RESEARCH ON THE IMPACT OF BIM MATURITY ON THE SUSTAINABILITY OF PROJECT ORGANIZATION BASED ON SOCIAL NETWORK ANALYSIS

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ABSTRACT

In a project organization, there are some primary dimensions of sustainability that, if managed well, will ensure the efficiency of the collaboration and operation during a construction project. BIM maturity has great impact on the information exchange among the stakeholders in a construction project. Thereby, with BIM adoption in different BIM maturity stages, sustainability of the project organization can be changed correspondingly.

This paper presented an approach to quantitatively measure the sustainability of project organization in different BIM maturity stages through analyzing several found indicators. Firstly, a new Construction Information Model was built based on the BIM Maturity Stages Model. And the project organization social network on the four stages of BIM Maturity was formed by recognizing the information flow between different entities in project organization and between different stages. Secondly, a conceptual framework of sustainability indicators for project organization was established. Further, several key indicators were found through questionnaire and Principal Component Analysis. At last, ORA software was applied to the stimulation in order to analyze the project organization social network and gained the value of the key indicators of sustainability in the four BIM Maturity stages. The results of this study indicated that BIM adoption affects the sustainability of project organization in varying degrees in different BIM Maturity stages. The internal mechanism of the impact was identified, and some suggestions were put forward at the end of this paper.

Keywords: project organization; sustainability; BIM maturity stages; social network analysis; ORA

1. INTRODUCTION

After decades of development, the theory of sustainable development has got in-depth researches and applications in various fields (Robichaud and Anantatmula 2011). Meanwhile, sustainable construction has been widely concerned and studied at home and abroad. However, the development of sustainable construction is facing challenges(Zheng 2005).

As a new technology and idea, which has a disruptive impact on traditional construction industry, Building Information Modeling (BIM) represents the dominant trend of the reform of construction industry (Eastman, 2010), and is expected to become an effective solution to address the challenges of sustainable construction. BIM was first introduced in China in 2004 and gradually accepted by the domestic leading users along with its application and implementation in some large-scale complex construction projects (Pan and Zhao 2012). Accordingly, project organization will be changed with the adoption of BIM. This paper is to explore the impact of the BIM application on construction project organization in different BIM maturity stages.

2. CONSTRUCTION INFORMATION MODEL BASED ON THE BIM MATURITY STAGES MODEL

2.1 Construction Information Model

Based on the analysis of the relationship between entities in both foreign and domestic construction projects, the Information Communication Model between Construction Project Entities has been worked out(Zhang and Guan 2005).As for the construction lifecycle, it mainly includes three phases: Design(D), Construction(C), Operations(O). These three phases can be further divided as Sub-phases, Activities, Sub-activities, up to Tasks (Succar 2009). In conjunction with Information Communication Model between Construction Project Entities and Linear Model of Construction Project Lifecycle by Succar, the Construction Information Model can be built as Figure 1.

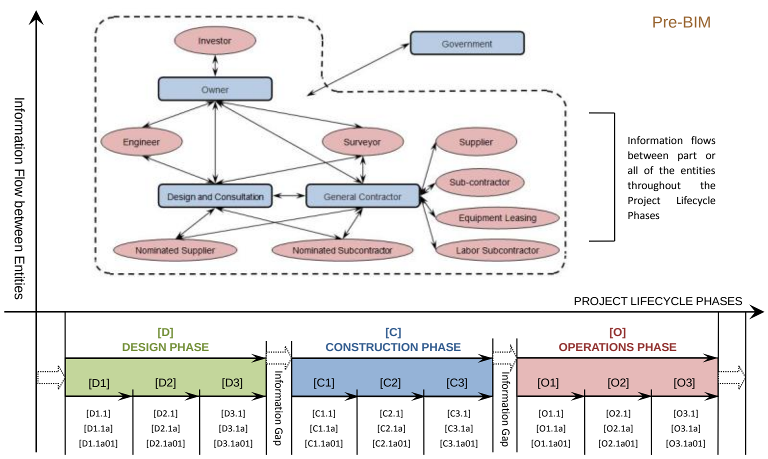

Figure 1: Construction Information Model：Pre-BIM

2.2 Construction Information Model based on the BIM Maturity Stages Model

In this paper, the Construction Information Model is formed based on the BIM Three-Stages Maturity Model proposed by Succar(Succar 2009). BIM Maturity is divided into three stages: BIM Stage 1: Object-based Modeling; BIM Stage 2: Model-based Collaboration; BIM Stage 3: Network-based Integration.

