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Optimizing Project Demolition Using Integrated Building Information Modelling (BIM) and Lean Construction Approach

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Highest amount of Construction and Demolition (C&D) wastes are produced during the demolition phase of building lifecycle stages, which results in significant loss of natural resources, and exhibits adverse environmental impact globally. BIM processes and Lean principles have been used in improving demolition waste management on the individual aspect basis; however, the synergies of both these systems are not fully explored especially during demolition stage. This paper focuses on alignment of integrated Lean-BIM processes to optimize the waste reduction aspect during project demolition phase. The method involves (1) developing 3D BIM demolition model using a selected real-time demolition project as a case study, and (2) establishing a client's need-based model of salvaged elements, using the developed 3D BIM model, for deciding the destination of demolished material as a Lean Construction approach. This approach can be expected to improve the rate of reuse and recycle of demolished material, that can ultimately lead to saving natural resources by sending less material to landfill/disposal sites.

Key Words: Demolition, Building Information Modeling (BIM), Lean Construction, 3D Model

Introduction

The Construction and Demolition (C&D) waste is defined as a mixture of debris materials generated from construction, rehabilitation, renovation, and demolition processes. The construction industry has been severely confronted with its negative economic, environmental, and social impacts throughout the whole building life cycle (Shen, Tam, Tam, & Drew, 2004). The key problem of C&D waste is the generation of highest waste rate compared with other industries (Yuan & Shen, 2011). Developing the strategies to manage C&D waste is becoming urgently required by all the stakeholders involved in the process, all over the world. Some of the current research highlights that waste minimization regulations do not sufficiently incentivize owners, contractors, and subcontractors to take preventive actions to eliminate waste during the building demolition stage (Karaz, Teixeira, & Rahla, 2021). The intensification of adoption of Building Information Modelling (BIM) has given a significant push to the implementation of Lean principles within the construction industry (Karaz et al., 2021). With the revolution going on in the industry for managing the demolition waste generated from a project, the BIM practitioners started recognizing Lean strategies as underlying processes for various BIM usage implementations. There has been an increase in the interest of visual components of BIM and Lean concepts, with multiple notable studies investigating the possibilities of Lean and BIM interactions (Sacks, Koskela, Dave, & Owen, 2010a). Recent research on BIM and Lean Construction shows that there is a need of significant synergy between these two areas. This paper discusses the alignment of integrated Lean-BIM processes to optimize the waste reduction aspect during project demolition phase. It is a notable point of discussion that the BIM-Lean synergy is not only limited to the design phase, as it might seem to be limited to, but also extends over the whole project life-cycle phases with the rapid advent of multi-dimensional BIM capabilities (Lean Construction Blog, 2022).

Impact of BIM in Project Demolition Phase

Building Information Modeling (BIM) is the process and practice of virtual design and construction throughout the project lifecycle phases (Eastman, Eastman, Teicholz, Sacks, & Liston, 2011). According to the National BIM Standard, Building Information Model is "a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from earliest conception to demolition" (NBIMS, 2010). Contributing evidence has been found regarding the capability of BIM functionalities in providing the end-of-life scenario analysis for a project. For an example, the researcher has demonstrated how the deconstruction and demolition plans can be obtained from a project BIM model (Akinade et al., 2017).

Over the last several decades, the significance of demolition and renovation (D&R) work has grown to a considerable extent and accordingly the volume of D&R debris disposed to the landfills, particularly in big cities, have increased throughout the world (Li et al., 2020). Quantitative waste prediction has been a crucial subject for managing the demolition waste, which can enable the contractors to critically plan and manage the waste generation processes and to plan waste control strategies in the demolition stages. A considerable amount of literature provides a picture of the latest developments in providing BIM-based tools for construction and demolition waste (CDW) management (Nikmehr, Hosseini, Wang, Chileshe, & Rameezdeen, 2021a). BIM-based tools and technologies for dealing with CDW throughout the whole life cycle of construction have been investigated at various levels. Research findings show that although various BIM-based technologies are closely associated with CDW, many of which only have focused on the design and construction phase and the problem of CDW in post-construction and demolition phases has received little attention (Nikmehr, Hosseini, Wang, Chileshe, & Rameezdeen, 2021b). In the current scenario, the available BIM tools and technologies are found to be lacking when dealing with project demolition waste aspects and are weak in theoretical accuracy (Marzouk, Elmaraghy, & Voordijk, 2019).

