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CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT USING BIM TECHNOLOGY

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ABSTRACT

The amount of waste generated in construction and demolition (C&D) processes is enormous. Construction wastes are mainly generated due to improper design, poor procurement and planning, inefficient material handling, residues of raw materials, and unexpected changes in building design. Building information modelling (BIM) can efficiently manage the C&D waste by avoiding design problems, changes, and rework. This paper investigates the potential of BIM technology for supporting building design and construction processes to manage C&D waste. In particular, BIM-based approaches that can reduce, reuse, recycle, and manage construction waste through clash detection, quantity take-off, planning of construction activities, site utilization planning, and prefabrication are proposed in this paper.

KEYWORDS

Building information modeling (BIM), collaboration, process, waste management, work flow.

INTRODUCTION

The amount of waste generated in construction and demolition (C&D) processes is enormous. For example, C&D waste comprises of 25~40% of the solid waste in the United States (Winkler, 2010) and contributes around 25% of the solid waste disposed at landfills in Hong Kong (Hong Kong Environment Protection Department, 2013). C&D waste is mainly composed of wood, asphalt, drywall, concrete, and masonry (Yeheyis, et al., 2013). Construction wastes are mainly generated due to improper design (Gavilan and Bemold, 1994), poor procurement and planning (Formoso, et al., 2002), inefficient material handling (Poon, Yu and Jaillon, 2004), residues of raw materials (Formoso, et al., 2002), and unexpected changes in building design (Jaillon, Poon and Chiang, 2009). The causes of C&D waste can be resolved through integrated building design and better construction planning and management,

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which could be facilitated by building information modelling (BIM) and lean construction. BIM provides the basis for improved planning and scheduling and helps to ensure just-in-time arrival of people, equipment, and materials (Eastman, et al., 2011). A visual interface to a BIM model would enable managers to visually select the work packages for immediate execution and have their material requirements measured automatically and compiled for delivery (Sacks, Treckmann and Rozenfeld, 2009b). Lean construction also eliminates waste from the processes to improve construction planning and management and then reduced material waste by 64% (Nahmens and Ikuma, 2012). Furthermore, integration between BIM and lean construction can create the synergy effects on construction sites by improving the processes (Sacks, et al., 2009a; Sacks, Treckmann and Rozenfeld, 2009b). Integrated building design can avoid design problems and changes, thereby reducing C&D waste generation. Better construction planning and management can also significantly reduce the generation of C&D waste by avoiding construction rework, unnecessary handling and unused raw materials. Porwal and Hewage (2012) claimed that BIM implementation reduced rebar waste by 1.6%. Liu, et al. (2011), Rajendran and Gomez (2012), and Ahankoob, et al. (2014) introduced the potential use of BIM technology to minimize construction waste, but these efforts were limited to the design phase and did not discuss the specific methods to utilize BIM for C&D waste minimization.

This paper investigates the potential use of BIM technology for supporting building design as well as construction processes to manage C&D waste. BIM-based approaches to construction waste management and minimization through design validation, quantity take-off, phase planning, site utilization planning, and digital prefabrication are reviewed and discussed in this paper. These BIM-based approaches are parts of the processes and work flows that involve different participants in an architecture, engineering, and construction (AEC) project for C&D waste management planning and execution. The structure of this paper is organized as follows. The next section introduces previous studies on C&D waste management using traditional ways and BIM. BIM-based approaches to C&D waste management and minimization are then proposed, followed by the conclusions.

LITERATURE REVIEW

Many previous research has been conducted to minimize the amount of C&D waste (Lawton, et al., 2002; Jaillon, Poon and Chiang, 2009; Meibodi, Kew and Haroglu, 2014). Meibodi, Kew and Haroglu (2014) explored various methods to minimize concrete waste on site and identified key factors for waste minimization by conducting a questionnaire survey. Prefabrication and procurement management were identified as the most recommended methods for minimizing concrete waste (Meibodi, Kew and Haroglu, 2014). Jaillon, Poon and Chiang (2009) analyzed an impact of prefabrication on waste reduction in Hong Kong and the average wastage reduction rate was 52%. Lawton, et al. (2002) estimated reduction of 70% in concrete waste by using prefabrication. However, there were insufficient techniques and tools for reducing construction waste during the design and procurement stages (Liu, et al., 2011).To minimize and manage C&D waste, we need an integrated management approach and process improvement because C&D wastes are generated due to improper design, procurement and planning, inefficient material handling, residues of raw materials, and unexpected changes (Poon, Yu and Jaillon, 2004; Yeheyis, et al., 2013).