Pre-BIM is the stage that BIM has not been brought into the traditional project. At this stage, all construction projects rely on 2D drawings. The Construction Information Model in this stage is shown as Figure 1.

In BIM Stage 1, architectural design, structural design, construction design etc. use professional software for modeling in their respective areas. Information sharing can be achieved within respective units. Thus, information gaps between the different stages of the project lifecycle can be eliminated partially. Construction Information Model in Object-based Modeling Stage is shown as Figure 2.

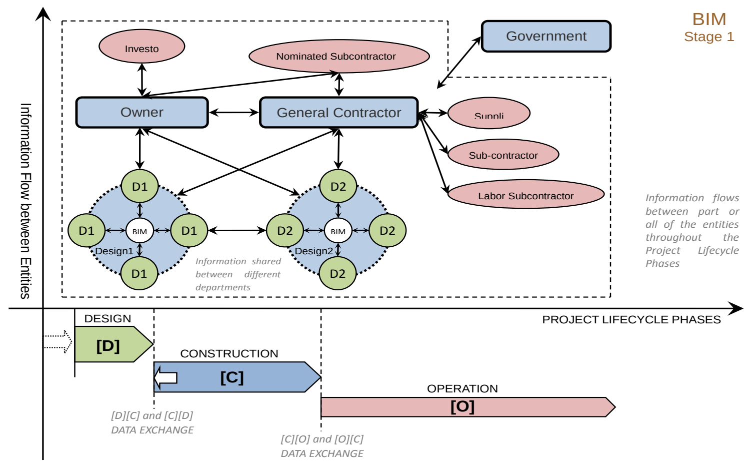

Figure 2: Construction Information Model: BIM Stage 1

In BIM Stage 2,construction information can be effectively shared in one stage or two stages in the construction project life-cycle, eliminating partial information gap. The Construction Information Model in Model-based Collaboration stage is shown as Figure 3.

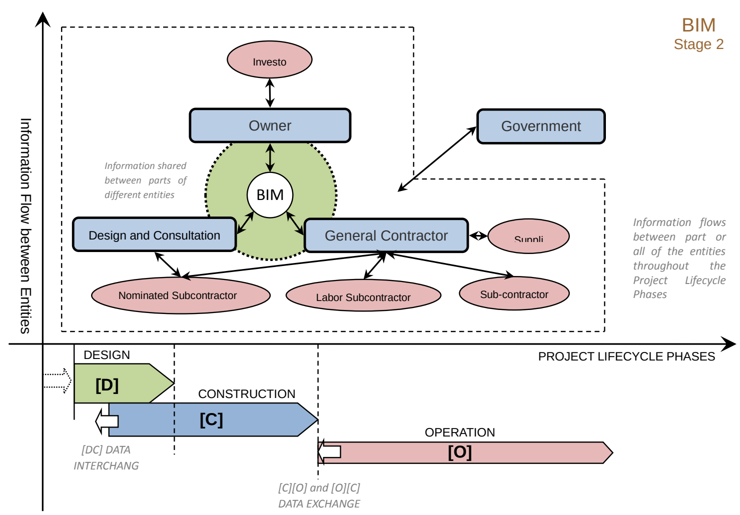

Figure 3: Construction Information Model: BIM Stage 2

In BIM Stage 3, BIM can be fully developed and applied. Cooperative working between different entities in the whole project lifecycle could be achieved. The construction information gap between phases in the construction project life-cycle and the difference of information flow in different phases are both eliminated. The Construction Information Model in Network-based Integration stage is shown as Figure 4.

