Research on dynamic evolution of innovative virtual prototyping technology diffusion based on cellular automata

Guangbin Wang[1], Honglei Liu[1], Lei Zhang[2*]

[1] *School of Economics and Management, Tongji University, Shanghai 200092, China*

[2] *School of Business, Shandong Jianzhu University, Jinan 250101, China*

Received 1 March 2014, www.tsi.lv

Abstract

The construction industry plays a very important role in the national economy; it is widely criticized because of its slow technical progress and long-term inefficiency all over the world. Building information modelling (BIM) is a transformative virtual prototyping technology for construction industry. VP (Virtual Prototyping Technology) based on BIM as the core technology has been widely regarded as a tool to solve this problem, but was questioned by both academia and industry due to its delayed diffusion. To solve this problem, this paper is based on the characteristics and the evolution rules of cellular automata, built on the CA model of the BIM proliferation process in construction projects, simulating this process, then analysing the impact of important factors such as diffusion willing, decision-making preferences, national and industry support and other factors to the BIM technology diffusion, studying the changes in the proportion of BIM recipients and the importance of the distribution position of the initial to the BIM proliferation process. Finally, it analyses the randomness of BIM technology diffusion.

Keywords: Building Information Model Diffusion, CA Evolution Model, Diffusion Willingness, Decision-Making Preferences, National and Industry Support

1 Introduction

The construction industry is the backbone of social and economic life, and supports national development and prosperity, but the long-term low productivity that results in energy consumption and serious environmental pollution makes it gain widespread attention. VP (Virtual Prototyping Technology) based on BIM as the core technology has been widely regarded as a tool to solve this problem in the whole world, and some scholars think it will bring an unprecedented revolution in construction industry because of its enormous potential impact for enhancing the construction project performance and industry production efficiency [1]. It is widely regarded as the most important technical concepts produced in the AEC industry (Architecture, Engineering and Construction Industry) in the last decade [2-4], and it can be effectively used in the whole construction project lifecycle such as site planning, collaborative design, clash detection, energy consumption analysis, construction schedule simulation, cost control and other aspects through digital and intelligent building facilities. Although the VP-related ideas and prototypes have already been considered to have broad application prospects as early as the 1970s, the breadth and depth of its application are not satisfactory now [5, 6]. Construction enterprises are the players in the construction market, and construction projects are the service targets and entities of BIM applications, so only the effective diffusion and application of BIM can affect project performance, enterprise performance and even industry efficiency. Nowadays, how to promote the diffusion of VP (Virtual Prototyping Technology) such as BIM in the construction industry has become the new proposition confronted with both academia and businessmen.

To solve this problem, many scholars have carried out relevant studies. In view of the progress and upgrading of hardware and software technology, the focus of related research has been shifted from technical issues to problems of implementation. Dulaimi investigated the motivation of technological innovation diffusion and innovation-related interaction between organizations of the construction projects, and identified the impact of the target incentive, participants' commitment and other factors on motivation of innovative applications [7]. Davis et al. pointed out that the main reason for the boycott to BIM lies in the failure to support organizational change of BIM application [8]. Jernigan also pointed out that the significant change that BIM brought in the construction industry caused organizational inertia and resistance to change [9]. The major barriers to BIM application include poor interoperability among different software, unclear business value and return on investment of BIM, and reluctance among construction companies to share information [10-12]. The above studies provide an important basis for understanding the impact of BIM

*__Corresponding author__ email: zhlei06@gmail.com

proliferation factors of construction projects. However, these studies, mostly based on case studies or surveys on various factors affecting the static identifier, also emphasize more on the technical aspects of the study, and take fewer dynamic evolution of the BIM technology diffusion process into account. This paper is based on the characteristics and the evolution rules of cellular automata, builds the CA model of BIM proliferation process in construction projects, simulates this process, then analyses the impact of important factors such as diffusion will, making preferences, national and industry support and other factors to the BIM technology diffusion, focused on the randomness of BIM proliferation, in order to provide a theoretical basis for the diffusion and application of VP whose core technology is BIM in the construction industry.

