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Economic and environmental assessment of deconstruction strategies using building information modeling

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ABSTRACT

Choosing the most sustainable deconstruction strategy requires assessment of the effects of various contributing factors including prices and energy embodiment of the materials and components, the travelling distances, energy use and cost associated with the recycling processes, inflation rate, costs of designing the components for reuse-ability, costs of disassembly and re-assembly. Furthermore, a typical building comprises thousands of different components with various characteristics which may affect their reusability and recyclability. These lead to an enormous amount of information that needs to be stored and made available for analysis prior to and during the deconstruction stage. The present study proposes a framework for evaluating and comparing the effects of various alternative deconstruction strategies on cost, energy use and carbon footprint of construction using the information provided by a typical building information model. The results of a case study are presented to illustrate the potential applications of the proposed method.

1. Introduction

The awareness among the owners, engineers and contractors about the importance of sustainability in the construction industry as well as the economic benefits achievable through deconstruction has increased significantly over the past few decades. As a result, particular attention has been focused on replacing the traditional demolition and landfilling strategy with more elaborate deconstruction strategies in which the energy and capital invested in building components are fully or partially retrieved through reuse and recycling.

Recycling is one of the main and oldest strategies in C&D waste management. Recycling reduces the demand for new resources by making use of waste that would be otherwise lost to the landfill sites. The environmental and economic benefits of recycling of C&D wastes have been widely reviewed in available literature [1]. Numerous studies have been conducted to investigate the possible applications for the recycled construction materials as well as to develop novel techniques to improve the yield and efficiency of the recycling processes [2]. Recycling is considered as a significantly more sustainable option compared to traditional demolition and landfilling because it reduces the cost and energy use incurred by landfilling and reduces the demand for extraction of new materials by making available alternative recycled materials. However, one major problem associated with recycling is that the recycled materials are normally used in a lower grade application compared to the initial application for which the parent components were designed and fabricated [3]. Therefore, it makes sense to assume that a great proportion of the initially invested energy used to fabricate these components is lost. This is on top of the additional energy that is consumed during the recycling process. For instance, concrete recycling involves energy intensive crushing and sorting processes which together with transportation to the recycling site may result in a significant amount of energy consumption and thus carbon emissions. Therefore, an accurate life cycle cost and energy analysis is required to assess the suitability of a particular recycling strategy for a specific project.

Alternatively, if designed properly, at the end of the building service life, building components may be re-usable for the same or similar applications as the original components. As a result of the consistently growing cost of construction materials and construction services, reusable components are likely to end up being of more value at the time of deconstruction than the time of their initial fabrication. A great deal of research has been recently focused on investigating the possibility of reusing the structural and non-structural components of a building at the end of the building's service life [4–7]. The technical and managerial procedures developed to make the latter possible are normally referred to as “design for disassembly (DfD)” or “design for deconstruction”. Disassembly and re-use of building components have several

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advantages over conventional demolition and/or recycling. First, unlike recycling, reuse of building components preserves the invested embodied energy of the deconstructed building components by re-using them and extending their service life. Reuse of materials also reduces significantly the cost, energy use and carbon emissions resulting from demolition, processing for recycling, and transportation to landfill and recycling facilities.

However, besides the technical difficulties in designing components for disassembly and reuse-ability, another factor preventing the widespread use of disassemble-able components in current practice is the extra cost and energy that has to be borne to design the components for re-usability. For instance, designing structural concrete elements for disassembly may require the use of additional embedded steel connections to facilitate assembly and disassembly operations to avoid damage. This may increase the initial costs, embodied energy and carbon emissions associated with fabrication of the components. Besides, construction using DfD components necessitates a number of non-traditional services during the assembly and disassembly processes such as selective removal of the cover concrete for access to connections as well as additional propping and lifting which may again have environmental and economic impacts.

As discussed, choosing a sustainable deconstruction strategy involves investigating many parameters contributing to the cost, energy use and carbon emissions. In addition, a typical building comprises thousands of different components with various characteristics which may affect their reusability and recyclability. These lead to an enormous amount of information that needs to be stored and made available for analysis prior to and during the deconstruction stage. Using the traditional documentation techniques for this purpose would mean hundreds more detailing and instruction sheets that need to be stored for a considerable length of time. However, the development of various building information modeling software as well as international data exchange schemes such as IFC could facilitate the storage and easy access of information for processing. The present study proposes a framework for evaluating and comparing the effects of various alternative deconstruction strategies on costs, energy use and carbon emissions incurred in various stages of the building life cycle using the information provided by a typical building information model. The objective is to provide decision makers with an easy to use method for selection of the most sustainable deconstruction strategy applicable to a particular building. The proposed framework does not use the special features made available by any particular BIM software nor does it propose new technological advancements in the capabilities of the existing BIM software. The results of a case study are presented to illustrate the potential applications of the proposed method.