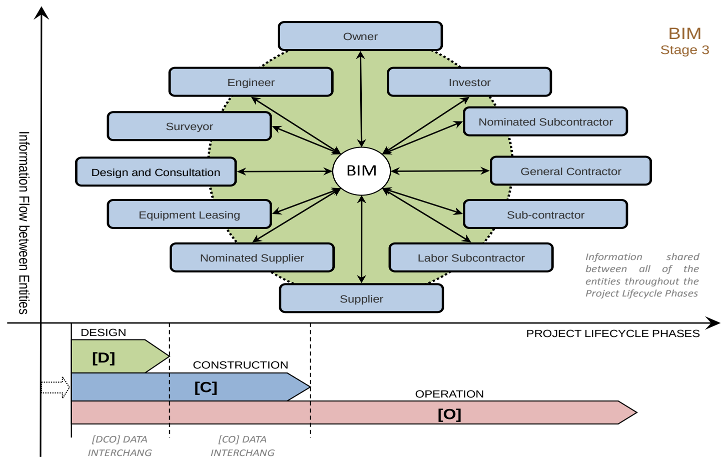

Figure 4: Construction Information Model: BIM Stage 3

3. SUSTAINABILITY INDICATORS OF PROJECT ORGANIZATION

3.1 The framework of Sustainability Indicators of Project Organization

3.1.1 Features of Project Organization's Sustainability

The research on the sustainability of project organization is relatively lacking. There is rare direct reference presenting the exact definition and featuress. Thus, papers and materials about concept of sustainability of construction project, the sustainable development of organization and sustainable organization are regarded as the appropriate source for reference.Therrby, the features of project organization are outlined to be as follows: Appropriate Structure; High Efficiency; Excellent Learning Ability; Good Environmental Adaptability.

3.1.2 Conceptual Framework for Sustainability Indicators of Project Organization

The altogether 20 indicators are composed by 2 ability indicators and 18 most related indicators selected from 76 network level indicators in ORA software (Carley, et al 2012). On the foundation of literature review, the framework for sustainability indicators of project organization is founded as Table.1according to the four features of sustainability of project organization.

Table1: Conceptual Framework for Sustainability Indicators of Project Organization

Relationship between ORA measures and sustainability features of the project organization ("•" represents the relationship)		Sustainability features of the project organization			
		Appropriate structure	High efficiency	Excellent learning ability	Good environmental adaptability
ORA Measures					
Organization features indicators	Average Communication Speed		•		
	Average distance	•			
	Communication Congruence		•		
	Communicative Need			•	
	Complexity	•			
	Density	•			
	Diameter	•			
	Diffusion		•		
	Efficiency		•		
	Fragmentation	•			
	Hierarchy	•			
	Isolate Count	•			
	Knowledge Based Task Completion		•		
	Knowledge Negotiation			•	
	Knowledge Under Supply			•	
	Organization Agent Knowledge Needs Congruence		•		
	Skip Link Count				•
	Total Degree Network Centralization	•			
Organization ability indicators	Micro Simulation			•	
	Near-term Analysis Simulation				•

3.2 The Selection of Key Sustainability Indicators of Project Organization

A questionnaire survey is used to figure out the key sustainability indicators. 57 experts in relative fileds scored the 20 selected indicators with the importance value from 1 to 5. The collected data is analyzed in the SPSS software (Norusis Marija 2008) and the statistical characteristics of the sample indexes are shown in Table 2.

