BIM Model View Definition (MVD) for disassembly planning of buildings

Benjamin Sanchez[1], Srijeet Halder[1], Ranjith K. Soman[2] and OK-Youn Yu[1]

[1] Department of Sustainable Technology and the Built Environment, Appalachian State University, USA
[2]Department of Management in the Built Environment, Delft University of Technology, The Netherlands
sanchezandradeb@appstate.edu, halderss1@appstate.edu, r.soman@tudelft.nl, yuo@appstate.edu

Abstract

Buildings are responsible for a huge amount of negative environmental impacts at the End-of-Life (EoL) stage because of the massive global production of waste. Therefore, there is an urgent need for developing design systems to decrease waste generation by facilitating the reuse and recycling of building materials. Building Information Modeling (BIM) has been demonstrated to be an effective tool for enhancing building performance at the different life cycle stages. However, the implementation of BIM for assessing the EoL stage of building projects is still underdeveloped. One important activity on the EoL stage is disassembly planning for reuse of building components and building renovation. The aim of this study is to develop the framework for a BIM Model View Definition (MVD) for disassembly planning. First, we developed a framework for an MVD for the disassembly planning of buildings based on the literature review in the field. Then, we proposed a workflow for implementing the MVD, as well as the validation procedures. In the end, the MVD was validated by compiling the information of a BIM-based disassembly model. Results of the case study show that the presented approach is efficient for corroborating the syntax, semantic structure, and information content of BIM models.

Keywords –

Model View Definition, disassembly information modeling, Building Information Modeling, circular economy

1 Introduction

The significance of reusing building components and systems has increased because the construction industry is annually accountable for around 40% of the global consumption of natural resources and the redirection of 40% of waste to landfills [1]. To address this challenge, technological advancements such as Construction Waste Management (CWM), Materials Passports (MP), Product Recovery Management (PRM), and Life Cycle Assessment (LCA) have been introduced in the last decades [2]. These innovations aim to enhance the rates of reusing and recycling building components. Nevertheless, the adoption of building components and system reuse remains limited, primarily due to a lack of research on reclamation protocols and the absence of standardized procedures [3]. In this matter, disassembly planning is a strategic approach for the recovery of building components and systems for their future reuse or recycling [4-8]. Disassembly planning involves identifying the necessary sequential steps for taking apart a building, delineating deconstruction activities, and arranging them in a logical order.

Unfortunately, disassembly planning for buildings is not as advanced as in other industries such as manufacturing, automotive, and electronics [4,9]. The definition of the information and data structure that a disassembly model must contain are critical for the implementation of disassembly planning methods and theories. In the following sections we present a framework for defining the information definition for disassembly planning of buildings in the context of Building Information Modeling (BIM).

2 Background

2.1 Disassembly planning for reuse of building components and building renovation

The potential benefits of building renovation rely on the fact that it is possible to take away components from an obsolete building and then repair, reuse, remanufacture, or recycle them. Planning for disassembly plays a key role in the building renovation process where the disassembly planning sequence, as well as the disassembly methods to recover target components, have to be performed in an efficient way. The objectives are to reduce building costs and to increase the reuse times for building components. If the design for disassembly is too complex or time-consuming, the associated economic and environmental costs could be higher than installing new components. This field has been studied in the manufacturing industry since the last decade, concluding that disassembly planning can reduce the time and cost associated with disassembling products [10]. Figure 1 shows the comparison of the material flows through the building lifecycle stages for the traditional approach of building demolition versus the disassembly planning approach. Building demolition produces large amount of waste with the possibility to recycle some material. In contrast, selective disassembly enables the direct reuse of buildings in different levels of decomposition (e.g. reus of a building, a subsystem, a component). Table 1 shows the generic classification of product disassembly methods, as well as the literature review of the applied theories to find the optimum, or near optimum, disassembly path for non-destructive disassembly methods.

