Building information modeling (BIM)

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BIM is defined as the“digital representation of physical and functional characteristics of a facility”. It is the process of producing and maintaining project related information throughout the different phases of the building life cycle. The information not only constitutes geometric properties of the building elements, but also extends to include any customized information related to the building. There are various uses for BIMs, which include 3D visualization, 4D scheduling, quantity take-off, etc. Although the use of BIM functionalities is an active field of research, exploiting the advantages of BIM in the deconstruction stage remains limited.

Keywords: building information modeling (BIM) ; design for deconstruction

1. Introduction

The construction industry is considered one of the major contributors worldwide of waste streams [1]. Construction and demolition waste (C&D) represents 25 to 30% of all the waste generated in the EU [2]. Hosseini et al. [3] reported that the amount of salvaged materials being recovered and pumped back into the supply chain is considered less than the waste. This leads to a significant loss in materials and energy opposed by an increasing demand of virgin materials to meet the ever-increasing consumption rates [4]. The rising rate of demolition projects is caused by several reasons. Buildings are designed to last longer, however, the change in the users’ functional needs are quite dynamic. This leads to a “use life cycle” of building materials that are shorter than their technical life cycle. In addition, conceiving our buildings as static, rigid structures with fixed connections hinders the possibility of the adaptability and reuse of building elements [5]. However, the recent years have witnessed a thorough investigation of barriers in adopting deconstruction planning processes that promote a circular loop supply chain in construction.

Time constraints are considered one of the main barriers in adopting less invasive deconstruction processes. Demolition contractors believe that deconstruction processes that focus on high material recovery is a time-consuming process with respect to mechanical demolition, which saves a lot of time [6]. Another complexity lies in the uncertainties related to the undocumented building conditions [7]. Most of the salvaged elements in a building are retrieved at the end of the building life cycle [3], where at that time, the building might lack a clear documentation of the modifications and changes applied throughout the operation and maintenance phase. Accordingly, precise evaluation of the current status of building elements remains a challenge. Not only do building conditions contribute to the uncertainties, but the logistics related to selling the salvaged elements are also a major source. This includes time, quantity, and location of the elements to be picked up and sent to the client for recovery or direct reuse [8]. In case these items still have an undefined destination, it will require a storage location whether on or off-site, which incurs more costs. Furthermore, in the case of on-site storage, it could affect the project schedule [9]. Therefore, deconstruction planning for the buildings should be executed with sufficient time before the actual demolition process starts. It should also be backed up by a clear understanding of the building conditions, detailed information about its elements and their recovery options, and the market needs for such elements. In this way, it is possible to optimize the deconstruction process to efficiently perform the dismantling of salvaged elements [10] with high recovery potential before the mechanical demolition activities take place.

2. Planning of the Deconstruction Processes

At the end of the building life cycle comes what is known as the “demolition phase”. Demolition is a linear process; it removes the building out of the supply chain loop. This is because demolition involves the elimination of all building elements at the end of the building life cycle and sending them to landfills [11]. This process produces gigantic amounts of debris, resulting in adverse environmental impacts [12]. On the other hand, deconstruction is emerging as an alternative to the demolition processes. Deconstruction is the systematic dismantling of buildings in order to maximize the recovery potential of building elements. The planning of the deconstruction process in a building is partly tied to what is called "reverse logistics". This term was identified as "the process of planning, implementing and controlling the efficient, effective inbound flow and storage of secondary goods and related information opposite to the traditional supply chain direction for the purpose of recovering value or proper disposal" [13].

Schultmann and Sunke [14] distinguished between recovery on the modules (an assembly of elements) or elements level and the recovery on the materials level. In a closed loop system, the smaller the loop, the less energy and material wastes are dissipated from the process. This means that recovery at the material level is regarded as the lowest recovery option as the element no longer exists in its original form, and it undergoes a "downcycling" process. However, the material is still in the supply chain loop, unlike the conventional disposal or incineration and being sent to landfills. Deconstruction is also described by the term "selective deconstruction" or "selective dismantling" [7]. This term was identified by Schultmann and Rentz [10]. The word "selective" points out the static nature of the current buildings, which makes it difficult to dismantle all the building elements available. Project planning, in general, constitutes two main components: strategic and operational. Accordingly, and in order to meet the required project goals, the deconstruction processes are planned both on the strategic and the operational level [7]. Strategic planning is more related to decision making on the macro level, while operational planning focuses on breaking down the work packages and planning the regular work on the tactical level. For instance, minimizing the overall project duration is considered a requirement for the strategic planning of a project. On the other hand, getting into the details of each activity in order to minimize its duration belongs to operational planning. Operational planning is considered "detailed scheduling", which is conceived from the strategic decisions made and the overall estimation of the general requirements. Therefore, the decisions made on the strategic level represent the reference that the operational goals and requirements are set up upon. Thomsen et al. [11] provided a detailed review of the deconstruction planning methods in the literature applied to both the operational and strategic levels. Since there is an obvious difference between the methods focused on strategic planning and others on operational planning, the research was classified based on the adopted planning method.