Since it is hard for contractors to come up with the 3D view of project from different traditional 2D drawings, the visualization capacity of BIM provides a better understanding of what the final product may look like. A common thread runs through all BIM software, i.e. Parametric Modelling, which is a characteristic that enables visualization of the aesthetics and functions of buildings (Sacks, Koskela, Dave, & Owen, 2010). This feature has aided the adoption of BIM across the construction industry to improve project delivery and building performance. Similarily, during project demolition phase, architects and designers can provide rendering and walkthroughs to better communicate the concept of project demolition sequential steps to the customer or end user (in case of salvaged material buyer) using BIM based 3D model. (Marzouk, Elmaraghy, & Voordijk, 2019b). Furthermore, virtual mockups of sequential demolition steps for a building can be provided to the owner and other stakeholders for decision making. This approach helps to visualize, better understand, and make decisions on the aesthetics and the functionality of the space available to the building owner after demolition gets completed in actual.

Lean Construction in Project Demolition Phase

Lean Construction (LC) is referred as the method of production in the construction industry, aimed at reducing costs, and saving material, time, and production effort (Akers, 2016, Warcup, 2015, Karaz et al., 2021). Usage and application of Lean concepts in the deconstruction and demolition phase of projects was found to be rarely mentioned in the literature. However, some insights have been found using the principles that directly conform with those adopted by Lean, for example Pull Planning principles. Schultmann & Rentz (2002) and Marzouk et al. (2019) have somehow referred to the efficiency of using Pull-planning principles in the demolition projects. This principle of Lean promotes pulling the data from downstream instead of the traditional push approach, using the Pull Planning strategy. This can be done by first selecting the building elements to be dismantled and demolished based on the end-customers' needs, and then designing the demolition plan backwards from the that point to reach the desired outcome. Thus, the Pull Planning strategy aids in engaging the customers in the early decision making for prioritizing the demolition plan.

The process of early planning and decision-making in the deconstruction and demolition process is related to making effective real-time decisions early in the process, before the actual demolition begins, on which building elements to be reused, repaired, refurbished, recycled, or sent to the landfills. (Marzouk et al., 2019). Early involvement of stakeholders can serve as a stepping-stone in engaging the demolition contractors and the end-users (customer) willing to purchase the salvaged elements, early in the decision-making of demolition process. Early planning and involvement of potential buyers aid in effective and efficient decision-making process for designing and strategizing the project demolition plan, as per the customer's demand of salvaged and demolished material. From demolition perspective, an important Lean principle related to value generation, which promotes the validation of products against the planned specifications and customer requirements (Sacks et al., 2010). In the context of project demolition, verification, validation, and assurance that all the salvaged elements are dismantled or demolished according to the planned sequence, and that they meet the end-user's requirements, are considered as key parameters or performance indicators that satisfy the customer satisfaction aspect of Lean.

Deconstruction and demolition process can be performed in phases for obtaining the lessons learned from each phase to verify and validate the adopted methodology of Lean based demolition. This principle of Lean promotes the aspect of in-person visual inspections compared to traditional reports (Johnson, Smith, & Mastro, 2012). This concept stresses on the importance of site visits for visual inspection (Sacks et al. 2010). In the context of demolition, visual inspection parameter evaluates both the building's actual current condition and the demolishing elements that have high recovery potential. It is also important for the end-customers who are interested in buying the salvaged elements to visually inspect the quality of demolishing building components before purchasing them. It is worth noting that inspecting the demolition process from the beginning would help in understanding what have been noticed to improve the process and recommending what better can be done for future to improve and restore the quality of demolished and salvaged material for their better re-use in other projects. One of the important principles of Lean is finding simplicity within complex projects (Kalsaas, Skaar, & Thorstensen, 2015) and structuring of the demolition workflow process to separate the standard or similar demolition activities from those demanding the change in information

