Frontiers of Engineering Management
DOI 10.15302/J-FEM-2016004

ENGINEERING MANAGEMENT TREATISES

Zhi-kun Ding, Yi-fei Wang, Jin-chuang Wu

CAS and ABM-based Demolition Waste Management Research in the AEC Industry

Abstract With the increase of the urban population and the rapid development of urbanization in China, a large number of old buildings will be demolished and produce a huge amount of waste. Currently the recycling ratio of old building materials is very low, which results in the problems of resource waste and environment pollution. This greatly challenges urban sustainable development. With respect to the continual growth of demolition waste quantities, it is urgent to research how to implement effective management of demolition wastes by focusing on the demolition agents' behavior. Based on the theory of complexity, this paper analyzes the demolition waste management from the perspective of complex adaptive system. Taking into account the "green" demolition (building dismantling) and conventional demolition (building demolished) methods, the agent-based modeling method with Repast Simphony platform is applied to simulate interactions between demolition agents. The longitudinal trend of demolition waste quantities is forecasted.

Keywords: demolition waste, complexity science, agent-based modeling

1 Introduction

With the acceleration of urban renewal, huge construction, renovation and demolition activities can be found across China causing the quantities of construction and demolition wastes (CDW) to increase at a high speed in the architecture, engineering and construction (AEC) industry. According to statistics, the amount of CDW generated each year has accounted for 40% of the total municipal solid waste in China (Wang, Li, & Wang 2012), among which more than 200 million tons of waste are generated due to the demolition of old buildings. The proportion of demolition waste (DW) to the total amount of CDW is more than 90% as illustrated in Shi (2013). A large quantity of DW landfilling consumes precious land resources leading to serious pollution of the environment, which greatly challenge the urban sustainable development. Therefore, the building demolition waste management (DWM) is crucial for the construction and demolition waste management as a whole. Currently, studies for building demolition focus on two aspects. On the one hand, the reasons for building demolition are researched primarily focusing on the building life. The average life of urban residential buildings in China is far below the design life of national standard and Liu, Zhang, and Xu (2013) quantitatively analyzed the reasons for the reduced building life using the data of 1,733 demolished buildings in Chongqing. On the other hand, the quantity estimation of DW which can provide the basis for government to assess the potential for recycling, control waste flows, develop disposal plans and prevent illegal dumping and has drawn much attention. Based on the analysis of DW estimation method in each country, Chen, He, Shao, Lv, and Zhang (2007) proposed an estimation method applicable to China. The above studies on DW estimation have paved the way for computer simulation research of DWM. However, these studies only consider objective factors affecting DW without analysis of subjective factors e.g., stakeholders' attitude or behavior.

By integrating complexity science, agent-based modeling and computer simulation technology, the paper analyzes the demolition waste management system (DWMS) from the perspective of complex adaptive system. The computer simulation platform of Repast Simphony is employed to conduct simulations for DWMS which cover the interactions between various stakeholders. Finally, the future development trend of DW generation is forecasted and new directions for the demolition waste management are proposed.

Manuscript received June 20, 2015; accepted October 31, 2015

Zhi-kun Ding (✉), Yi-fei Wang, Jin-chuang Wu
College of Civil Engineering, Shenzhen University, Shenzhen 518060, China
Email: ddzk@szu.edu.cn

2 Demolition waste management system

2.1 Complex adaptive system

The science of complexity known as the "the sciences of the twenty-first century" focus on understanding nonlinear phenomena in complex systems which are composed of many interdependent, heterogeneous agents that self-organize and co-evolve (Gell-Mann, 1994; Waldrop, 1992). Complex adaptive system (CAS) theory as one of the core theory of complexity science was officially proposed by the American professor Holland in 1994. The essence of the theory is "Adaptation builds complexity." The basic idea of the theory is that each CAS is a dynamic network of many agents acting in parallel and each agent exists in the environment produced by its interactions with other agents, constantly acting and reacting to what the other agents are doing. The control of a CAS tends to be highly dispersed and decentralized. If there is to be any coherent behavior in the system, it has to arise from competition and cooperation among agents. The overall behavior of the system is the result of a huge number of decisions made by many individual agents (Waldrop, 1992).