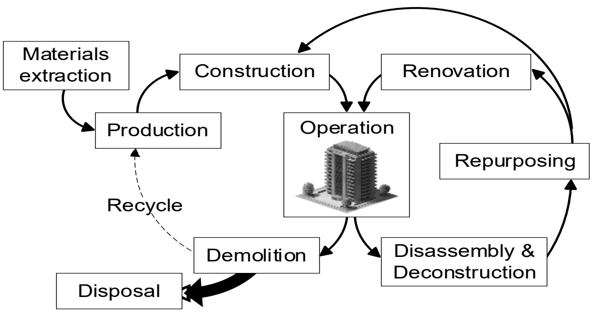

Figure 1. Building lifecycle stages: Demolition versus disassembly planning

Table 1. Disassembly planning methods and models for non-destructive disassembly optimization

Non-destructive disassembly (complete and selective)	Sequential disassembly	Complex wave propagation algorithms [11-13]
		Less complex transition matrices, mixed integer linear programming, and genetic algorithms [14,15]
		Disassembly sequence structure graphs (DSSGs) and expert rules [16]
		Disassembly precedence graphs and linear programming models [17]
		Genetic algorithms optimisation [18,19]
		Ant colony optimisation [20-22]
	Parallel disassembly	Directed AND/OR graphs and linear programming [23]
		AND/OR graphs and constraint programming [24]
		Petri nets and network searching algorithms [25]
		Liaison graphs and grouping genetic algorithms [26]
		Fuzzy-rough set mapping model, Disassembly factors and Disassembly membership functions [27]

In accordance with disassembly planning, the process of planning the dismantling of an existing asset is known as deconstruction project planning. Hübner et al. [28] provided a comprehensive literature overview of project planning methods for deconstruction of buildings as well as some research gaps in this field. The authors classified the existing deconstruction planning methods according to specific construction project objectives. The proposed project objectives are time, cost, resources, risk, and quality, which, in turn, have been the main performance indicators on the field of construction project management. Their study presents a full-range variety of methods for the decision-making process on strategic and operational deconstruction planning, based on the optimization of single or multiple project objectives. In comparison to the manufacturing industry, just few disassembly planning methods have been developed for buildings and building subsystems. This have limited the implementation of disassembly planning for building projects.

2.2 BIM Model View Definition use cases in construction

Building Information Modeling (BIM) is a data-rich, object-based, intelligent, and parametric digital representation of a building, from which views appropriate to various users' needs can be extracted and analysed to generate feedback and improvement of the facility design [29]. In the last decades BIM has been implemented in diverse research fields in construction such as design visualization, construction reviews, structural analysis, design coordination, planning of trades and systems, construction scheduling and sequencing, among others [2,30]. The standard BIM data structure is known with the name of Industry Foundation Classes (IFC) schema. IFC is an open, international standard (ISO 16739-1:2018), meant to be usable across a wide range of hardware devices, software platforms, and interfaces for many different use cases [31].

A Model View Definition (MVD) is a subset of the overall IFC schema to describe data exchange for a specific use or workflow, narrowing the scope depending on the need of the receiver [32]. An IFC View Definition, or MVD, defines a subset of the IFC schema, that is needed to satisfy one or many exchange requirements of the AEC industry. Some examples of MVDs for specific exchange requirements are quantity take-off view, structural design to structural analysis, indoor climate simulation to HVAC design, architectural design to thermal simulation, architectural design to circulation/security analysis, energy analysis view, among others [32].

For a long time, everyone could create their own MVD and approach software vendors to implement it. This created a situation with several MVDs that have been created that are not interoperable with each other and need additional efforts for implementation in software tools. Therefore, the MVD structure is now regulated by the buildingSMART International (bSI) Standard [33] and has been implemented in numerous BIM interoperability studies [34]. The aim of MVD is to specify exactly which information is to be exchanged in each exchange scenario and how to relate it to the IFC model [33]. The development of MVDs for new purposes in the construction industry is highly recommended by bSI to help satisfy arising industry needs, explore limitations in current approaches, and propose new necessary extensions [34]. According to Son et al. [35], the number of MVDs is still too small considering the number of information exchange scenarios required by the industry. Even though, disassembly planning has been recently implemented using BIM in multiple tools and methods [36,37], none of them have described the structure for IFC data exchange. In this paper, we argue the need for the development of an MVD for disassembly planning for enabling the use of BIM for the assessment of dismantling operations. The conformation of an MVD can use existing extensions of the IFC schema, add new extensions, add additional restrictions, and overrule others.