2 Dynamic evolution of the BIM proliferation model

Cellular automata, which is in accordance with certain local rules in a discrete, finite cellular space composited of cellular, is dynamical systems in the evolution of discrete time dimension. CA models, constructing individual (cell) on the micro-level and obtaining the macro results by summing the micro individuals from the perspective of complex systems, is a bottom-up (bottom-up) research method. Essentially, the CA model is a dynamic evolution system based on the interactions of a large number of cellular.

2.1 RESEARCH ASSUMPTIONS AND THE DYNAMIC EVOLUTION OF THE CA MODEL BUILDING

(1) Hypothesis 1: The BIM proliferation process of Construction Projects is a dynamic system according to certain rules of non-linear interaction of actors. In the process of BIM technology diffusion, the owner, designer and construction side, government departments and agencies and other project participants showed a nonlinear and varied relationship on the overall level; from the perspective of the individual level, the individual participants are the core elements in the process of BIM technology diffusion. This process manifested in the interaction relationships of project participants, and in a certain context, can achieve the dissemination and diffusion of BIM technology.

(2) Hypothesis 2: In the BIM technology diffusion process, the project involved individual implemented dissemination and diffusion by communicating with its nearest individuals. The occurrence of local interactions between individuals makes the project happen. Individuals involved in the project send or receive innovative BIM technology are limited only by the project participants or the closest; at the same time, there is no priority when many diffusion processes of BIM technology are at the same observation point.

(3) Hypothesis 3: The project involved individuals adjusting the BIM technology diffusion process based on their relationship. They assess their own scenarios, and then adjust the BIM technology diffusion rate according to the above evaluation and expected results to be adjusted.

(4) Hypothesis 4: Participating individuals have completed information about the individual states of the diffusion process. Meanwhile, once innovative technology is received, it will never be changed.

(5) Hypothesis 5: Every involved individual will not be affected by their property differences in each project. Individuals act independently without disturbing each other.

2.2 MODEL

Based on the above assumptions, the diffusion process for the BIM evolution model is established as follows:

(1) Set the rows or columns of the square-type grid of the cellular automaton model. The number of cells of cellular automata $n \times n$ in the grid represents the number of individuals $N = \sum i$ involved in the process of BIM proliferation. This model uses a 50 × 50 grid to construct cellular space, the grid intersection points of rows and columns represent recipients and proliferators of BIM technology.

(2) There are two like bodies $\{0,1\}$ representing whether the individual accepts the diffusion of BIM technology: 1 represents that BIM innovation has been accepted by the individual, and 0 represents the opposite.

(3) Neighbours form. In the CA model, there are many neighbours' forms. This model uses mole (Moore) type; that is, each user has eight neighbours, and the eight neighbours at the t-1 moment will affect the central users who are at the t moment.

(4) The evolution function and state transition rules of cellular.

This article assumes that all individuals involved in the evolution of BIM technology diffusion are affected by diffusion willingness (γ) and decision-making preferences (δ), then select support on BIM from country and industry bodies (ε) and the choice of other ones (i) around the involved individual as external factors. Its influence function is:

$$f(t) = \gamma(t) \times \delta(t) + \varepsilon(t) + p\sum_{i=1}^{8} s_i(t-1) \quad (1)$$

In the formula (1): (γ) Diffusion willingness: the possibility of BIM technology diffusion $\gamma(0 \le \gamma \le 1)$, $\gamma = 0$ means unwilling, $0 < \gamma < 1$ means the degree of willingness, $\gamma = 1$ expressed complete readiness, the innovators of BIM who want to obtain and maintain a reputation for higher qualifications expect to solve the practical obstacles and has a higher degree of willingness, but considering the competition, the experience will be reserved to a certain extent. Therefore, the range of value is $(0.5 \le \gamma \le 0.8)$; (2) Decision Preference (δ): This article use emphasize degree on income from BIM innovation accepted corporate representing decision-making preferences $\delta(0 \le \delta \le 1)$, $\delta = 0$ means no attention, $0 < \delta < 1$ means the degree of attention, $\delta = 1$ means absolute attention. There are some differences in decision-making preferences of trying BIM technology in different individuals. (3) National and industry organizations supporting (ε). The value of support from country and industry bodies to BIM is $0 \le \varepsilon \le 1$, which indicates the support is 0, the diffusion of BIM mainly relies on self-development of the industry, the value of ε is more which means the support is greater.