2.2 Theoretical analysis of DWMS

A CAS-based analysis of DWMS identifies stakeholders in the system including demolition companies, transportation companies, recycling centers, landfills, government departments and so on (*Figure 1*). The characteristics of the system come from the following aspects: (1) Aggregation. Stakeholders in the DWMS can unite as different large components with small units e.g., agent which will form the different hierarchical structures or subsystems via aggregation. Those (e.g., demolition companies) who contribute to the DW generation can aggregate as DW generation subsystem; those (e.g., government) who make DWM plan or policy will aggregate as DWM policy subsystem. (2) Nonlinear. In linear systems, effort and return have a direct relationship as compared to the CAS where small events can have large effect and not necessarily predictable change. For example, interactions between the different agents (e.g., demolition companies) and subsystems (e.g., DW market subsystem, DWM policy subsystem) are quite complicated, which is reflected by the structure of a nonlinear relationship. (3) Flows. DWMS has sufficient waste flow, capital flow and information flow. The flow of waste reflected most vividly in the process of DW generation, transportation, reuse, recycling and land filling. Meanwhile, the capital flow is reflected during waste flow so that each stage can function properly. More importantly, the information flow between the stakeholders (e.g., demolition companies, government, etc.) is the key factor that influences the decision-making. (4) Diversity. Diversity in DWMS comes from the heterogeneous agents which pave the foundation for the dynamic evolution of DWMS. Firstly, the types of agents are diverse including waste generation agents, waste disposal agents, waste management agents, etc. Furthermore, diverse demolition, waste-reusing, waste-recycling methods and technologies are available with the development of science and technology. In addition, the objectives of stakeholders are diverse. For instance, the target of the government is to maximize the environmental benefits, social benefits and minimize the economic costs but profit-maximizing companies are more concerned with their own interests and ignore the DWM. (5) Tagging. Tagging means the agents' identification and response to different information, which help to achieve the exchange of information. In the DWMS, different stakeholders have different identification and response mechanism for the information of waste flow, capital flow, and management policy. Only in this way can the agents identify and adapt to the surrounding environment. (6) Internal models. Internal models are an internal mechanism of an agent, which distinguishes the agent from other agents. The attributes and behavior are encapsulated in the internal model so that agents know how to change their behavior according to the environmental change. Thus, they can better adapt to the surrounding environment. For example, during the interactions between the demolition companies, they will learn from each other to choose the most effective demolition method with the help of government. (7) Building blocks. Internal models as described in the previous section need to be enhanced by realistic mechanisms. These realistic mechanisms are termed as the building blocks, for example, in the management policy subsystem; each policy can be regarded as the building block. Source reduction, on-site sorting, waste disposal charging, propaganda and education are the different management strategies. Different combination of these policies will form diverse DWM strategies, which will have a greater effect on the DWM.

From the above analysis, it is concluded that DWMS is a kind of CAS and its dynamic evolution can be interpreted according to the CAS theory.

2.3 Evolution analysis of DWMS

The DWMS consists of different types of agents such as government, demolition companies, etc. Different agents in the system are somehow connected and mutually affect each other through interactions. The connected agents form a higher level of subsystems and these subsystems then form larger ones. Finally, the top level system i.e., DWMS is derived. The whole system is actually a "bottom-up" complex system created by the interactions between adaptive agents and the system evolution dynamics come from agents' adaptability and repeated interaction with the environment.