Table 2:Statistical Characteristics of the Sample Indexes

编号	指标	均值	N	标准差	极小值	极大值
x01	Average Communication Speed	3.65	48	.785	2	5
x02	Average distance	3.06	48	.727	1	4
x03	Communication Congruence	3.00	48	.799	1	4
x04	Communicative Need	3.58	48	.767	2	5
x05	Complexity	3.02	48	.699	2	4
x06	Density	2.87	48	.703	1	4
x07	Diameter	3.00	48	.715	1	4
x08	Diffusion	3.56	48	.681	2	5
x09	Efficiency	3.13	48	.761	1	5
x10	Fragmentation	2.96	48	.713	1	4
x11	Hierarchy	3.46	48	.713	2	5
x12	Isolate Count	3.02	48	.668	1	4
x13	Knowledge Based Task Completion	3.60	48	.644	2	5
x14	Knowledge Negotiation	3.06	48	.633	2	4
x15	Knowledge Under Supply	3.13	48	.606	1	4
x16	Organization Agent Knowledge Needs	3.27	48	.536	2	4
x17	Skip Link Count	3.00	48	.583	2	4
x18	Total Degree Network Centralization	3.60	48	.736	2	5
x19	Micro Simulation	3.90	48	.592	3	5
x20	Near-term Analysis Simulation	3.87	48	.672	3	5

Using the Principal Component Analysis (Jolliffe I. 2005), a composite score model of sustainability indicators of project organization is put forward. Each coefficient assigned to each index within the main component is multiplied by the contribution rate of the main component, summed and then divided by the sum of all the contribution rates of 10 main components.Shown as Formula1（Fu , et al 2011）

$$Y = 0.2491x_{01} + 0.4484x_{02} + 0.3933x_{03} + 0.1823x_{04} + 0.3556x_{05} + 0.3725x_{06} + 0.3706x_{07}$$
$$+ 0.3005x_{08} + 0.3158x_{09} + 0.2167x_{10} + 0.2440x_{11} + 0.4569x_{12} + 0.1476x_{13} + 0.4245x_{14}$$
$$+ 0.3252x_{15} - 0.0527x_{16} + 0.1176x_{17} + 0.5185x_{18} + 0.5050x_{19} + 0.5279x_{20}$$

Formula 1

Treat the average scores, which represent the degree of satisfaction, as horizontal axis, while the coefficients of index in the composite score model, which represent the degree of importance, as vertical axis. The quadrant diagram is figured out as Figure 5 (Fu , et al 2011).

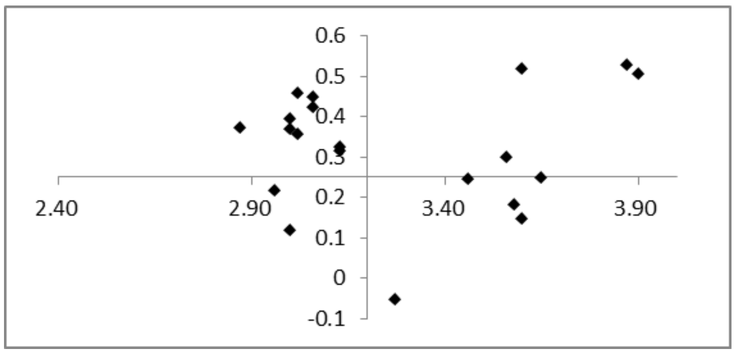

Figure 5: Quadrantal diagram of indicators' satisfaction degree and importance degree

As shown in Figure 5, the four indicators allocated in quadrant one where is the area of great concern is the final outcome of key sustainability indicators of project organization. They are: x08: Diffusion; x18: Total Degree Network Centralization; x19: Micro Simulation; x20: Near-term Analysis Simulation. These four indicators rightly represent the four features of project organization's sustainability analyzed in 3.1.1. The following study in this research will be based on these four indicators.

4. SOCIAL NETWORK ANALYSIS OF CONSTRUCTION PROJECT ORGANIZATION BASED ON BIM MATURITY

Shanghai Tower project is a suitable case for this research due to its application of BIM in the life cycle of construction project. Social network in this research is established on the basis of Shanghai Tower project organization. Then the analysis of its project organization's sustainability is conducted in different stages of maturity BIM.