2. Building information modeling

Building information modeling (BIM) may be defined as the process of generating and managing building information during the service life of a building. A typical building information model contains information such as building geometry, spatial relationships, geographic information, quantities and properties of the building components and the materials used as well as any other customized information added by designers, owners and contractors. Building information models are normally generated using three-dimensional, real-time and dynamic software [8].

The use of building information modeling in architecture and structural design and detailing, especially in modular construction, has been widely adopted both by industry and academia [8–11]. These applications take advantage of the capabilities of BIM in 3D visualization as well as in simultaneous planning and management of the various construction sectors including the structural, architectural and mechanical and electrical sectors. In addition, another aspect that has recently attracted a great deal of attention is the possibility of using such comprehensive databases provided by the building information models to design, construct, manage, demolish and re-use building components to address sustainability and environment issues [8]. The most emphasized applications of BIM in sustainable design include selection of the optimized orientation of a building to reduce the energy costs, building massing to analyze the building form and optimize the building envelope, daylight analysis, water harvesting to reduce water needs in a building, energy modeling to reduce the energy needs and analyzing renewable energy options, and site and logistics management to reduce waste and carbon footprint [8,9,12,13]. These applications are usually made possible by linking the BIM software to a secondary software suited for sustainability analysis. All the abovementioned analyses are performed mainly during the design stage. For instance, the new Autodesk Ecotect 2010 analysis software permits various sustainability analyses of data imported in the gbXML format from Revit Artictechture, ArchiCAD and Bentley Architecture [14]. These analyses include the shading design, solar analysis, lighting design, photovoltaic array sizing and load matching, acoustic analysis, thermal analysis, ventilation and air flow analysis, etc. In addition, the Autodesk Green Building Studio can be used in conjunction with Ecotect 2010 to evaluate the energy use and carbon footprint of the various design alternatives [14]. Such analyses may also be conducted using other available software with similar capabilities such as the Graphisoft Ecodesigner integrated with Graphisoft ArchiCAD and Virtual Environment by IES which has Plug-ins for Revit and SketchUp.

However, although a great deal of attention has been placed on sustainable design and construction using BIM, significantly less effort has been put on investigating the possibility of using the comprehensive database available through BIM in the deconstruction stage of a building. The present paper proposes a potential application of BIM for use at the deconstruction stage of the buildings. A conceptual framework is developed for identifying the best deconstruction strategies in term of economic and environmental impacts, among a set of predefined or automatically generated strategies, using the information stored in the building information model.

3. BIM-based deconstruct-ability analysis framework

The importance of developing a comprehensive scheme for evaluation of deconstruction strategies was briefly explained in Sections 1 and 2. It is inevitable that not all building components can be designed to be reused or recycled and optimum sustainable deconstruction may require a well-managed strategy that combines recycling, re-use and landfilling. Such a strategy should be designed to achieve a balance between the environmental and economic impacts.

The main objective of the present paper is to provide a systematic approach for identifying the most economic and environmental friendly deconstruction strategy applicable to a particular building through evaluating and comparing the economic and environmental impacts of the various alternative deconstruction strategies using the information provided by a typical building information model. Fig. 1 shows the general steps involved in the proposed method. As shown, the procedure starts with the creation of a comprehensive building information model containing a set of deconstruction related attributes using the information input by the designers, components fabricators and contractors at various stages of building design, construction and service life (Stage I). In computing, an attribute is defined as a specification that defines a property of an object, element or file. Attributes can be defined in various levels including element, model, and system levels to assign various properties to the elements, the model and all models (every model developed using the software), respectively. The deconstruction relevant information is a set of information determining the various deconstruction options applicable to an individual component in the model. This information may be entered manually by individual users or imported automatically from available component libraries. The methodology for inclusion of this information in the BIM software and that for using this information is discussed in Section 4.1. At the