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Optimizing Urban Construction and Demolition Waste Management System Based on 4D-GIS and Internet Plus

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Abstract: China is experiencing the urbanization at an unprecedented speed and scale in human history. The continuing growth of China's big cities, both in city land and population, has already led to great challenges in China's urban planning and construction activities, such as the continuous increase of construction and demolition (C&D) waste. Therefore, how to characterize cities' construction activities, particularly dynamically quantify the flows of building materials and construction debris, has become a pressing problem to alleviate the current shortage of resources and realize urban sustainable development. Accordingly, this study is designed to employ 4D-GIS (four dimensions-Geographic Information System) and Internet Plus to offer new approach for accurate but dynamic C&D waste management.

The present study established a spatio-temporal pattern and material metabolism evolution model to characterize the geo-distribution of C&D waste by combing material flow analysis (MFA) and 4D-GIS. In addition, this study developed a mobile application (APP) for C&D waste trading and information management, which could be more effective for stakeholders to obtain useful information. Moreover, a cloud database was built in the APP to disclose the flows of C&D waste by the monitoring information from vehicles at regional level. To summarize, these findings could provide basic data and management methods for the supply and reverse supply of building materials. Meanwhile, the methodologies are practical to C&D waste management and beyond.

Key words: C&D waste, 4D-GIS, material flow analysis, internet plus, management system

1. INTRODUCTION

China has experienced the world's largest and fastest urbanization process since the reform and opening in 1970s. The urbanization level has risen from 19.4% in 1980 to 57.4% in 2016 [1, 2]. The sustained and stable urbanization has led to large-scale urban construction and demolition activities, which had already caused 2.18 billion tons of construction and demolition (C&D) waste in 2015 [3]. However, the recycling rate of C&D waste was only 5% in China [4]. The rapid growth of C&D waste not only pollutes the environment, but also wastes a great amount of resources and blocks the sustainable development of environment and society. In the past decade, the State Council and ministry of construction and local governments has published a series of regulations and laws. Specifically, Shenzhen city has promulgated and implemented the regulations on the reduction and utilization of building waste. "Technical specifications for construction waste reduction" (SJG212011) has put forward specific requirements for C&D waste reduction from design, construction management and construction measures of emission reduction.

Meanwhile, to solve this pressing problem, many studies have been conducted to optimize C&D waste management both from methodologies and technologies perspectives. Construction materials are the largest flows entering urban areas after water, while they constitute of the top waste deposit [5, 6, 7,

8]. Take the material flow analysis (MFA) method for example, therefore, the study of MFA in the building sector is useful for optimizing resource and waste management and alleviating the environmental impacts. Müller (2006) used a dynamic MFA model to present diffusion of concrete in the Dutch dwelling stock from 1900 to 2100, and found that residential construction and demolition followed a cycle process [9]. Yang and Kohler (2008) estimated Chinese buildings' infrastructure and their material input and output from 1978 to 2050 through MFA [10]. To integrated with more information, a few studies used GIS as a tool to analyze and integrated MFA with geospatial information and spatial data. GIS, integrated maps and geographic analysis into general database operations (such as queries and statistical analysis), has been used in C&D waste management in recent years. Wu et al. (2016) established a model in GIS to evaluate the temporal and spatial distribution data of demolition waste management from generation to disposal [11]; Dong (2013) and Cao (2015) combined MFA with 4D-GIS to analyzed the material metabolism of urban residential buildings and their environmental impact [12,13]. To summarize, the MFA based on 4D-GIS can provide the basic data for C&D waste management, however, the reverse supply chain still needs to be built through an information interactive platform.

Besides the MFA researches to analyze the C&D waste, internet-based technology was studied as well. Song (2016) analyzed the opportunities of resource recycling in China, and found that the Internet Plus mode would improve the management and recycling of municipal solid waste (MSW) [14]. Xu (2015) built an O2O e-commerce app of MSW gathering and trading to realize the management system between residents, government and enterprises [15]. Apart from the application of Internet Plus technology in MSW management, it has been used in C&D waste management as well. Liu (2014) and Li (2016) used RFID tagging, electronic tagging and satellite positioning technologies to build a dynamic haulage vehicles supervision and management platform of excavated soil [16,17]. Su (2017) developed a construction waste management platform to achieve the online approval management, transactions, market-oriented transportation, and online payment of construction waste through Internet Plus, big data, cloud computing, location based services and other advanced technologies [18].