Lean strategies have been proven effective in improving processes and performance (Song and Liang, 2011) by eliminating wastes from the process (Nahmens and Ikuma, 2012). Particularly, material waste reduction was achieved through lean construction (Huovila and Koskela, 1998; Nahmens, 2007; Nahmens and Ikuma, 2012). Lean construction resulted in a significant environmental effect by reducing material waste by 64% (Nahmens and Ikuma, 2012). BIM can also enable us to minimize the amount of C&D solid waste by improving quality and accuracy of design and construction, thereby reducing design errors, rework, and unexpected changes. Therefore, several previous studies have proposed BIM-based systems or methods to manage C&D waste (Cheng and Ma, 2013; Hamidi, et al., 2014; Park, et al., 2014) and have introduced potential use of BIM to minimize C&D waste (Liu, et al., 2011; Porwal and Hewage, 2012; Rajendran and Gomez, 2012; Ahankoob, et al., 2014). Park, et al. (2014) developed a demolition waste database system based on BIM, whereas Hamidi, et al. (2014) proposed a BIM-based demolition waste management system. Cheng and Ma (2013) leveraged the BIM technology to develop a system for C&D waste estimation, disposal charging fee calculation, and pick-up truck planning. However, these studies did not proposed specific methods to minimize and manage C&D waste. To minimize C&D waste, we should manage and eliminate causes of C&D waste. Porwal and Hewage (2012) proposed a BIM-based model to analyze reinforced concrete structures to reduce waste rate of reinforcement. The model simulated architectural and structural design requirements and compared results to make necessary changes in the designs to reduce and reuse rebar waste. Although Porwal and Hewage (2012) reduced the amount of rebar waste by selecting proper length of rebars and considering available cut-off lengths, the paper focused on minimizing waste rate of structural reinforcement and did not provide a method to reduce the amount of C&D waste such as concrete and glass in general. These materials are also typical C&D wastes. Rajendran and Gomez (2012) claimed that waste could be minimized through designing-out-waste by using BIM tools. Liu, et al. (2011) and Ahankoob, et al. (2014) explored the potential application of BIM to minimize waste on a construction site by conducting in-depth literature review and analyzing causes of construction waste and current practices of waste minimization. However, they did not concretely provide how to use BIM for C&D waste minimization and management. Therefore, this paper aims to introduce and discuss the BIM-based approaches to C&D waste and disposal management. The BIM-based approaches can be integrated with lean construction to minimize and manage C&D waste by improving construction processes.

BIM-BASED C&D WASTE MANAGEMENT

C&D WASTE MANAGEMENT

C&D waste management planning consists of minimization and disposal plans. C&D waste minimization is categorized into 3R that includes reducing, reusing, and recycling the waste. Reduction is the first step to minimize C&D waste generation and the generated C&D waste should be reused and recycled to minimize disposal waste. C&D wastes that are not reused or recycled should be disposed at disposal facilities and managed. Efficient management of disposal waste is also based on calculating disposal waste amount, charging fee, and required number of hauling trucks in advance. Therefore, precise estimation and planning of the amount of 3R and disposal of waste are fundamentals of waste management planning and execution. Based on these activities, C&D waste can be minimized and monitored efficiently.

BUILDING INFORMATION MODELING (BIM)

BIM is not only a technology innovation, but also a significant shift in the overall AEC processes. Improvement of productivity and reduction of project duration and cost by using BIM have been demonstrated in many projects (Eastman, et al., 2011). Furthermore, BIM can reduce waste-related costs and materials in construction projects (Krygiel and Nies, 2008). However, there has been no technique and tool available that explores BIM as a platform to minimize C&D solid waste. Therefore, this paper investigates how BIM can be implemented to minimize and manage C&D waste on a construction site. Typical BIM uses that can be implemented in planning, design, and construction phases were identified through literature review (Table 1). The BIM Project Execution Planning Guide (Anumba, et al., 2010), which has been referenced by many BIM guidelines and standards because this was an early version of the BIM guideline, introduced various BIM uses and their descriptions. The BIM Guideline of New York City (Bloomberg, Burney and Resnick, 2012) also presented BIM uses, but the BIM uses were similar to those of the BIM Project Execution Planning Guide.