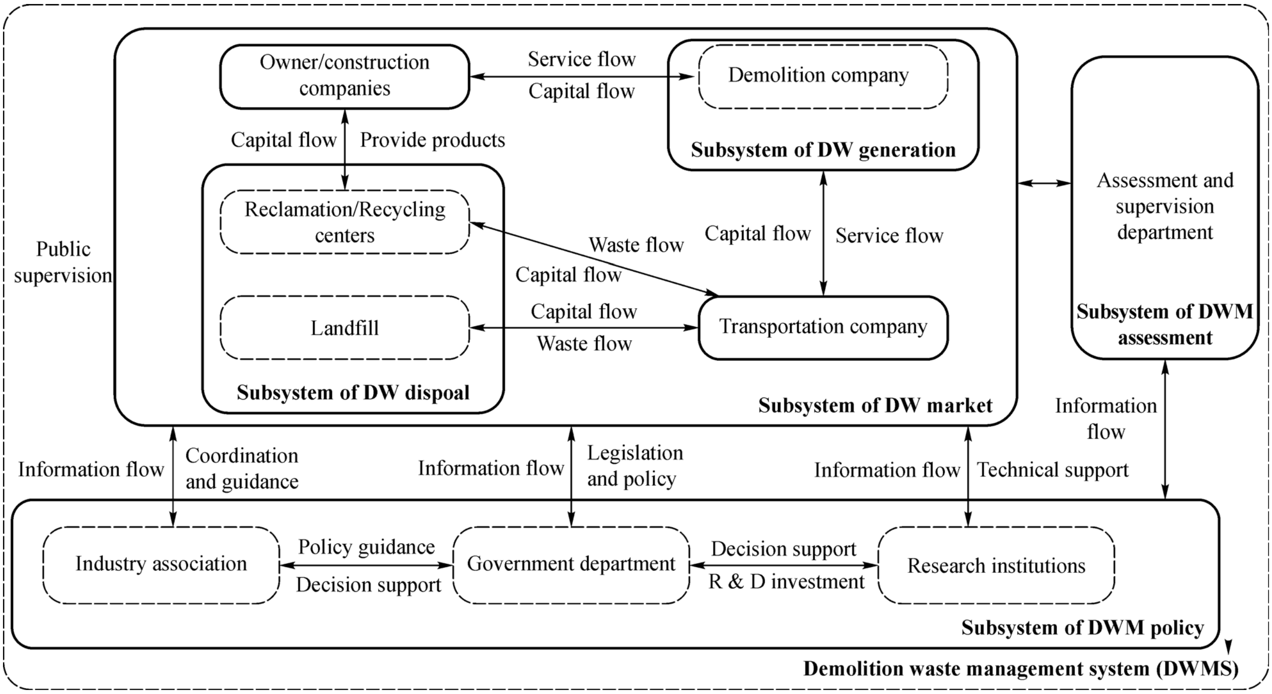

Figure 1. Demolition waste management system.

3 Simulation of DWMS

3.1 Research method-agent-based modeling

The basic idea of agent-based modeling (ABM), a bottom-up modeling method, is to select the agents in a system as the research object, identify their key attributes, design the model of agents and set the attribute, behavior standard, interaction rules, evolutionary mechanism and constraints for agents. System simulation can be conducted to observe the effects of agents' behavior on the whole system and to identify the regular pattern to explain, appreciate and forecast macroscopic phenomena of human society (Knoeri, Binder, & Althaus, 2011). Compared with other modeling methods, ABM has the following advantages: (1) ABM has the ability to describe a complex adaptive system; (2) Macroscopic system and microscopic agent can be effectively integrated; (3) ABM can model agents' behavior and achieve effective description of adaptive agents; (4) Reuse of the model is optional (Qiu, Li, & Wu, 2009). Based on the above advantages, this method is totally consistent with the theory of CAS. Therefore, this method was selected for modeling and simulation in this research.

3.2 Research Platform-Repast Simphony

Repast (Recursive Porous Agent Simulation Toolkit) is an open source visual agent-based modeling and simulation platform with a Java language environment. The latest version is Repast Simphony 2.2 (Repast S) evolved from the Repast J. Repast S can build, analyze and conduct experiment with a model consisting of heterogeneous agents who can interact with other agents in the man-made environment. Thus, the simulation of complex social behavior can be implemented to identify the regular pattern in a CAS (Ran & Yang, 2012).

3.3 DWMS modeling and simulation

3.3.1 Prototype model description

By following the basic modeling and simulation principle i.e., "from simple to complex models," this paper only consider the agent of demolition companies in the prototype model of DWMS. The aim of this simulation study is to explore the relationship between the interactions of demolition companies adopting the different demolition approaches and the dynamic evolution of DW generation.