This article will use the simulation tool - MATLAB to program the evolution model of the BIM technology diffusion based on cellular automata, and analyse the simulation results based on the above.

3 Simulation of evolution model of BIM technology diffusion

The diffusion of the BIM Construction Project is the process of partial interactive process between individuals, and its complexity is suitable for the "bottom-up" complex systems - cellular automaton model. Through the establishment of the diffusion process evolution model of BIM technology based on cellular automata, this paper simulated the diffusion process, analysed the individual wishes, internal factors of the participants in decision-making preferences and the influence of relationships between individual and neighbours, and also analysed the variation of acceptable BIM technology innovation under certain parameters.

3.1 PARAMETER INITIALIZATION

In this paper, the initial value of willingness, decision-making preferences, the relationships with neighbours of BIM involved individual, support from country and industry bodies on BIM and the position of the initial proliferators is defined, in which diffusion willingness and decision-making preferences are shown in Table 1.

TABLE 1 The value of Diffusion willingness and decision-making preferences

Diffusion willingness γ \ Decision-making preferences δ	$\delta = 0.3$	$\delta = 0.6$
$\gamma = 0.5$	$\gamma \times \delta = 0.15$	$\gamma \times \delta = 0.30$
$\gamma = 0.6$	$\gamma \times \delta = 0.15$	$\gamma \times \delta = 0.36$

In BIM proliferation, the simulation is divided into two cases, no support from state and industry bodies and the presence of support. In this paper, cellular space is represented by a square grid $n = 50$ that takes Moore type. Assuming that the 1/10 (diffusion random position) of the involved individuals accept the innovation in the initial state, while the 9/10 did not receive the innovation. The frequency of simulation is 50 times.

3.2 ANALYSIS OF SIMULATION RESULTS

(1) The change of proportion of BIM recipients in different iterations.

Setting of parameters: the value of diffusion will and decision-making preferences are 0.5 and 0.3. Without the support from national and industry bodies, BIM proliferation depends on the innovative diffusion of core corporate, which will be affected by the external environment. The black areas in the figure consist of the cells obtaining the innovation of BIM, while the cells that are not transmitted are components the white areas.

As we can see from Figure 1, BIM technology transmits to each direction at almost equal speed, and also the transmission is random. BIM technology will soon transmit around the diffused sources (several companies who initially mastered the technology) under the bringing in of a number of aggressive decision-makers and the initiating of the conservative ones. Finally, apart from a few enterprises, almost all companies will introduce the technology.

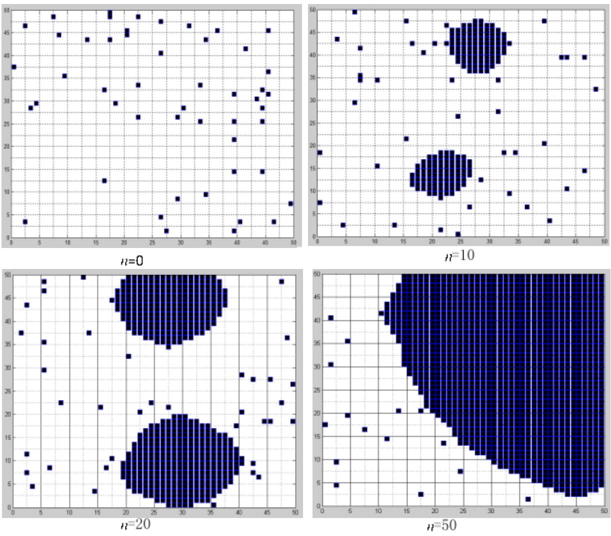
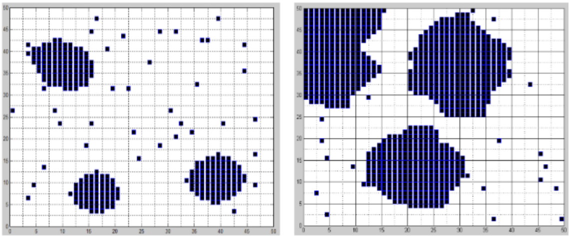