Table 1. BIM Uses in Plan, Design, and Construction Phases

BIM use	Phase		
	Plan	Design	Construction
Existing conditions modeling	O	O	O
Quantity take-off (cost estimation)	O	O	O
Phase planning (4D simulation)	O	O	O
Programming	O	O	
Site analysis	O	O	
Design reviews	O	O	
Design authoring		O	
Engineering analysis		O	
Code validation		O	
3D coordination (clash detection)		O	O
Site utilization planning			O
Construction system design			O
Digital fabrication			O
3D control and planning			O

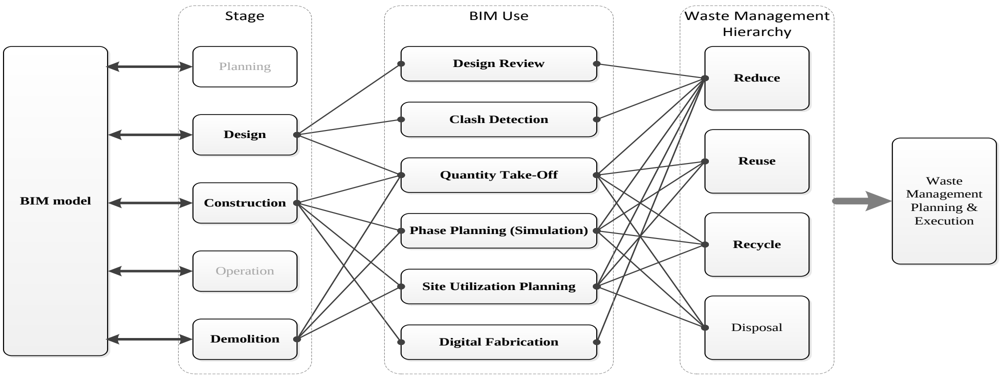

Figure 1. BIM-based Approaches to C&D Waste Management

We investigated potential application of several BIM uses that can reduce improper design, residues of raw materials, and unexpected changes in building design and improve procurement, site planning, and material handling in construction management. The BIM uses selected in this paper were quantity take-off, phase planning (or 4D simulation), design reviews, clash detection (or 3D coordination), site utilization planning, and digital fabrication. Figure 1 shows the BIM-based approaches to manage C&D waste in design, construction, and demolition phases. The proposed approaches are not simply technologies, but also involve a process shift that involves different project participants. Therefore, collaboration among participants is required for BIM-based C&D waste management, which is aligned with lean construction. The selected BIM uses can also reduce various types of waste that can be removed by lean construction. Although the typical types of waste related to lean construction are waiting, motion, processing, over-production, conveyance, inventory, and correction waste, this paper focused on the types of waste that can affect C&D waste management, which were over-production, conveyance, inventory, and correction wastes. Table 2 shows the types of waste that can be reduced with each BIM use through literature review (Young, et al., 2009; Eastman, et al., 2011; Azhar, 2011). These wastes are managed by lean techniques like Just-In-Time, total quality control, continuous improvement, and value-based strategy (Eastman, et al., 2011; Azhar 2011). The approaches to implement the selected BIM uses and lean construction in order to minimize and manage C&D waste will be further discussed in this paper.

Table 2.Relations between BIM uses and types of waste

BIM use	Waste type			
	Over-production	Conveyance	Inventory	Correction
Design validation		O	O	O
Quantity take-off	O	O	O	O
Phase planning		O	O	O
Site utilization planning		O	O	O
Digital fabrication	O	O	O	O