Throughout the challenges in the management of C&D waste, the major problems as follows: (1) imperfect law, regulatory and supervision system; (2) lack of quantities and geo-distributions (3) non-standardized transportation system and illegal dumping; (4) relatively backward disposal [19]. MFA is a systematic analysis of the material flows to estimate and forecast the material inputs, outputs and stocks of a particular system in a certain spatial scale. It has become an effective method to evaluate the flows of energy and materials within the construction sector, thereby providing present situation of resource consumption and insights into the sector's sustainability [20,22]. The combination of MFA and 4D-GIS has become an important method of studying construction sector's sustainable development. However, this method has not been used into C&D waste management in China, yet. Therefore, this study employs this method to develop an Internet Plus-based system for C&D waste management.

2. Methodology

2.1 Objectives

The C&D waste management system developed in this study mainly consists of two parts: spatio-temporal pattern and material metabolism evolution model (4D-GIS MFA model) and the reverse supply chain management APP (APP). The 4D-GIS MFA model, built on the 4D-GIS MFA, can quantify and forecast the geo-distribution of construction material inputs, outputs and stocks in buildings. Besides, the trading and information tracking of C&D waste is available on the APP. Specifically, the following goals have been set: (1) estimates of the geo-distribution of construction material flows; (2) demonstration of a geographic map of building and demolition activities; (4) establishment of an online platform for trading C&D waste; (5) quantification and further prediction of C&D waste flows.

2.2 Scope and system boundary

Four kinds of construction materials, mainly including metal, timber, concrete and bricks, have been chosen to characterize MFA of buildings materials during use stage, demolishing and constructing activities. The material inputs, outputs and stocks will be analyzed in MFA.

2.3 Material flow analysis based on 4D-GIS

In this paper, MFA is mainly applied to quantify and analyze the construction material inputs, outputs, flows and stocks from the whole life cycle stage with 4D-GIS information. Unlike the traditional MFA, it can display the spatial and temporal geo-distribution of MFA, which could be more effective to characterize material flows dynamically.

This study takes building sector as a system, and quantifies the materials flow of this system. According to MFA, the material inputs mean the demand of construction materials during construction activities. The material outputs represent the amount of C&D waste generated in a year. The material stocks, quantity of construction materials that are currently used in buildings, will be converted into outputs (C&D waste) in terms of their service lifespan (See in **Fig. 1.**). Calculations of the material inputs, outputs and stocks are expressed in Equation 1 to 3:

$$T_{-iy} = NA_{-y} \cdot N_{-t} \tag{1}$$

$$D_{-iy} = DA_{-y} \cdot M_{-d} \tag{2}$$

$$S_{-iy} = BA_{-y} \cdot P_{-s} \tag{3}$$

In which, i means the type of material, y means the y year, T means the input volume; NA means the new constructing area, N means the unit input volume index (differs from the research areas); D means the demolition waste (output), DA means the demolishing area, and M means the unit demolition waste generation index (differs from the research areas), S means the material stock, BA means the existing building area, P means the unit stock index (differs from the research areas).