4.1 Construction of Shanghai Tower Project Organization Network

4.1.1 Elements Selection of the Project Social Network

According to the SNA theory (Gurugé A. 1984), network model is built based on three elements, namely nodes, relationships and environment. Node refers to the variety of entities in a social network, including Agent, Knowledge, Task, Resource, Location, etc.; Relation refers to the relations between entities in social network, including instruction relations, information relations, process relations, etc.. Environment refers the settings of the entity's internal and external environment in the social network. In this case study, considering the characteristics of ORA software (Carley, et al 2012), the elements are set as follows:

Node: Agent: Parities in Project Organization; Knowledge: Construction and Management related knowledge owned by agent; Task: Construction related affairs for agent.

Relation: Agent and agent have direct information relation. Task and task have the process relation. Knowledge and Knowledge have no relation. Agent and Knowledge, agent and task have both possession relation. Task and knowledge have requirement relation. According to the default binary matrix in ORA (Carley, et al 2012), 1 indicates that a couple of notes are directly related, while 0 indicates they have no direct relation.

4.1.2 Definition of the Nodes

According to the Shanghai Tower project organization structure, construction project lifecycle model (Succar B., 2009) and Project Management Body of Knowledge (PMBOK), 43 Agents, 27 Tasks and 19 Knowledge items in Meta-Network are defined and imported into ORA software (Carley, et al 2012).

4.1.3 Definition of the Relations

The relation between each element varies in different BIM maturity stages. Then the five types of relations are defined respectively in four BIM maturity stages and the Meta-Networks are built correspondingly.

According to the Construction Information Model in defferent BIM maturity stages, put the matrix of Agent ×Agent , Task ×Task relation respectively into ORA software (Carley, et al 2012), the Network shown as Figure 6, Figure 7

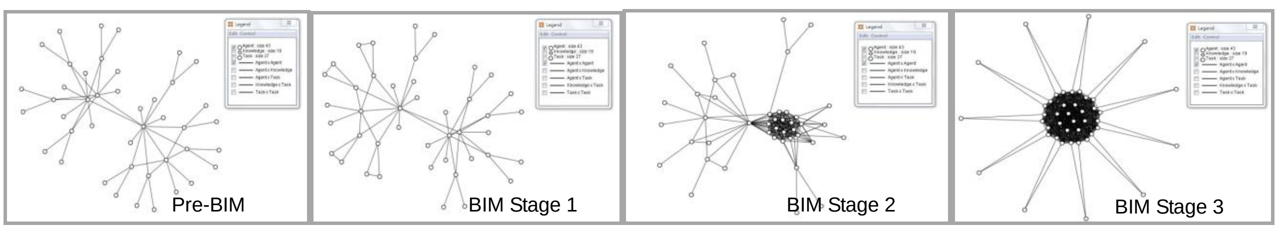

Figure 6: The Network of Agent×Agent in ORA

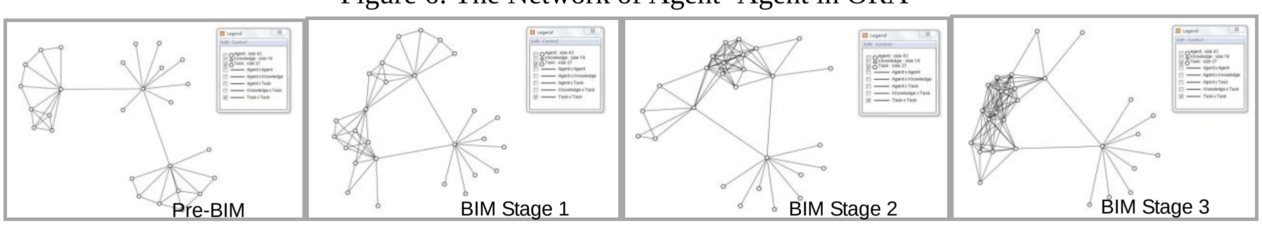

Figure 7: The Network of Task×Task in ORA

According to the case of Shanghai Tower, put the matrix of Agent ×Task, Agent ×Knowledge, Knowledge × Task relation into ORA (Carley, et al 2012) respectively, the Networks shown as Figure 8

