in Figure 8. Letting λ₁₂ = 0.8, λ₂₁ = 1.2 in the diffusion equation and the simulation situation of O&M management diffusion at this time is shown in Figure 9.

It can be seen from the figure that under the condition of ③–⑤, if the initial proportion of BIM-O&M management in the social market is large, the market share will be replaced by the traditional way first, resulting in the proportion reducing to a certain value and then increasing rapidly. If the initial proportion of BIM-O&M management is small, it will directly increase to the full market, while the traditional O&M management will be gradually replaced by BIM-O&M, resulting in the market share occupying. The share of the traditional O&M management is gradually reduced to exit from the market, and finally BIM-O&M management mode completely occupies the market.

(3) Taking S₀ = 9, C₀ = 8, S₁ = 20, C₁ = 16, T = 7, W = 6, G = 5, S₀ = 4, C₁ = 10; S₀ = 6, C₀ = 3, S₁ = 16, C₁ = 16, T = 4, W = 7, G = 4, S₀ = 4, C₁ = 4; S₀ = 9, C₀ = 5, S₁ = 20, C₁ = 23, T = 6, W = 12, G = 4, S₀ = 11, C₁ = 8; S₀ = 9, C₀ = 3, S₁ = 20, C₁ = 14, T = 8, W = 7, G = 4, S₀ = 6, C₁ = 4 respectively, and the corresponding value are values outside the range of conditions ③–⑤. The simulation situation of the three-party game at this time is shown in Figure 10 (I–IV). At this time, there are two situations of O&M management diffusion in the social market.

Case 1. Letting λ₁₂ = 0.8, λ₂₁ = 0.6 in the diffusion equation, and the O&M management diffusion simulation is shown in Figure 11.

It can be seen from the figure that at this time, the inhibition of both parties is weak, and the two O&M management modes in the market gradually reach their respective stable proportion, and the stable value is the value of point P (Figure 4).

Case 2. Letting λ₁₂ = 1.4, λ₂₁ = 1.2 in the diffusion equation, and the O&M management diffusion simulation is shown in Figure 12.

As can be seen from Figure 12, both sides have a strong inhibitory effect at this time, and the final state of diffusion is determined by the initial value of diffusion of both sides under O&M management. When the original value is below the dotted line in Figure 5, the traditional O&M management mode completely diffuses, reaching the diffusion result of (1). When the initial value is above the dotted line in Figure 5, the BIM-O&M management mode completely
diffuses, reaching the diffusion result of (2). When the original value was in the dotted line in Figure 5, BIM-O&M
Figure 8: Evolution diagram under conditions 5–8.

Figure 9: Simulation diagram of O&M management under conditions 5–8.
management mode and traditional O&M management mode continuously competed in the market and reached
point P, reaching the diffusion result of (3) Case 1.

5. Conclusions and Recommendations

This paper analyzes the attitude of building owners, operators, and managers towards the application of BIM-O&M technology management and the diffusion effect of BIM-O&M under the different strategy choices of the three parties in the game; this paper constructs the three-party game revenue matrix of the game by using the idea of the three-party asymmetric evolutionary game and based on this, through the evolutionary model, analyzes the two kinds of O&M markets in the diffusion model. The mutual inhibition of O&M mode is analyzed in depth, and the conclusion is drawn through simulation analysis. (1) All three parties of the game are stakeholders, so they will choose appropriate game strategies according to their maximum interests. (2) When the strategy combinations of the three parties in the game are different and the diffusion results of O&M methods in the market are different, only one or two O&M management methods will coexist. (3) When in the market, the phenomenon of the two O&M modes coexist. If you want to change the market share of these two O&M models or admire one of them, you need to change the costs and benefits involved in the O&M process, and the introduction of BIM-O&M need to adjust the O&M mode and the traditional market situation, finally get to the spread of the results.