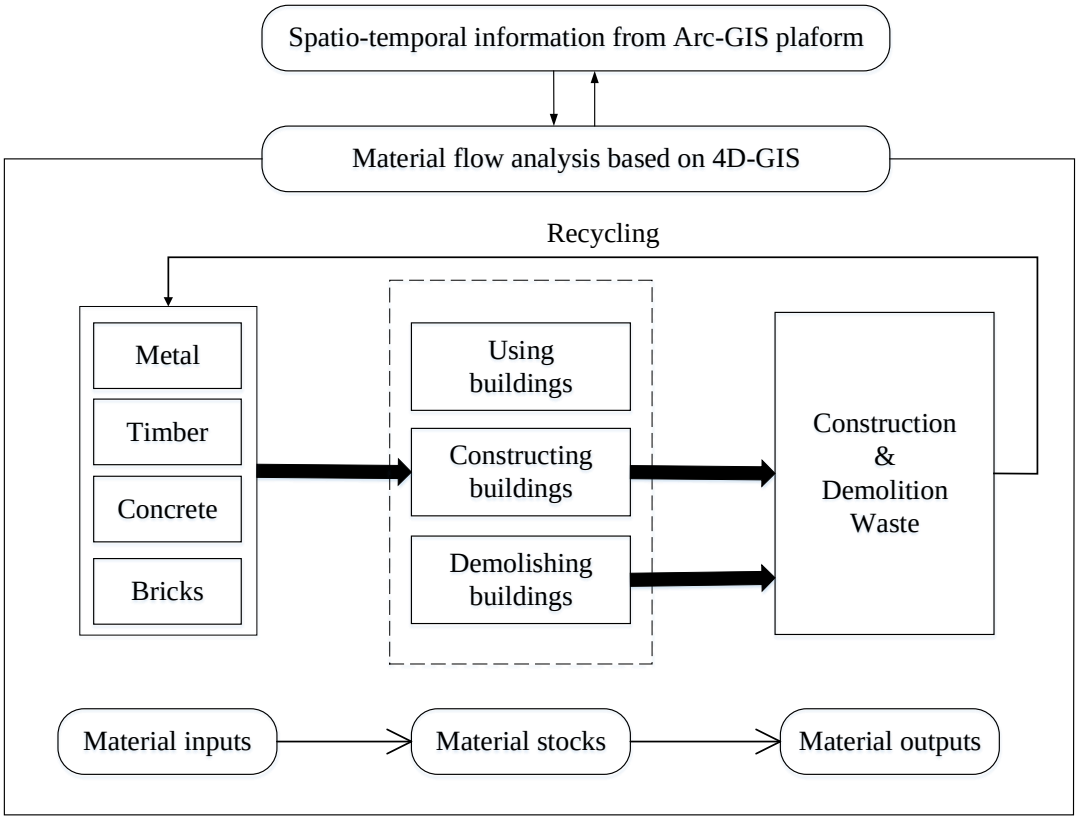


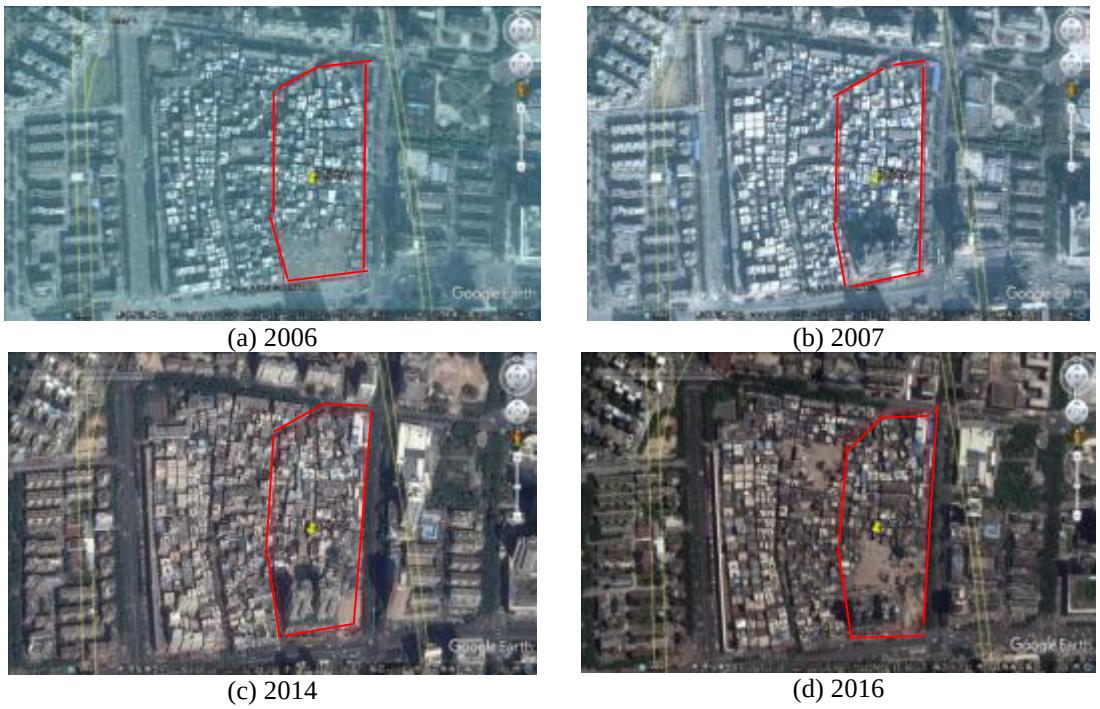
Fig. 1. The material flow analysis framework based on 4D-GIS

3. Spatio-temporal pattern and material metabolism evolution model

Based on 4D-GIS MFA theory, this study developed the 4D-GIS MFA model in Arc-GIS (a software). A case, Longwu village, was chosen as an example to display and illustrate the functions of 4D-GIS MFA model.

Longwu village, located in Shenzhen Nanshan district, has the cover area of 40499 square meters and the building area of 140384 square meters. it started to be demolished in 2013, and expected to be reconstructed in 2020.

To collect the data of Longwu village, first, this study used the Google Earth time lapse function and comparative analysis of adjacent years to collect the past construction and demolition changes from 2006 to 2016 (See in **Fig. 2.**). Second, an on-site survey was deducted to check the present geographic information and demolition in Longwu village by an unmanned aerial vehicle. Then, according to the District Plan of Nanshan 06-02 & 08 [Daxin Block] [23], this study predicted the demolition and reconstruction data of Longwu village from 2018 to 2022.