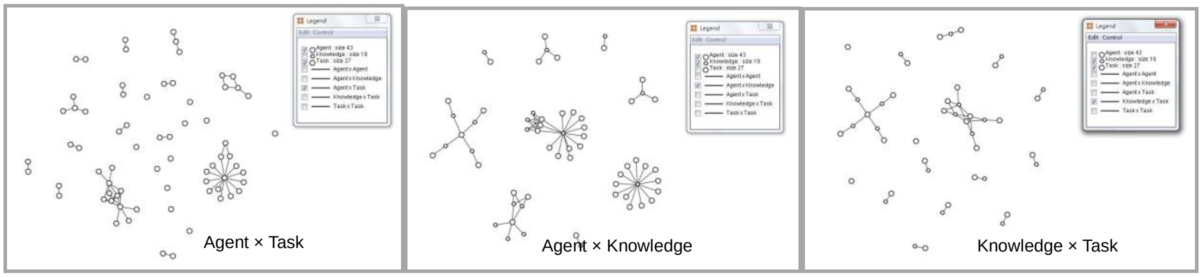

Figure 8: The Network of Agent×Task, Agent×Knowledge, Knowledge×Task in ORA

4.1.4 Meta-Network of Project Organization.

After the definition of nodes and relation, the Meta-Network in four BIM maturity stages can be formed in ORA (Carley, et al 2012).

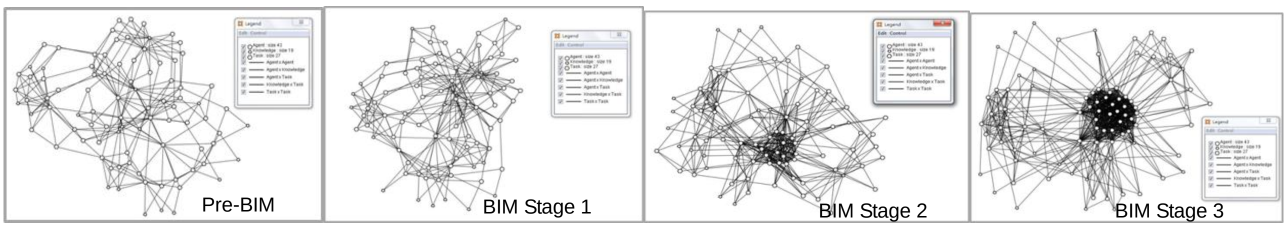

Figure 9: The Meta-Network of Shanghai Tower Project Organization

4.2 Social Network Analysis of Construction Project Organization

4.2.1Diffusion and Total Degree Network Centralization Analysis

Diffusion describes the degree of difficulty of the information diffusion in the Meta-Network. Total Degree Network Centralization describes the concentration of entire Meta-Network.

The outcome of ORA software Net-work level analysis is represented in Figure 10. As shown in the diagram, the value of Diffusion gradually become larger with the improvement of BIM maturity stages, indicating that the information diffusion ability of project organization is getting stronger and the distance between the entities in project organization is getting smaller. The value of Total Degree Network Centralization indicates that the cohesion of the organization project is enhanced.