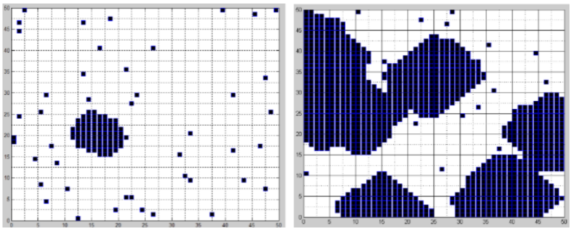
FIGURE 1 Influence of Different Iterations of Simulation on the Diffusion Process

(2) Impact of different values of γ and δ on BIM proliferation

Iterations are analysed from the number $n = 10$ that the involved individual has been diffused by BIM technology. In Figures 2 (a) and (c), when the value of the diffusion willingness of participants and decision-making preferences of recipients are both small, BIM knowledge spreads in fewer individuals in the diffusion process; in Fig 2 (b), BIM knowledge spreads in a large number of individuals in the diffusion process; in Fig 2 (d), when the value of the diffusion willingness of participants and decision-making preferences of recipients are both large, BIM knowledge spreads to almost half of the involved individuals in the diffusion process.



(a) $\gamma = 0.5, \delta = 0.3$ (b) $\gamma = 0.5, \delta = 0.6$

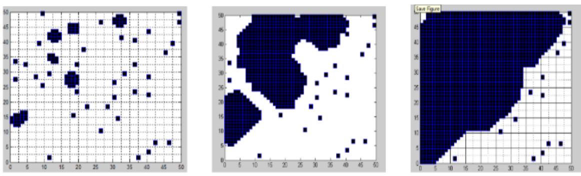


(c) $\gamma = 0.6, \delta = 0.3$ (d) $\gamma = 0.6, \delta = 0.6$

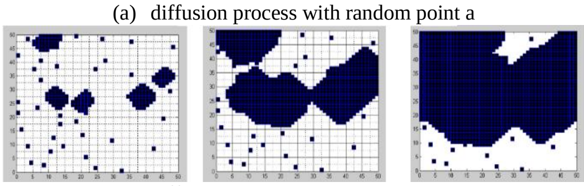
FIGURE 2 Simulation Diagram about the Influence of Diffusion wishes γ and Decision-making Preference δ on BIM Proliferation Process

Meanwhile, it can be seen from Figure 2, as the value of the diffusion willingness and decision-making preferences of the involved individual increase, the average speed of BIM proliferation is accelerates. Decision-making preferences of the involved individual have great influence on the average speed of BIM proliferation, while diffusion willingness has great impact on the diffusion region of BIM proliferation.

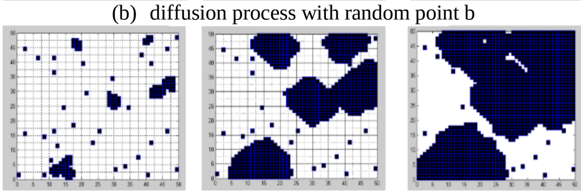
(3) Impact of the location of initial knowledge proliferators on the BIM proliferation process



(a) diffusion process with random point a



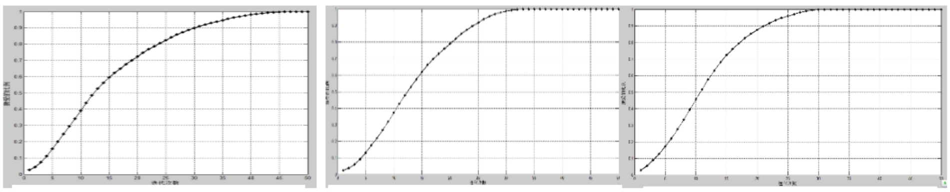
(b) diffusion process with random point b



(c) diffusion process with random point c

FIGURE 3 Simulation Diagram about the impact of the Location of Initial Knowledge Proliferators on the BIM Proliferation Process