(Sacks, Derin, & Goldin, 2005). In the context of project deconstruction and demolition, an example of simplicity can be found in trying to detect patterns between the different types of elements that have the same dismantling patterns or methods. Furthermore, another form of process standardization in project demolition is about separating the standard tasks from those subject to information change. This can be achieved by detecting the salvaged elements that are difficult to dismantle and separating their demolition activities from those elements that can be dismantled easily (Marzouk et al., 2019b).\

Development of 3D Demolition Model

An actual ongoing project was used as demolition-based case study for the BIM-Lean based demolition waste management analysis. The 3D model development process begins with the collection of 2D drawings and floor plans of the building from the project owner due to the age of buildings. After the collection of all set of building drawings, a study of structural, architectural, plumbing, and HVAC elements of the building was conducted to understand the building design and analyze the level of design complexity. Further, real-time camera images were taken prior to the start of demolition process for physical analysis of actual condition of the building elements which were to demolish. Later, using the 2D drawings and camera images of building components, 3D model has been constructed using Revit (Figure 1), for reconstructing the demolition model of the building. Due to time limitation, the reconstruction of 3D demolition model was limited to only two rooms of second floor of the building in demolition.

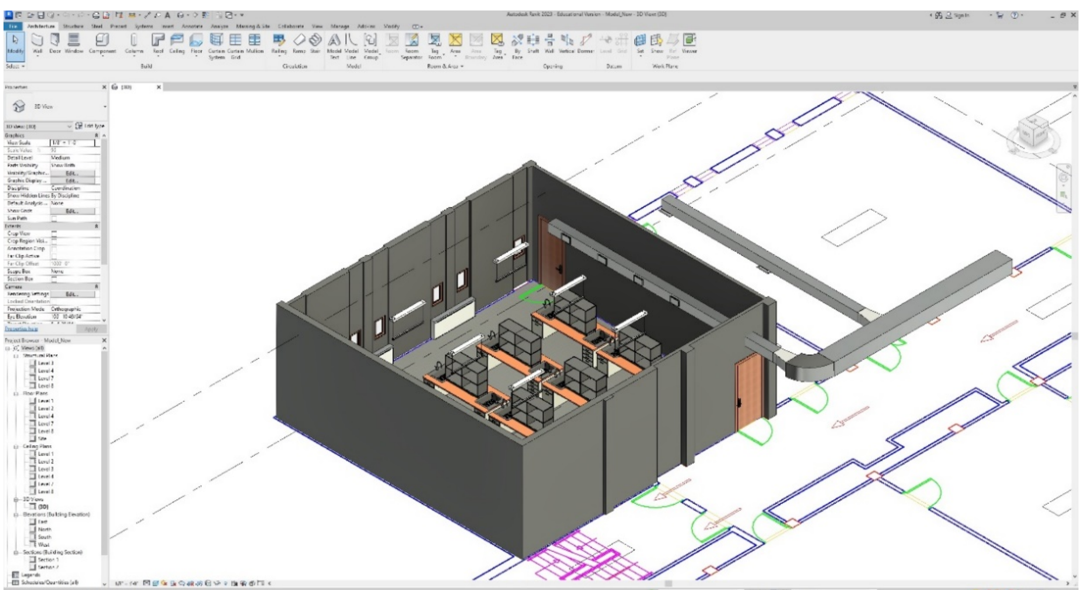

Figure 1. 3D BIM Demolition Model Developed with Revit

After integrating the 2D drawing/floor plans and actual photos of the building elements to be demolished with the reconstructed 3D BIM model, a category-based list of building elements, including furniture, door and windows, light fixtures, plumbing and firefighting accessories, etc. is generated for formulating the Re-use, Recycle, and Disposal destination of the demolished elements in order to optimize the demolition process and deciding final destination of salvaged building material (Table 1).