Network-Level Measure	Pre-BIM	BIM Stage1	BIM Stage2	BIM Stage3
Average Distance	2.249	2.628	2.370	1.870
Breadth, Column	0.472	0.517	0.697	0.910
Breadth, Row	0.742	0.753	0.753	0.753
Communicative Need	0.000	0.000	0.000	0.000
Component Count, Strong	89.000	89.000	89.000	89.000
Component Count, Weak	1.000	1.000	1.000	1.000
Connectedness	1.000	1.000	1.000	1.000
Count, Column	89.000	89.000	89.000	89.000
Count, Node	89.000	89.000	89.000	89.000
Count, Row	89.000	89.000	89.000	89.000
Density	0.031	0.032	0.052	0.095
Density, Clustering Coefficient	0.126	0.128	0.188	0.279
Diameter	89.000	89.000	89.000	89.000
Diffusion	0.105	0.134	0.209	0.304
Efficiency	0.960	0.957	0.915	0.825
Efficiency, Global	0.382	0.393	0.451	0.556
Efficiency, Local	0.436	0.438	0.569	0.733
Fragmentation	0.000	0.000	0.000	0.000
Hierarchy	1.000	1.000	1.000	1.000
Interdependence	0.003	0.003	0.002	0.001
Isolate Count	0.000	0.000	0.000	0.000
Link Count	242.000	252.000	412.000	756.000
Link Count, Lateral	0.380	0.393	0.602	0.806
Link Count, Pooled	0.810	0.833	0.947	0.991
Link Count, Reciprocal	0.000	0.000	0.000	0.000
Link Count, Sequential	0.190	0.167	0.053	0.009
Link Count, Skip	0.368	0.393	0.684	0.839
Network Centralization, Betweenness	0.011	0.027	0.019	0.032
Network Centralization, Closeness	0.882	0.881	0.089	1.195
Network Centralization, Column Degree	0.140	0.138	0.175	0.256
Network Centralization, Eigenvector	0.379	0.361	0.250	0.154
Network Centralization, In Degree	0.140	0.138	0.175	0.256
Network Centralization, In-Closeness	0.017	0.037	0.052	0.043
Network Centralization, Out Degree	0.162	0.161	0.231	0.335
Network Centralization, Row Degree	0.162	0.161	0.231	0.335
Network Centralization, Total Degree	0.067	0.066	0.114	0.150
Network Levels	7.000	8.000	7.000	5.000
Redundancy, Column	0.020	0.021	0.042	0.085

Figure 10: Result of Network Level Measure in ORA (patial)

4.2.2 Micro Simulation

Micro Simulation reflects the study ability of the whole project organization.

While putting the Agent × Agent network of the project organization in four BIM maturity stages into ORA (Carley, et al 2012), an idea is given to the owner's project manager in the first day. Then set the spread of resistance as 0.4 (the greater of the resistance, the smaller probability of the agent idea acceptance). The required time to diffuse the idea to the entire network is shown in Table 3.

Table 3 The required time to diffuse the idea to the entire network

BIM Maturity Stage	Pre-BIM	BIM Stage 1	BIM Stage 2	BIM Stage 3
Time/Day	13	11	6	4

As shown in Table 3**,** time has been largely reduced from Pre-BIM stage to BIM Stage 3, indicating that the study ability of project organization is increased with the improvement of BIM maturity. The time of idea diffusion is largely reduced between BIM Stage 1 to BIM Stage 2, indicating that the study ability of the project organization can be most affected from BIM Stage1 to BIM Stage 2.

4.2.3 Near-term Analysis Simulation

Near-term Analysis Simulation is used to analyze the Environmental Adaptability of the project organization.

In the simulation, remove a certain note/some certain notes, such as Agent, Knowledge, Task etc. at any given time, and observe the change and restorability of the project organization.

In this case, define the simulated time-point is 50 and simulation time is 100; Remove the contractor's project manager at the time point 0,10,20 respectively. The true value of Knowledge Diffusion Baseline in four BIM maturity stages and the distance between the cases and the baseline are shown in Table 4.

Table4: Value Result of Near-term Analysis Simulation

Knowledge Diffusion		Distance between the cases and the baseline		
	Baseline	Time 0	Time 10	Time 20
Pre-BIM	0.2827	-0.033	-0.028	-0.024
BIM Stage 1	0.2878	-0.03	-0.025	-0.023
BIM Stage 2	0.5138	-0.026	-0.021	-0.019
BIM Stage 3	0.6812	-0.024	-0.02	-0.017

As the result shown in Table 4, after removing the owner's project manager, there appears deleys of knowledge diffusion in different degrees. Compared the cases with the Baseline respectively, it found that the amplitude deviation declines with the improvement of BIM maturity (for exemple from -0.033 to -0.024 in the case of 'Time 0'), indicating that the recovery ability of the project organization has been enhanced.