Each demolition company is represented by the top manager who can make decisions on the choice of demolition approaches. Depending on the different demolition approach taken, top managers can be classified into two types. One kind of managers is referred to as Green Managers who take the green demolition (building dismantling) method and denoted using a green icon in Repast S. The other kind is referred to as Managers who adopt the conventional demolition (building demolished) methods and denoted using a red icon. Social space which can be manifested by the use of a grid space in Repast S is the surrounding environment for all demolition companies. Managers of demolition companies in the system can move around in the grid space to communicate with other demolition company managers. Green managers can persuade the managers using conventional demolition method to adopt the green demolition approach and vice versa. The amount of DW generated will be affected by the number of the two different types of managers. Therefore, the longitudinal trend of DW generation can be obtained by simulations.

The model parameters such as the total number of managers, the ratio of green manager, the rate of DW reduction etc. can be set in the initialization. The initialization of the simulation is as following:

(1) Demolition companies are located in a grid environment and the grid size is 100×100 i.e., 10,000 grid cells.

(2) The total number of demolition companies i.e., the managers is 800 which are represented by 800 agents. Therefore, about 90% of the grid is empty so that managers can move around in the environment. The percentage of green managers symbolized with green icons is 20%. Managers using the conventional demolition method are displayed with red icons in the model. Waste reduction rate of green managers follows the normal distribution that is waste Reduction Rate ~ N (0.5, 0.05).

(3) The neighborhood range of an agent is 2.

(4) Agents' moving and decision rules are set as following: The autonomous agents communicate with other agents and their local environment with random movement in the grid space. The probability of transition to the other kind of agents is 0.5 and agents keep moving in the next simulation time step.

3.3.2 Model construction

The prototype model was programmed through Java language to realize Green Manager class, Manager class, Constants class in the Repast Simphony 2.2 as shown in *Figure 2*.

3.3.3 Simulations and outcome

After the model is programmed, simulations are conducted. First, the model was initialized and a single or multiple parameters can be set or varied on the control panel so as to observe the system evolution. At the same time, each manager is randomly distributed in the grid space as shown in *Figure 3*.

Initially, DW generation is zero and the number of green managers is 160. Hence, the number of managers using the conventional demolition method is 640. As the simulation time goes on, the amount of DW generated will gradually increase and the number of different types of managers will change. In the course of a simulation, the interactions between the agents are shown in *Figure 4*. The left diagram shows the state of each agent when the simulation time step was 40.0. The right diagram shows the status of each agent at the end of the simulation and all the agents were transformed into the green managers. The end time of the