Using the reconstructed 3D BIM model as mentioned above, material characteristics-based categorization of building elements has been established, by analyzing the current condition and life of building elements (with the help of camera photos available). The purpose of this step is to segregate the building elements based on their characteristics and re-usable capabilities, to classify them into a framework of Re-use, Re-cycle, and Disposal/To-be Landfill categories (see Figure 2). The basic aim of this strategy and designing the material category-based framework is to plan and direct the destination of demolished building elements.

The material or the building elements with least re-usable condition and below acceptable standard life will be sent directly to disposal without any further process on them. Material possessing re-usable or re-cyclable characteristics (by visualizing the photos) will be considered for their reuse into other similar projects, based on the input and requirements from building owner or stakeholders (client) using the information obtained from constructed 3D BIM demolition model (Table 1).

Table 1. Demolished material categorization of building elements using 3D model visualization

Demolishing Material Category	**Reuse**	**Re-cycle**	**Disposal/To-be-Landfill**
Civil/Architectural Elements			
Furniture (wooden shelves)			
Furniture (tables)			
Flooring (tiles)			
Concrete (column)			
Concrete (wall & floor)			
Ceiling			
General Doors			
Fire Doors			
Window Glass			
Window Frames			
MEP Elements			
Ceiling Lights			
Table Sinks			
Electric Unit Ventilator			
HVAC Elements			
Grills and Diffusers			
Square Duct			
Duct Connector			
Duct Connector (90º)			

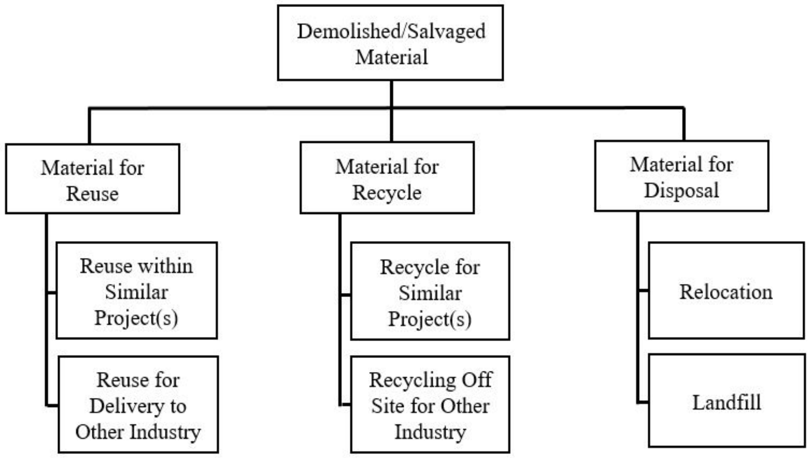

Figure 2. 3D BIM model-based demolition material categorization framework

Discussion

The utilization of created 3D BIM demolition model encourages the involvement and participation of the project owner, i.e., client, in planning and directing the demolition process. Based on the reconstructed 3D BIM demolition model and the building images available of the items to be demolished, inputs from the building owner/project client can be taken at this point for prioritizing the demolition activities based on clients' demands of building elements to be demolished. Development and use of as-built 3D BIM demolition model (using Revit and Navisworks software) can aid and simulate in linking the demolition flow process with the supply of salvaged elements, aligning with the customer's needs. Model simulated on Navisworks, linked with the real time images of building elements, can provide good visualization for clients to make early decisions on whether to Re-use, Re-cycle, or Disposed the material. Figure 3 below depicts how this synchronized decision-making process can work for optimizing the best use of demolished material.

At this stage, one of the core principles of Lean, i.e., Customer Satisfaction, gets involved in the deconstruction and demolition process. As the customer can be mainly the potential buyer of these dismantled salvage material, so the quality of salvaged building elements to be dismantled can be visualized and analyzed even prior to the start of the actual demolition process. The customer can be from recycling facilities background that deal with the new construction projects that directly reuse the salvaged elements into their other new projects, resulting a considerable amount of monetary saving for procuring new construction material.