Several research efforts [15][16][17] have proposed a decision support system based on the analytic hierarchy process (AHP). The tool they developed helps in deciding between the different demolition techniques based on economic, environmental, technical, and social criteria. The three strategies to choose from include progressive demolition, which is the controlled removal of sections of the structure; deconstruction or dismantling a structure, which is usually carried out in reverse order of construction; and finally, the deliberate collapse mechanism or what is known as mechanical demolition. The latter strategies are then assessed quantitively against the overall costs, where selling salvaged elements recovered in both the first and second strategies are deducted from the costs incurred. Moreover, Anumba et al. [18] continued toward an explanation of different demolition techniques for the contractor to choose from. This was followed a presentation of the criteria needed for the selection of the optimum demolition technique. These criteria included time constraints, financial constraints, environmental considerations, and recycling considerations. However, the results were not formulated into a decision-making model. Instead, the author provided guidelines on selecting the most convenient strategy based on the mentioned criteria.

Liu et al. [19] proposed a detailed cost analysis to evaluate the economic performance of different strategies. Based on actual case studies, the authors concluded that deconstruction was the best strategy to be adopted for the cost savings it guarantees. Kourmpanis et al. [20] introduced a multi-criteria decision-making model (PROMETHEE II) to investigate the different waste management strategies at the end of the building life cycle. The research was more focused on the material recovery options rather than focusing on the reuse potential of the building components. The proposed material management system relied on several criteria. These criteria were classified under four groups: social-legislative, environmental, economic, and technical. Schultmann and Sunke [21] extended their work to include the amounts of energy savings due to different construction strategies. Moreover, Volk et al. [22] managed to link the strategic and operational planning by developing a decision-making system that plans the organization resources to solve multi-project scheduling problems. Afterward, Sunke [23] introduced different optimization models for deconstruction planning, however, it should be noted that these models did not consider uncertainties in their objective functions.

3. Use of Digital Technologies in Deconstruction Projects

BIM is revolutionizing the architecture, engineering and construction (AEC) industry. BIM is defined as the [24] "digital representation of physical and functional characteristics of a facility". It is the process of producing and maintaining project related information throughout the different phases of the building life cycle [25][26]. The information not only constitutes geometric properties of the building elements, but also extends to include any customized information related to the building. There are various uses for BIMs, which include 3D visualization, 4D scheduling, quantity take-off, etc. Although the use of BIM functionalities is an active field of research, exploiting the advantages of BIM in the deconstruction stage remains limited [27]. The development of BIM-based tools exploiting the domain of waste minimization in the construction industry can be classified into three groups. The first focuses on assessing the de-constructability of buildings or to what extent they are designed for disassembly (DFD) and circular economy [28][29]. The second focuses on construction waste minimization [30], while the third is concerned with the waste associated with the demolition or renovation of buildings and evaluating different deconstruction options [31][32][33].

The work of Akbarnezhad et al. [31] involved the development of a BIM-based plug-in to assess different deconstruction strategies. The operational flow of processes relied on customized deconstruction-related attributes. These attributes are then attached to its corresponding BIM object. Then, the proposed tool analyzes the data entered and depicts the suitable overall deconstruction strategy that achieves the optimum solution in terms of costs, energy use, and carbon footprint. This BIM-based framework included the environmental aspects in the decision-making criteria. These aspects were not only related to on-site activities, but also extended to include the transportation logistics. For instance, the carbon emissions caused by the transportation trucks hauling the salvaged materials to the recycling or disposal facilities were included in the assessment criteria. It is worth noting that recycling facilities process different varieties of construction materials [34][35][36].

4. Using BIM within Lean Construction Principles

Many research efforts have highlighted the importance of synergies between BIM and lean concepts [37][38][39][40][41]. The exploitation of both BIM and lean relies on the proper understanding of their theoretical processes. This integration is expected to yield more benefits to the construction industry than just the implementation of each one of them independently [37]. Since BIM and lean principles can be adopted separately, there is a need to prove that the integration should yield better results. Several initiatives have been dedicated to this approach, an example of which is integrated project delivery (IPD), and another is virtual design and construction (VDC). As for IPD, it mandates the project participants be involved in decision making as early as possible in the project. Additionally, IPD forms of contracts are designed for “collaborative project delivery”. In other words, it is a framework within which the owner, designers, and contractors are required to work together. In other words, there is no more room for the individual gains in the project by one entity, instead, the revenue gained by all project participants is tied by the project success [42]. Accordingly, new forms of contracts have been introduced to the construction market based on the IPD approach, an example of which are those forms of contracts issued by the American Institute of Architects (AIA). One of these forms is the AIA Document E202-2008. This document provides a framework for the adoption of BIM in IPD projects. This comprehensive framework based on BIM protocols, the level of development, and model elements is proof that BIM can yield extra benefits when applied in a collaborative environment [43]. Finally, IPD is an approach that adopts lean principles and encourages the use of BIM tools and processes.