DESIGN VALIDATION – DESIGN REVIEWS AND CLASH DETECTION

Design errors are common in the AEC industry because a building consists of components which are designed by different project participants such as architects, structural engineers, and mechanical, electrical, and plumbing (MEP) engineers. These design errors may lead to rework and C&D waste. BIM-based approaches to C&D waste minimization by eliminating design errors detected in construction are design reviews and clash detection. Design review is implemented to quickly analyze design alternatives and resolve design and constructability issues. Clash detection is a coordination process to determine field conflicts by comparing 3D models of building systems and eliminate the conflicts prior to installation (Anumba, et al., 2010). Detecting and resolving building element clashes and other causes of rework were chosen as the most beneficial ways of using BIM (Young, et al., 2009) and have become common BIM practices, called a BIM-based design validation process. BIM-based design validation can improve design quality by reducing the number of design errors, change orders, and rework (Khanzode, Fischer and Reed, 2008; Williams, 2011). Khanzode, Fischer and Reed (2008) found that the rework costs in electrical work in a hospital project were reduced to 0.2% of the work costs through BIM implementation, although 1–2% of electrical work costs is generally incurred as rework costs due to design changes in similar projects. Consequently, the design validation can reduce the amount of C&D waste by preventing change orders and design errors in design and construction phases. Lean construction also reduces correction waste producing a part that is scrapped or requires rework. Integration between BIM and lean construction can create a synergy effect on C&D waste reduction by eliminating rework.

QUANTITY TAKE-OFF

C&D wastes are generated due to improper residues of raw materials and poor procurement and planning (Poon, Yu and Jaillon, 2004; Yeheyis, et al., 2013). Therefore, it is important to accurately estimate the amount of materials required on a construction site to reduce unnecessary raw materials and improve a procurement process. A process in which a BIM model can be used to accurately perform quantity take-off in the design and construction processes and provide modifications with potential to save time. The BIM-based quantity take-off as well as lean construction prevents the amount of over-production producing unnecessary materials. Furthermore, BIM-based quantity take-off can explore different design options and concepts by considering the perspective of C&D waste management. Based on quantity take-off, proper length, area, or volume of materials can be ordered. Furthermore, available cut-off length, areas, or volume can be considered to maximize the amount of C&D waste that can be reused and recycled. Porwal and Hewage (2012) claimed that consideration of proper length of rebar and available cur-off length reduced 1.6% of waste of structural reinforcement by maximizing the reuse rate of remained rebar. Remained materials should be appropriately stored to reuse them for other activities on a construction site or dispose. While the remained materials are stored for other purposes, additional C&D waste may be generated due to inefficient material handling. Therefore, we need a plan to manage the remained raw materials on site.

BIM-based quantity take-off can also be utilized in demolition and renovation projects. Accurate quantity take-off using BIM can help calculate the amount of C&D waste, disposal charging fee, and required number of pick-up trucks (Cheng and Ma, 2013). The precise results help participants manage waste. Cheng and Ma (2013) compared the total volume of demolition waste estimated by using the Spanish model provided by Solis-Guzman, et al. (2009) and BIM. The total volume of demolition waste based on the traditional way was 15.8% different from the result using BIM.

PHASE PLANNING (4D SIMULATION)

Phase planning based on integration of a schedule and BIM model enables to effectively plan the phased occupancy and show the construction sequences and space requirements on a construction site. BIM model can be integrated with planning of human, equipment, and material resources for better schedule and quantity, identify, and resolve space and work space conflicts ahead of the construction process (Anumba, et al., 2010). A well-planned and smoothly-executed construction process can reduce errors, rework, and generation of C&D waste.

Procurement status of project materials can be monitored through BIM-based phase planning. The right amount of right materials should be delivered and made available on site when they are required because early material delivery may lead to inventory problems, unnecessary moving, and material deterioration due to weather conditions, which could increase the amount of C&D waste. BIM can also track and manage the supply chains of different building components and materials. Precise scheduling enables just-in-time delivery of materials and equipment, reduction of the amount of C&D waste by decreasing a likelihood of damages, and maximization of reusing and recycling rate of generated C&D waste by forecasting appropriate time to use the remained waste. The generated disposal waste can be also managed efficiently by forecasting accurate location and time that disposal waste will be generated on site.

SITE UTILIZATION PLANNING

Inappropriate material handling is one of the major causes to generate unexpected C&D waste. Better site layout planning improves the movement of materials and reduces the number of double handling of materials, which effectively reduce material wastage by reducing the number and distance of material handling (Ahankoob, et al., 2014). Site utilization planning based on a 4D model and quantity take-off graphically can calculate the amount, location, and time of expected C&D waste to be reused, recycled, and disposed on site with the construction activity schedule. Equipment and storage space for reusing, recycling, and managing C&D waste can be analyzed and planned.