Keep the value of the diffusion willingness of participants and decision-making preferences of recipients unchanged, take the influence of BIM proliferators Moore type, and compare three different and random positions with the same number of iterations, as shown in Figure 3. From the perspective of the number of the involved individual who has been proliferated by BIM innovators, the value of the diffusion willingness of participants and decision-making preferences of recipients are. Selecting no support from national and industry organizations, after 50 simulation clockings, the state of the iterations at different and random locations are shown in (a) in Figure 4. Compared to (b) and (c), the proliferated cells appeared in a small black area, and only occupies the top left of the grid spatial location, and the diffusion rate is relatively slow, indicating that the BIM is spread to a small number of individuals involved when the initial positions of the proliferators are far away from the organized centre in the BIM proliferation process. Compared to (a), the proliferated cells are relatively in the centre of Figures (c) and (b), and diffusion speed is fast, which shows that BIM spreads to a large number of individuals involved when the initial positions of the proliferators are close to the organized centre in BIM proliferation process.



(a) random location a, n=45 (b) random location b, n=32 (c) random location c, n=30

FIGURE 4 Simulation Diagram about the impact of Proliferators' Initial Position on BIM Proliferation

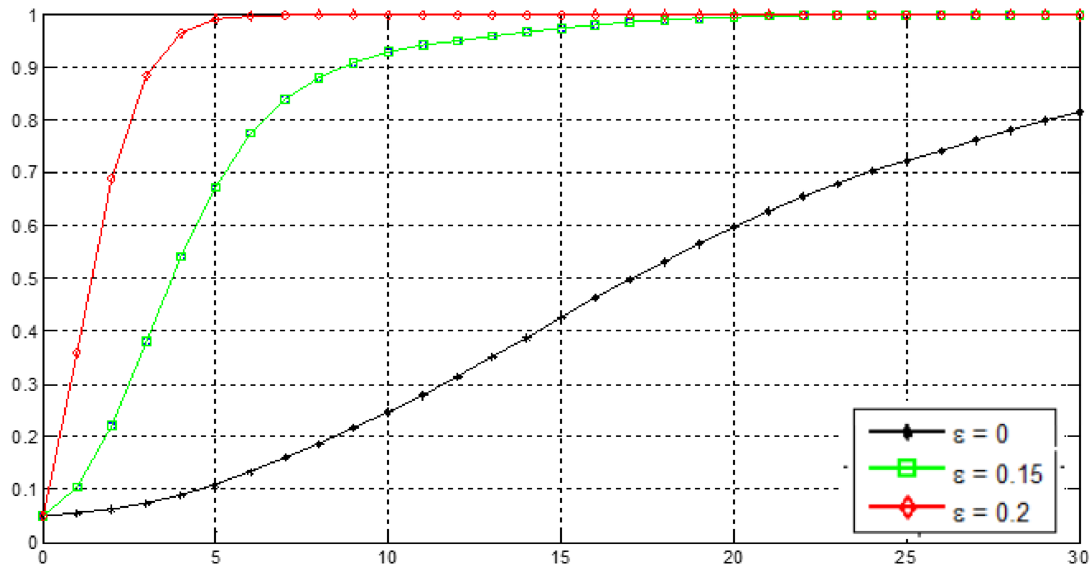
From Figure 4 we can see that the iterations of BIM proliferation spreading to the whole are at locations b and c, while to achieve the overall diffusion at location a, the three curves all need to be in line with the classic innovation diffusion model of Bass "S" curve. Thus, the initial location of BIM proliferation in the organization has a greater impact on the BIM proliferation rate. If the initial BIM proliferators are the core participating member, they can ensure a faster diffusion rate of BIM; conversely, if the initial BIM proliferators are at the edge, it is not conducive to BIM proliferation. This reveals that the core participants plays an important role in the construction project.