3 A framework for a MVD for disassembly planning of buildings

The proposed research approach is developed in three main stages. In the first stage, a literature review was carried out to determine the necessary information for disassembly planning of buildings. The objective of this first stage is to define the subset of information needed for developing a disassembly planning assessment for buildings. In the second stage, we develop the MVD. Then we propose the workflow for the implementation of a disassembly planning MVD for BIM models. This workflow describes the main concepts, actors, and information flow for the use case of disassembly planning. In a final stage, we present a validation approach of the disassembly planning MVD. We present the results of a case study as a functional demonstration of the proposed methodology and the proposed technology. Figure 2 displays the proposed research approach as well as how the sections of this study are organized.

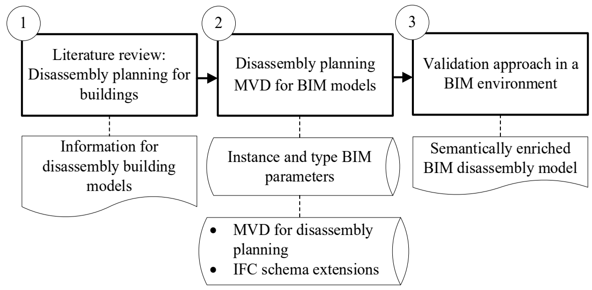

Figure 2. Research approach for a MVD for disassembly planning of buildings (*MVD-Model View Definition, BIM-Building Information Engineering, IFC-Industry Foundation Classes).

3.1 Parameters for disassembly planning for buildings

In previous studies, Sanchez et. al [36,37] developed a literature review for identifying the key parameters for BIM-based disassembly planning of buildings. In these studies, the authors identified three stages in the BIM-based disassembly planning process. The three stages are the preprocessing stage, the analytical model, and the performance analysis. In each one of the stages, the authors identified the key parameters (information packages) for disassembly planning models. Figure 3 shows the workflow for implementing disassembly planning MVD for BIM models, and Table 2 shows the stages and parameters for BIM-based disassembly models. For the purposes of this study, we use the proposed key parameters in Table 2 as the basis for the information package for the MVD for disassembly building models. It is worthy to mention that this list of parameters can be expanded according to the requirements for BIM assessment.

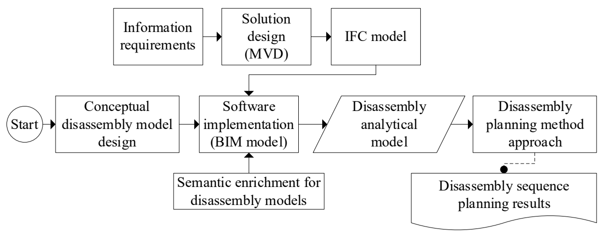

Figure 3. Workflow for implementing disassembly planning MVD for BIM models (*MVD-Model View Definition, BIM-Building Information Modeling, IFC-Industry Foundation Classes)

3.2 Disassembly planning MVD development

The parameters of the MVD information package are described and mapped according to the existing IFC entities (IFC4) (see Table 2). The parameters can be categorized according to the nature of the source of the information such as existing (E), new (N), or retrievable (R). The existing parameters are embedded in the BIM