DIGITAL PREFABRICATION

The use of precast concrete and prefabricated steel elements can reduce C&D waste on site. The use of prefabricated elements could reduce the amount of construction waste by 52% (Jaillon, Poon and Chiang,2009). However, prefabrication is technically challenging because accurate dimensions are required early in the design process and proper installation is then needed on site. BIM digitally provides accurate detailed geometrical representation of each building component and allows the geometrical information to be exported to data formats used in fabrication shops. Fabricators can manage and automate a fabrication process using information extracted from BIM models. Moreover, BIM-based digital prefabrication enables lean construction and material handling efficiently by reducing the number of material handling on site.

WORK FLOW OF BIM-BASED C&D WASTE MANAGEMENT

Since the selected BIM uses for C&D waste management change design and construction processes, they may also affect work flows for waste management (Figure 2).To reduce C&D waste in design and construction phases, design errors, change orders, and reworks should be eliminated through BIM-based design validation, quantity take-off, and digital fabrication.

The first step for BIM-supported C&D waste estimation is to extract quantities of each material from a BIM model and integrate them with a construction schedule. Based on quantity take-off and a predefined C&D catalogue, we classify C&D waste into inert waste like concrete and non-inert waste like wood without additional time and efforts. Then, the volume of C&D waste, disposal charging fee, and required number of pick-up trucks can be accurately estimated using the waste index and help architects and contractors plan C&D waste management at the beginning stage of a project. The C&D waste generated on the construction site can be managed efficiently through site utilization planning based on BIM models that are integrated with the quantities and project schedule.

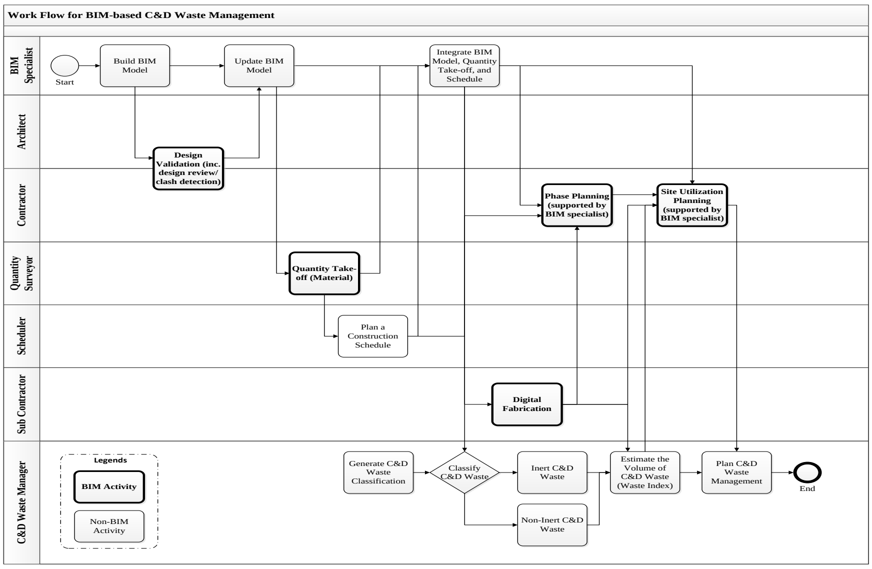

Figure 2. An Example of the Work Flow for BIM-based C&D Waste Management

CONCLUSIONS

C&D wastes are generated due to improper design, poor procurement and planning, inefficient material handling, residues of raw materials, and unexpected changes in design, construction, and demolition phases. This paper investigates the potential of BIM technology for supporting integrated building design and construction processes to eliminate the major causes of C&D waste generation and manage the waste. We explored that C&D waste could be reduced through design reviews, clash detection, quantity take-off, phase planning, site utilization, and digital prefabrication. In addition, C&D waste could be reused and recycled by managing a process based on quantity take-off, phase planning, and site utilization planning. The minimized and disposed wastes could be monitored by BIM-based waste management planning and execution. Integration between BIM and lean construction can create the synergy effects on C&D waste reduction on site by eliminating waste from processes.

Since the BIM-based approaches and lean construction focus on the process changes that involve different types of project participants, close collaboration among them is required for C&D waste management. However, this paper does not provide expected or actual benefits associated with C&D waste minimization and management using the proposed BIM-based approaches. In the future, these approaches will be attempted in pilot BIM projects to evaluate the actual effectiveness of BIM for minimizing and managing C&D waste in AEC projects.

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