Based on the proposed client's requirement-based demolition model and waste management framework, material's Re-use, Re-cycle and Disposal destinations can be planned prior to start of actual demolition. Use of BIM model provides visualization of building elements that are to demolish, to the stakeholders (client) in pre-demolition stage. This approach can be expected to potentially enhance the decision-making process for the salvaged and demolished material for planning their destination in advance before actual demolition process starts. This study is expected to promote a behavior change in the construction industry towards improving the circular economy by encouraging salvaged material Re-use and Recycle strategies and lowering the disposal of demolished material to the Landfill sites. Further, for future work, BIM based project demolition cost information can help the project team to forecast and estimate complete demolition cost. It can aid in decision-making process for the project owner and other stakeholders for initiating the demolition process based of material's cost-effective reusability factors. Identification of demolishing material in pre-demolition phase can potentially assist in formulating waste management strategies as per the need of the customer/buyer of salvaged material.

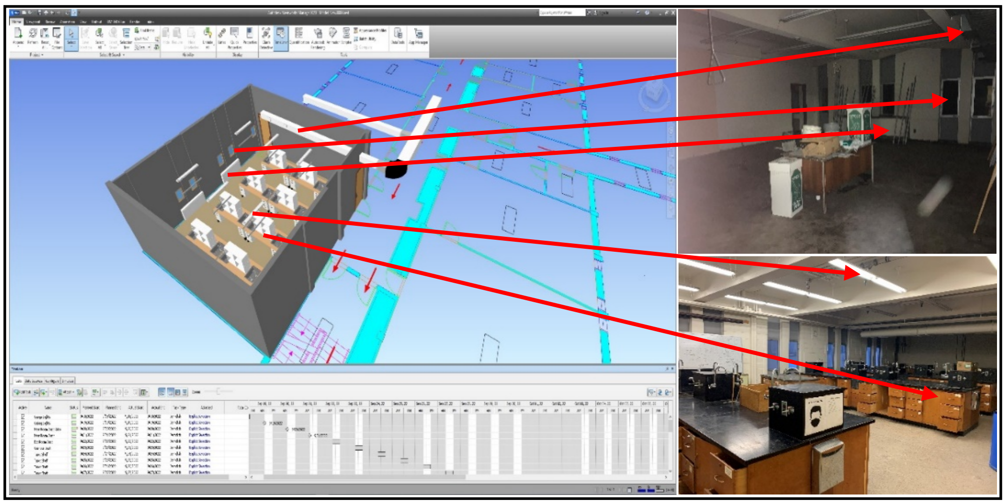

Figure 3. 3D BIM Model-based Simulation of Demolition Process

Conclusion

This paper has explored the usability of reconstructed 3D demolition model to analyze the integrated approach of BIM and Lean Construction for developing client's requirement-based demolition model and waste management framework. Based on the study on BIM-Lean synergy at project demolition stage, and analysis of the reconstructed 3D demolition model, the conclusions that can be drawn are:

- the use of reconstructed 3D demolition model provides visual environment for the client, in pre-demolition stage, which can potentially enhance the decision-making process for the salvaged material;
- the use of BIM model provides visualization of building elements that are to demolish, and thus making demolition waste management plans more efficient due to planning of the final destination of salvaged and demolished material prior to the start of actual demolition; and
- the identification of demolishing material in pre-demolition phase assists in formulating waste management strategies as per the need of the client.

A combination of the conclusive findings indicates that the approached presented in this paper can help improve the rate of reuse and recycle of demolished material, that can ultimately lead to sending less material to landfill/disposal sites. Further, logistical costs of mobilizing unnecessary (unwanted) demolished material to the landfill sites can also be efficiently reduced to a greater extent. Deciding demolished material's destination prior to start of actual demolition can aid to resolve mismanagement of bulk demolished building material handling and storage at project site. Overall, more resources can be preserved.

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