Furthermore, when it comes to the term virtual design and construction (VDC), it has been defined by the Center for Integrated Facility Engineering (CIFE) at Stanford University. VDC is involved in the alignment of the BIM process with lean construction practices [44]. The term is sometimes interchanged with BIM in a lean context. Gilligan and Kunz [45] reported that using VDC in the early project phases facilitated the implementation of lean construction methods. The early involvement of key participants, along with the application of lean delivery process, has been leveraged by the 3D data rich models. The result of true value engineering had saved $6 M in the project driven by owner Sutter Health in California. From IPD and VDC, it is clear that the initiatives for collaborative work and lean thinking implementation are stressing the significance of BIM processes. In order to capture the interaction between lean principles and BIM functionalities, Sacks et al. [37] provided a framework for analyzing these interactions. They arranged them in a matrix, where each BIM functionality is analyzed against each lean principle. The result can be positive, which indicates full compliance to the indicated lean principle, or negative, where the BIM functionality opposes the lean principle in its implementation. After postulating the interactions, Sacks et al. [37] sought evidence to support each of them. Evidence was either theoretically proposed in previous research efforts or has been retrieved from practice. In some cases, the interaction was inferred from the informed reasoning of the authors. Thus, they suggested that more investigation is needed to prove the reliability of their suggestions. Their results showed a near complete synergy between BIM functionalities and lean principles in construction projects. The framework is regarded as being suitable for exploratory research where the conformity between two processes that are needed is identified and explored, especially when one is in the form of general principles and the other provides practical solutions and functionalities that are aligned with the core concepts of the principles. This constructive approach was then extended and built upon by other researchers.

For instance, Oskouie et al. [46] built on the interaction matrix of Sacks et al. [37]. The new matrix was extended with additional lean principles and BIM functionalities. The authors classified the principles into main categories rather than breaking down the categories. The reason was that some of the sub-categories provided by the Sacks et al. [37] matrix was related to the production process, whereas the extended framework dealt with BIM functionalities that support the operation and maintenance phase or the "facility management". In this phase, BIM functionalities are more involved with the general lean concepts apart from the production process. The authors reached the conclusion that BIM-enabled tools, when used in the operation and maintenance phase, guarantees the "lean" execution of the process. Consequently, the costs related to maintaining the facility can be reduced.

The use of BIM technologies that lineate with lean principles has been investigated in the construction projects. However, the analysis of synergies between BIM and lean in deconstruction processes is only merely mentioned. Most of the research efforts that exploit the BIM–lean integration in reducing the amounts of construction and demolition wastes (C&D) have focused on wastes generated during the construction phase. For instance, Cheng et al. [47] investigated the use of BIM functionalities in enabling the waste minimization in construction processes. Among these functionalities were design validation, quantity take-off, phase planning, and site utilization planning. Therefore, the perspective of optimizing demolition and deconstruction processes have not yet been explored within a lean–BIM interaction perspective.

5. Limitation and Research Gaps in Deconstruction Planning

Based on the comprehensive literature review, some of the current research gaps and opportunities in leveraging deconstruction planning are provided. To start with, detailed project planning techniques need to be further developed, and the use of BIM-based scheduling capabilities can be a handy solution. This option was implicitly suggested by Hübner et al. [7] by stating that the improvements in computer applications will enable the planning of activities with a high level of detail. This can be done by adapting the IT-based computational solutions for the planning of construction activities to be used for deconstruction planning. Furthermore, Hübner et al. [7] found that the current deconstruction planning problems on the operational level are optimized using single-objective functions or a single-criteria is involved. Multi-criteria decision making was only applied on the strategic level. Therefore, several criteria affecting the deconstruction planning should be taken into consideration. This would increase the accurate simulation of the solutions to real-world problems that are expected to happen. The use of BIM simulation capabilities could also be a suitable environment for evaluating different scenarios. Furthermore, several criteria affecting the deconstruction planning have never been mentioned in previous research. One of these remains the customer satisfaction, a cornerstone in establishing a successful business. Customer satisfaction in deconstruction is partly involved with the quality of the salvaged elements to be dismantled, since the customer is mainly the buyer of these salvaged elements. These customer segments extend from recycling facilities that deal with buildings on a material level to include new construction projects that directly reuse the salvaged elements. When considering the overall project quality, the environmental impact should be taken into consideration. Akinade et al. [48] mentioned some criteria related to the environmental impact of transporting the salvaged elements, however, the impacts of using different deconstruction tools and techniques have never been mentioned in a quantitative analysis nor the compliance to environmental standards. Additionally, there are no sensors currently used in the context of tracking the impacts resulting from deconstruction activities. Perhaps a reason would be the extra costs incurred to buy these sensors and the lack of regulations that necessitates the application of this kind of environmental assessment.

Additionally, capturing the current state of buildings was fairly mentioned in Ge et al. [49]. The modifications and repair of building elements necessitate the documentation of the latest conditions before deconstruction. This is considered as one of the major uncertainties in deconstruction planning, however, these uncertainties are often not taken into consideration in the decision making. Furthermore, on the strategic level, current integrated project delivery methods require the early involvement of key participants in the project, which would back up the early informed decision making. However, this approach has not been considered in deconstruction planning yet. This approach would also be beneficial for creating long-term relationships and building up an extended network of partners.

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