(4) Randomness of BIM technology diffusion

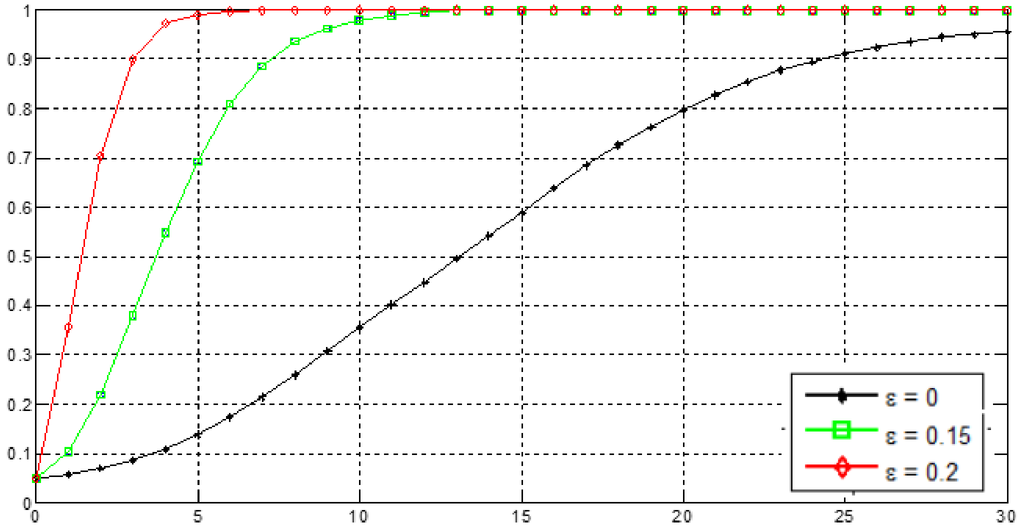
From the above analysis about the simulation results, we can conclude that establishing good relations between involved individuals and encouraging the spreading wishes of BIM proliferators can effectively improve the speed and efficiency in BIM proliferation. As mentioned above, the arbitrariness is largely due to the different positions of the distribution of the initial BIM proliferators. The grid cells at different locations means that the initial BIM proliferators face different environments, which will influence the direction and speed of diffusion greatly. In the practice of BIM proliferation, this arbitrariness is mainly broken down by the software vendor's marketing promotional efforts and a market leader in the design side. Project participants, including the owners, have passively accepted the form that regarding projects as a link to BIM implementation at present. Therefore, BIM technology diffusion will show certain regional stability. On the other hand, the BIM theory and practical experience in foreign countries show that the influence of external factors on BIM technology (such as the support from government and industry organizations) is very important. With the popularity and recognition of BIM technology, BIM software developers have completed the mission of marketing and have begun to focus on technical services and consulting. Leading designers have changed direction to the diffusion of inter-enterprise technology, adjustment of organizational structure, and the change of workflow designing, the internal training of technical staff, and pilot projects have become the main task for initial BIM proliferators.

(5) Impact of external factors ε on the BIM diffusion process

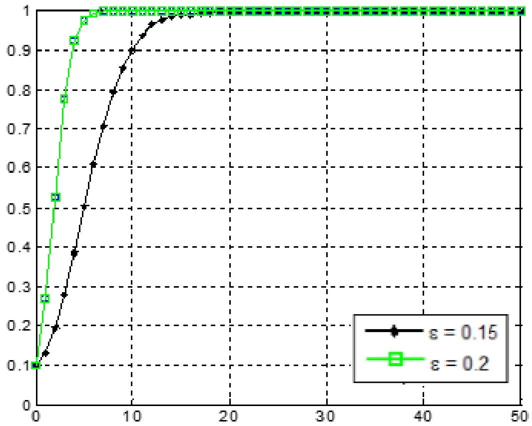
Keeping the value of the diffusion willingness of initial participants γ and decision-making preferences of recipients δ unchanged, defining the national and industry agencies' supporting ε as influence of BIM projects proliferators, executable program for Moore-type, and comparing the change of influence. In order to conveniently observe the ratio of the initial proliferators, we take is 5%. As we can see from Figure 5, the effect of the national and industry agencies' supporting ε on BIM proliferation is obvious, and greater supporting strength will be more conducive to the innovation diffusion. Taking (A) as an example, when the value of ε is 0, BIM techniques spread from the initial proliferators to the entire grid, and the number of iterations is up to 37 times (Figure 30 shows only 30 iterations), the whole diffusion process is relatively long, while the value of ε are 0.15 and 2, the number of iterations which will significantly decrease are respectively 12 and 7. Therefore, national and industry agencies' support has obvious promoting effect on BIM proliferation. Through comparing (a) and (b) in Figure 5, ε has high rate of sensitivity to BIM diffusion. Each small increase proportion will influence BIM diffusion greatly. The value of ε is 0.2, the expansion curves are almost the same, which can compensate the lack of willingness and decision-making preferences to a large extent.