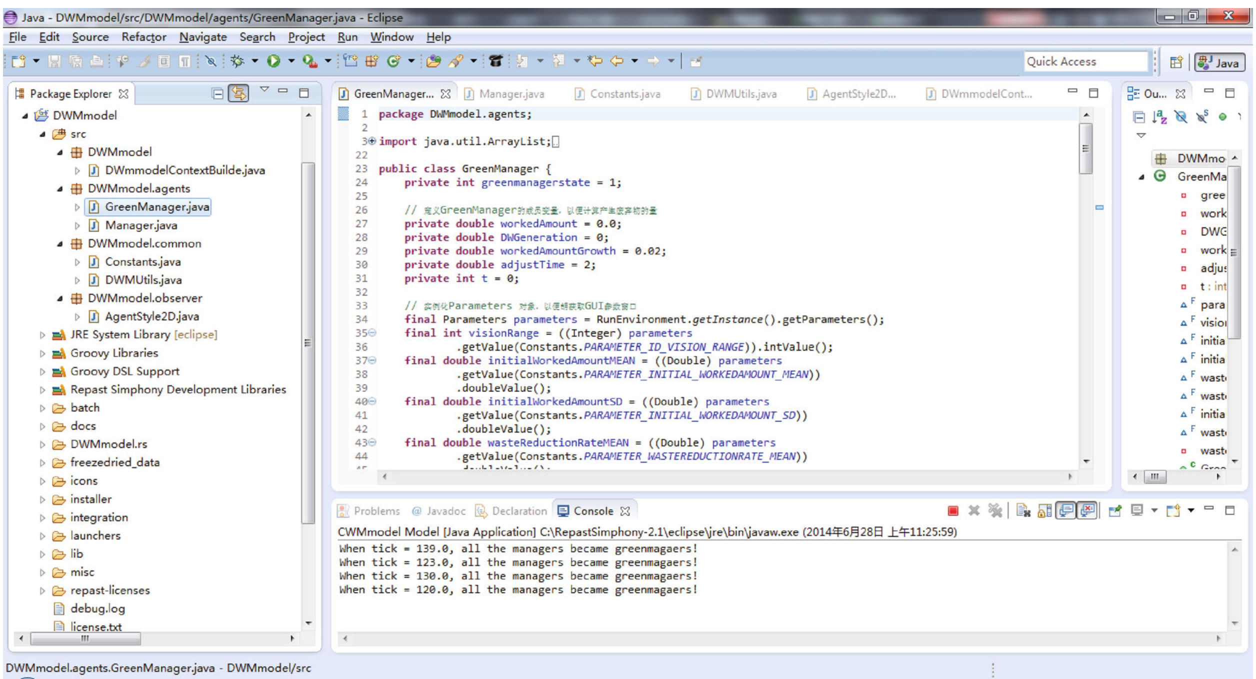

Figure 2. Model construction.

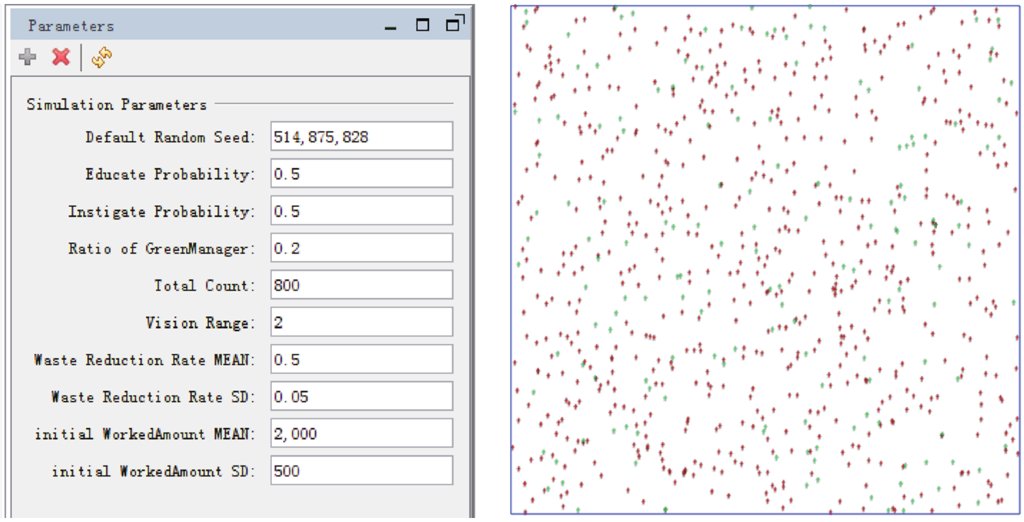

Figure 3. Model initialization.

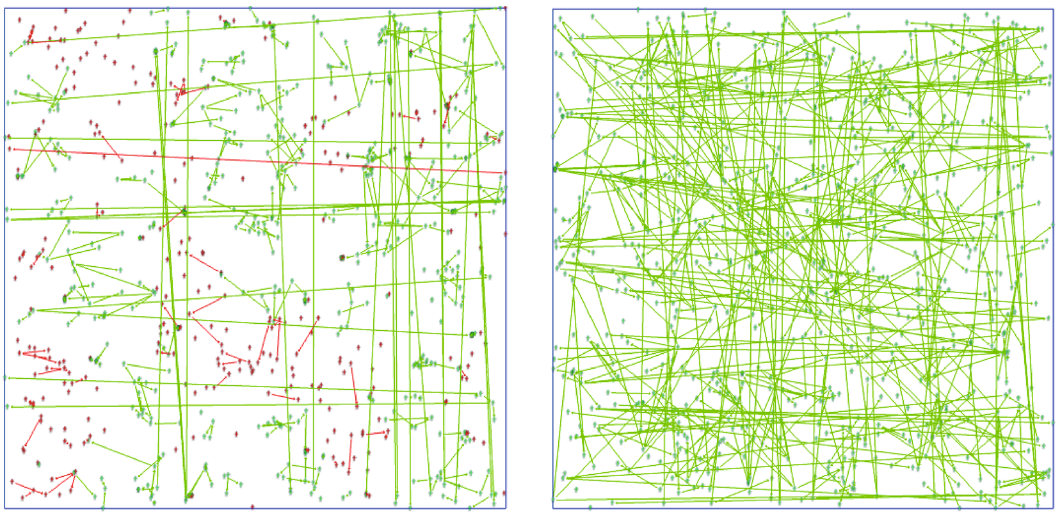

Figure 4. Model run.

simulation is 139.0. The lines between agents illustrate the historical interactions between agents.