Based on the above conclusions, in order to promote the application of BIM Technology in O&M management in China, the following suggestions are put forward. (1) When building operators are preparing to adopt BIM technology for building O&M management, they need to choose whether to carry out innovation in O&M management according to the cost such as the salary of BIM technology managers and the investment required for training, and the income that may be obtained when using BIM technology for O&M management. As a building owner, it is necessary to make a strategic choice according to the investment cost of supporting operators to adopt BIM-O&M and the income such as public praise. As a manager, he needs to improve his management ability in BIM-O&M at any time according to the market demand, especially in this era of diverse access to resources and low cost of self-study and strengthen the application ability of his BIM-O&M technology combined with big data, Internet of things, and artificial intelligence technology. (2) If countries or regions want to change the application degree of BIM-O&M management, they can change the corresponding three-party cost-benefit and the initial proportion of two BIM-O&M modes through appropriate macro policy adjustment, such as changing the threshold of using BIM Technology for O&M management or the specified policies of using standards, so that the BIM-O&M management mode can gradually spread and finally meet the needs of O&M management. (3) In the future, the potential operators need to conduct a strict research of the market, understand the impact of the changes in the revenue and cost of the three parties of O&M on themselves and the diffusion trend of BIM-O&M in the market and seize the opportunity to choose their own O&M management mode to obtain their maximum revenue.

Data Availability

No data were used in the study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] W. Sisson, C. van-Aerschot, C. Kornevall et al., Energy Efficiency in Buildings: Transforming the Market, World Business Council for Sustainable Development, Geneva, Switzerland, 2018.
[2] R. Santos, A. A. Costa, A. António, and A. Grilo, "Bibliometric analysis and review of Building Information Modelling literature published between 2005 and 2015," Automation in Construction, vol. 80, pp. 118–136, 2017.
[3] C. Yilmaz, A. Akcamete, and O. Demirors, "A reference model for BIM capability assessments," Automation in Construction, vol. 101, pp. 245–263, 2019.
[4] M. K. Ansah, X. Chen, H. X. Yang, L. L. Patrick, and T. I. Lam, "A review and outlook for integrated BIM application in green building assessment," Sustainable Cities and Society, vol. 48, Article ID 101576, 2019.
[5] P. Poorang, E. R. P. Farr, A. H. M. Zadeh, S. T. I. Inacio, S. Kilgallon, and R. Y. Jin, “Facilitating building information modelling (BIM) using integrated project delivery (IPD): a UK perspective,” Journal of Building Engineering, vol. 26, Article ID 100907, 2019.
[6] X. Gao and P. Pishdad-Bozorgi, “BIM-enabled facilities operation and maintenance: a review,” Advanced Engineering Informatics, vol. 39, pp. 227–247, 2019.
[7] J. Zhang, Y. Long, S. Lv, and Y. Xiang, “BIM-enabled modular and industrialized construction in China,” Procedia Engineering, vol. 145, pp. 1456–1461, 2016.
[8] Y. Liu, S. van Nederveen, and M. Hertogh, “Understanding effects of BIM on collaborative design and construction: an empirical study in China,” International Journal of Project Management, vol. 35, no. 4, pp. 686–698, 2017.
[9] C. Peter and S. Chaitanya, “Gokhale, Disentangling eco-evolutionary effects on trait fixation,” Theoretical Population Biology, vol. 124, pp. 93–107, 2018.
[10] R. Cressman and J. Garay, "Evolutionary stability in Lotka-Volterra systems," Journal of Theoretical Biology, vol. 222, no. 2, pp. 233–245, 2003.
[11] I. Antai and H. Olson, “Interaction: a new focus for supply chain vs supply chain competition,” International Journal of Physical Distribution & Logistics Management, vol. 43, no. 7, 2013.
[12] S. Sharma and A. G. Choudhury, “A qualitative study on evolution of relationships between third-party logistics providers and customers into strategic alliances,” Strategic Outsourcing, vol. 7, no. 1, 2014.
[13] S. Y. Xie, Economic Game Theory, Fudan University Press, Shanghai, China, 4th edition, 2017.
[14] V. Volterra, “Variazione fluttuazioni del numero d’individuo in specie animal convivente,” Memorie Ricerca Academia Nazio-nale dei Lincei Serie, vol. 6, no. 2, pp. 31–113, 1926.
[15] R. Cressman, A. Halloway, G. G. McNickle, J. Apaloo, J. S. Brown, and T. L. Vincent, “Unlimited niche packing in a
Lotka-Volterra competition game,” *Theoretical Population Biology*, vol. 116, pp. 1–17, 2017.

[16] D. Friedman, “On economic applications of evolutionary game theory,” *Journal of Evolutionary Economics*, vol. 8, no. 1, pp. 15–43, 1998.

[17] S. Yin, B. Li, and Z. Xing, “The governance mechanism of the building material industry (BMI) in transformation to green BMI: the perspective of green building,” *Science of The Total Environment*, vol. 677, pp. 19–33, 2019.

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