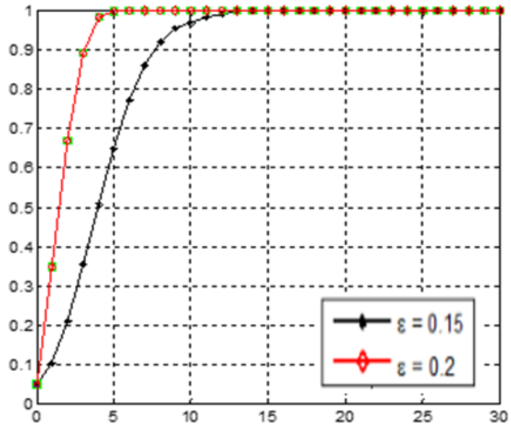
(a) $\gamma = 0.5, \delta = 0.3, \varepsilon = 0, 0.15, 0.2$



(b) $\gamma = 0.6, \delta = 0.3, \varepsilon = 0, 0.15, 0.2$



(c) $\gamma = 0.6, \delta = 0.5, \varepsilon = 0.15, 0.2$



(d) $\gamma = 0.6, \delta = 0.6, \varepsilon = 0.15, 0.2$

FIGURE 5 Simulation Diagram of Impact of National and Industry Organizations Supporting on Different Parameters on BIM Diffusion Process (X: number of iterations; Y: acceptance ratio)

4 Conclusions

This article is based on characteristics and evolution rules of the cellular automata, selected the CA as the BIM proliferation process model, and established the evolution function and state transition rules of the cellular simulate the diffusion process, and analysed the relationships between individual wishes of project proliferators and internal factors of participation in decision-making preferences, participated individuals and neighbours. Studies have shown that the design unit as a leader in the application of BIM selected random diffusion in a certain internal factors and external factors, showing obvious regional (block) distribution with the diffusion process. Moreover, the decision-making preferences of Individual recipients of project participants showed greater impact on the average speed of BIM proliferation, but wishes of BIM proliferators influenced greatly on BIM proliferation regions. In the different process of the simulation graph, we can find that the position of the initial BIM proliferation in construction project organization has a greater impact on BIM proliferation velocity. Due to the large randomness between the diffusion and the recipients, the distribution area and diffusion wishes of the diffusions are different, which lead to a greater difference in the proliferation of BIM. Taking the convergence of research into account, this paper was unsuccessful in quantifying the various parameters in the model in order to further explore the influence degree of various factors on the dynamic evolution of BIM proliferation. This paper is just a beginning on the applications of BIM proliferation in the construction industry, which need a more in-depth follow-up study in the future.

Acknowledgments

This paper is supported by the Ministry of Science and Technology of China and South Korea Joint Research Projects (No.OS2012GR0050, Research on ICT-based Construction Management using Open BIM), as well as Natural Science Foundation of China (NSFC) (NO.71272046).

References

[1] Young N W, Jones S A, Bernstein H M 2008 *Building Information Modeling: Transforming Design and Construction to Achieve Greater Industry Productivity* New York: McGraw - Hill Construction

[2] Eastman C, Teicholz P, Sacks R, Liston K 2011 *BIM handbook: A guide to building information modelling for owners, managers, designers, engineers, and contractors* (2nd Edition) New Jersey: John Wiley & Sons, Inc.