As the simulation runs, the amount of DW generated and the numbers of two types of agents vary together. Their dynamics are shown in *Figure 5*. On the left, the horizontal axis represents the time step and the vertical axis denotes the amount of DW generation. The red line represents the amount of DW generated by the managers using the conventional demolition method on the one hand. On the other hand, the green line represents the amount of DW generated by the green managers adopting the green demolition method. The blue line represents the total amount of DW generation. On the right, the horizontal axis represents the time step and the vertical axis represents the number of agents. Furthermore, the red line delineates the number of managers using the conventional demolition method and the green line represents the number of green managers.

As can be seen from above, the green managers and the managers using conventional demolition method communicate with each other in the grid space over time so that the demolition methods are constantly changing. Moreover, through the preliminary simulation, it can be seen that managers using the conventional demolition method are transformed toward the green managers and eventually all agents are turned into green managers. Therefore, the model can reflect the trend of the amount of DW generation, which can further reveal the dynamic evolution for the DWMS.

4 Conclusions

Based on a literature review, this paper analyzes the

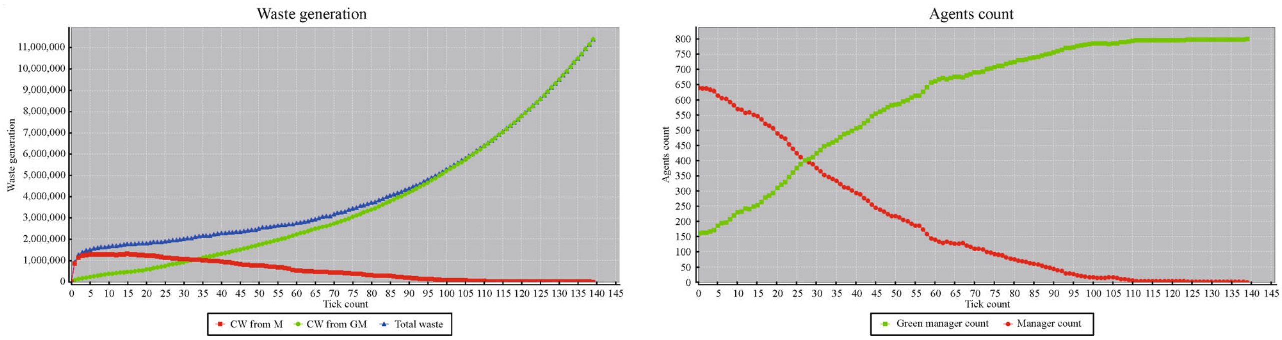

Figure 5. Dynamics of the DW generated and the number of two types of agents.

characteristics of demolition waste management from the perspective of CAS and proposes a conceptual framework of DWMS. Then, the prototype model of DW generation is constructed using the ABM method to achieve the interactions between the different types of managers on the Repast Simphony platform. Finally, the longitudinal trend of DW generation is forecasted and the dynamics arising from the interactions between agents is explored.

Future research on demolition waste management should take into account big data issues. Big data can be used to expand the research horizons in the field. For example, data of all buildings in Shenzhen cover the construction area, completion time, building height, location and so on. All these data have reached as much as 100,000 records and keep growing. To take full advantage of big data of buildings and to enable the simulation space more close to the real geographical space, GIS with the powerful spatial analysis capabilities could be applied. For example, GIS and Repast S could be integrated to study the trends and spatial distribution of DW generation, the arrangement of DW transportation routes, the land filling site selection and so on.

Acknowledgements This research is conducted with the support of the National Science Foundation for Young Scholars of China (Grant No. 71202101); Scientific Planning Research Grant (No. 2009-K4-17, No. 2011-K6-24), Ministry of Housing and Urban-Rural Development of P.R.C.

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