4.2.4 Result Analysis

The four sustainability indicators' values of the project organization: Diffusion, Total Degree Network Centralization, Micro Simulation, Near-term Analysis Simulation in BIM four maturity stages are shown with a comprehensive comparison in Figure 11. Left are the true values of indicators and they are all improved with BIM maturity stages. Therefore, it shows that the deeper BIM is adopted, the more sustainable the project organization will be. Right is absolute value of indicators' change rate. The variations between Pre-BIM and BIM Stage1 are relatively small, while from BIM Stage 1 to BIM Stage 2 the variations are larger. It means that the sustainability of the project organization from BIM Stage 1 to BIM Stage 2 has been improved most significantly.

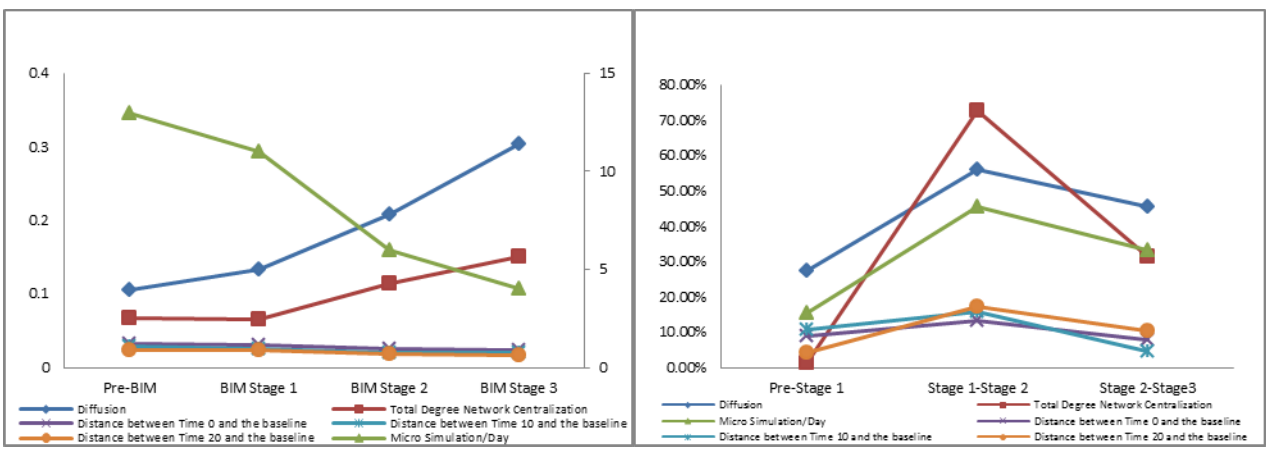

Figure 11: Sustainability Indicators of Project Organization Analysis

5. CONCLUSION AND FUTURE WORK

In this research, the Construction Information Model which is based on the BIM Maturity Stages Model was firstly put forward.Then four features of the sustainability of the project organizations were figured out: appropriate structure, high efficiency, excellent learning ability, good environmental adaptability. Accordingly, the key indicators of the sustainability of the project organization were Diffusion, Total Degree Network Centralization, Micro Simulation and Near-term Analysis Simulation. Based on all above, the case study of Shanghai Tower indicated that the application of

BIM has vital impact on the sustainability of the project organization. However, the improvement rates of the four stages were different. The sustainability of the project organization was limitedly enhanced from Pre-BIM to BIM Stage 1, while it was greatly improved in later stages. It means that the application of BIM can significantly affect the sustainability of the project organization only when it arrives at BIM Stage 2 and BIM Stage 3.

The future research shall focus on the following aspects: Firstly, describe the impact of BIM on Construction Information Model in details and establish a more objective and practical project organization social network in the case study. Secondly, adopt more scientific research methods to systematically analyze the definition of the sustainability of project organization and put forward a more integrated and accurate sustainability evaluation indicator system. Lastly, study further on the mechanism of the impact of BIM maturity on the sustainability of project organization.

6. ACKNOWLEDGEMENTS

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