[3] Guo H L, Li H, Skitmore M 2010 Life-Cycle Management of Construction Projects Based on Virtual Prototyping Technology *Journal of Management in Engineering* **26**(1) 41-7

[4] Jernigan F 2007 *Big BIM little BIM - The practical approach to Building Information Modelling-Integrated practice done the right way* USA: Booksurge Llc

[5] Taylor J E, Bernstein P 2009 Paradigm Trajectories of Building Information Modeling Practice in Project Networks *Journal of Management in Engineering* **25**(2) 69 - 76

[6] Hartmann T, Gao J, Fischer M 2008 Areas of Application for 3D and 4D Models on Construction Projects *Journal of Construction Engineering and Management* **134**(10) 776 - 85

[7] Dulaimi M F, Ling F Y Y, Bajracharya A 2003 Organizational Motivation and Inter - organizational Interaction in Construction Innovation in Singapore *Construction Management and Economics* **21**(3) 307 - 18

[8] Davis K A, Songer A D 2008 Resistance to IT change in the AEC industry: An individual assessment tool *Electronic Journal of Information Technology in Construction (ITcon)* **13**(14) 56-68

[9] Jernigan F 2007 *BIG BIM little bim - The practical approach to Building Information Modelling - Integrated practice done the right way! (1st ed.)* Salisbury: 4Site Press

[10] http://images.autodesk.com/adsk/files/final_2009_bim_smartmarket_report.pdf (last access: 3/11/2013)

[11] He G P 2012 *The Theory of BIM and Nonsense Arguments: The Theory is not Nonsense, and Vice Visa* ChinaBIM, Source: http://www.chinabim.com/school/heguanpei/2012-12-13/4715.html (last access:3/11/2013)

[12] Pan J, Zhao Y 2012 Research on Barriers of BIM Application in China's Building Industry *Journal of Engineering Management* **26**(1) 6-11

Authors

Guangbin Wang, born in April, 1967, Heze, Shandong province

Professor, doctoral advisor and PhD. Professor Wang got PhD in Tongji University in 1998; engaged in research work in Stanford University in 2007-2008; several times went to the United States, Germany and other countries for short-term academic exchanges. Major research fields include: project management, project finance, construction management information. Professor Wang also undertakes international cooperation research subject of the Ministry of science and scientific research subject in Shanghai, as well as a number of enterprise research subject. Main courses: project management, project finance. Published materials: construction project management, Investment construction project organization, over 80 papers, and so on. Participate in project research and practice: Shanghai Yindu Building project management and Guangzhou Airport overall management, Beijing Olympic Games project management information platform and Sino-German Friendship Hospital.

Honglei Liu, born in December, 1982, Puyang, Henan province

PhD student. Research Field: Theory and Practice of BIM-Based Project Management, Information Integration;
Academic Experience:2013/1~Present Research on the Internal Mechanism and Structure Optimization for Contractual Governance of Construction Project with BIM Application Project supported by the National Natural Science Foundation of China (71272046); 2012/1~Present Research on ICT-based Construction Management using Open BIM, International cooperation in science and technology special project (OS2012GR0050)
Working Experience:2012/7~2012/10 Consultant of strategic planning of BIM implementation for Shanghai Jianke Engineering Consulting Co., Ltd; 2009/10~2011/8 Project Management of Shanghai Electronic Industries Procurement Centre

Lei Zhang, born in November, 1973, RiZhao, Shandong province

Associate Professor and PhD. Zhang worked in Shandong Jianzhu University since 1998, and got PhD in Tongji University in 2014. Major research fields include: project management, construction management information, theory and practice of BIM. Main courses: project management, Real estate market research. Academic Experience: 2013/1~Present, Research on the Internal Mechanism and Structure Optimization for Contractual Governance of Construction Project with BIM Application Project supported by the National Natural Science Foundation of China (71272046); 2010/9~2012/7, key technology research on integrated management of Shanghai West Railway Station Hub project based on BIM supported by Science and Technology Program Foundation of Shanghai (10DZ1202603). 2008/1~2009/4, Status and Trends of Shandong Province residential real estate analysis supported by Soft Science Project in Shandong Province. Published materials: Market research and forecasting, over 20 papers, and so on.