(a) 2006 (b) 2007

(c) 2014 (d) 2016

Fig. 2. Remote sensing information map of Longwu village from 2006 to 2016

Based on the data collection above, this study developed the 4D-GIS MFA model of Longwu village in Arc-GIS (See in **Fig. 3.**). Firstly, a time-series map of demolition and construction activities was demonstrated over the years in this model. **Fig. 3.** shows that the selected case has quiet frequent demotion and reconstruction activities in recent years. Secondly, a geographical map of material stocks, outputs (C&D waste) and stock was built. This study choses metallic materials and a specific phase of material flows to introduce this function of this model. Overall, this 4D-GIS MFA model could accurately quantify the amount of C&D waste and provide a C&D waste distribution map.

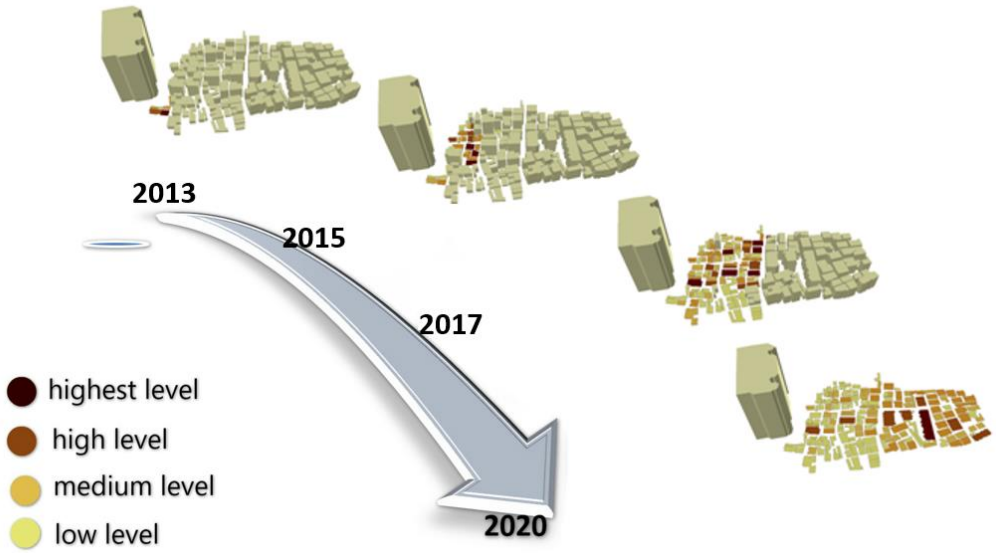


Fig. 3. Spatio-temporal pattern and material (metal) outputs evolution model

4. The reverse supply chain management APP

Given the quantity of C&D waste was obtained, this study developed a reverse supply chain management APP for dynamic management for building materials during their end-of-life stage (reverse supply chain). The APP is created as an online trading and information platform to illustrate the supplies and demands of C&D waste through GIS, big data, shared economy concept, Internet Plus and other advanced technologies. And this APP, providing a wide range of services for the main stakeholders of the construction projects, including the government, suppliers and recycling enterprises, is suitable to use in Android and IOS system by mobile phone and desktop.

Actually, to make the online trading for C&D waste effective and efficient, the users could search for target sites through regional screening and background GPS positioning function. The most economical and reasonable target site for trading will be chosen according to private needs and site supply with the combination of quantity, price and distance of the project. To solve the information asymmetry in the disposal process through information sharing, users could have comprehensive understandings of general situation of project site. The origin of C&D waste could be classified through the dynamic database provided by the APP. Meanwhile, the basic information including qualification level and contact information of relevant stakeholders will be shown to contact directly with each other for users. This will greatly break the information asymmetry in the trading process of C&D waste. In addition, supervision over the whole process of the transport vehicles of C&D waste will be completed through logistics tracking after transaction. In another word, a real-time monitoring and intelligent control platform for the whole process of the transportation of C&D waste could be established to realize the precise control of the transport of in the region as well.

Therefore, this APP can provide statistics and collection information of transport vehicle in urban cities, and the amount of C&D can be stored and further can be predicted though the data collected and the model built. Therefore, the whole process management of C&D waste could be realized through the model and the reverse supply chain management APP.

5. Conclusion

This study has established an optimized C&D waste management system, which mainly consists of two parts: 4D-GIS MFA model and reverse supply chain management APP. The 4D-GIS MFA model could offer the geo-distribution data of material inputs, outputs (C&D waste) and stocks, while the reverse supply chain management APP integrated the C&D waste data from the model with their tacking information and formed a trading platform. This system provides a C&D waste data acquisition and mining mean for efficient management. Additionally, this study formed a reverse supply chain of

construction materials. To summarize, the methodologies and new technologies used in this study provide a useful support for C&D management and recycling.

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