Table 2. Key parameters for BIM-based disassembly planning of buildings

	Parameter	Description	Source	IFC Schema	Type*
Preprocessing	Global disassembly model	Unique descriptor for identifying all the parts.	[5,9,10,40]	*IfcGlobalUniqueID*	E
	Disassembly part type	Component (c) or connection (f).	[5,9,10]	*IfcBuiltElement; IfcElementComponent*	N
	Disassembly part id.	Numerical identifier for part types (e.g., c_1 , f_1).	[5,9,10,40]	*IfcGlobalUniqueID, IfcBuiltElement; IfcElementComponent*	N
	Hosted components	Components attached to a host component.	[5,9,40]	*IfcRelConnectsElements*	N
	Hosted connections	Connections attached to a host component.	[9,40]	*IfcRelConnectsElements*	N
	Connection disassembly	Type of connection.	[5,10,40]	*IfcRelConnectsWithRealizingElements*	N
	Fastener constraint type	Extraction constraints.	[9,10,40]	*IfcElementComponent*	N
	Physical interface	Type of connection.	[10,40]	*IfcRelConnectsWithRealizingElements*	E
	Global coordinate system	Global reference system of the model.	[9,10,40]	*IfcCoordinateReferenceSystem*	E
	Local coordinate system	Local reference system of each part.	[10]	*IfcObjectPlacement*	E
	Assembly elements location	Location of each part in the coordinate system.	[9,10]	*IfcLocalPlacement*	N
Analytical model	Structural composition	Structural interdependence of components.	[5,9,40]	*IfcElementAssembly*	N
	Graph data structure	Abstract representation of a disassembly model.	[5,9,10,40]	*IfcRelDecomposes*	N
	Extraction directions	Directions for removing any part.	[9,10]	*IfcElementAssembly*	E
	Object geometry (2D, 3D)	Virtual representation of BIM elements (parts)	[9,10,40]	*IfcProductRepresentation*	E
	Physical constraints	Constraints of a part in any extraction direction.	[9,10]	*IfcShapeRepresentation*	N
	Modular subassemblies	Group of parts that conforms a disassembly module.	[10,40]	*IfcProductRepresentation*	E
	Working space	Space for a human worker to develop disassembly works.	[5,9,10]	*IfcElementAssembly*	N
Performance	Disassembly tool	Equipment for disassembly works.	[10]	*IfcRelSpaceBoundary*	N
	Disassembly method	Mode of disassembly works.	[10,40]	*IfcPropertySet*	N
	Environmental impacts (LCA)	Life Cycle Assessment (LCA) per building component.	[9,10,40]	*IfcPropertySet*	R
	Disassembly time	Time for disassembling.	[5,10,40]	*IfcPropertySet*	R
	Disassembly cost	Cost for disassembling.	[5,9,10,40]	*IfcPropertySet*	R
	Disassembly revenue	Profit for disassembling.	[5,10,40]	*IfcPropertySet*	R
	Disassembly distance	Distance moved in disassembling a component.	[10]	*IfcPropertySet*	N
	Operation number	Number of activities developed for the disassembly process.	[10]	*IfcPropertySet*	N
	Disassembly energy consumption	Energy consumption of machinery for disassembly.	[10]	*IfcPropertySet*	R

*Information type: existing (E), new (N), or retrievable (R) elements. The new parameters must be defined by the user. Also, these parameters can be generated automatically with customized subroutines. The retrievable parameters are properties of the BIM elements that can be retrieved from external databases. The full description of the parameters can be found in [36].

3.3 Workflow to implement disassembly planning MVD

Figure 3 shows the proposed workflow for the implementation of the disassembly planning MVD for BIM models. In the first step, a conceptual disassembly model design must be developed according to the building assembly under study. In the second step, the BIM disassembly model must be developed. In this step, the minimum IFC entities for disassembly models are defined as a template according to the MVD for disassembly planning. Also, in this second step, the BIM model must be semantically enriched according to the MVD. The semantic enrichment can be done manually (by the user) or through algorithms that retrieve geometrical and non-geometrical information from the BIM model. With a functional BIM disassembly model, in the next steps, it is possible to develop an appropriate analytical model, as well as a disassembly planning solution.

3.4 Validation approach for disassembly planning MVD

An MVD is the computational application of an information package that maps the data exchanges to a subset of the IFC schema and describes their needs in a computer-readable data model [34]. Figure 4 shows the workflow for the validation of the MVD for disassembly planning. The BIM-Q tool is proposed for MVD configuration and to generate the mvdXML file. The BIM-Q tool is a commercial software for supporting BIM use case requirements. The BIM-Q tool has useful MVD templates for the different IFC use cases (IFC models) such as structural analysis, building energy analysis, and cost estimation. Due to the specific characteristics of analysis and data structure for processing, a new IFC use case for disassembly planning implementation and standardization was necessary. The mvdXML format is a data schema used to specify the minimum exchange requirements and it is the currently recommended data schema for model validation [34]. The result of the MVD configuration is a description of the appropriate IFC information model and their exchange data requirements. In the final step, simplebim® software is proposed for validating the IFC file. This MVD validation approach has been used for other studies in the field of BIM data exchange [34,38,39].

The disassembly planning MVD was validated by compiling the information of the BIM-based disassembly model of a case study described in a previous research [36] and by verifying the resulting IFC files using the simplebim® tool. To test the MVD construct, the information depicting disassembly planning characteristics was included in the IFC files for the disassembly model prototype. The simplebim® tool was implemented to corroborate syntax, semantic structure, and content of the output IFC file. This validation process was necessary to refine the enrichment process by detecting errors of semantic structure (e.g., erroneous property set labels, mistaken entity relationships) and missing information (e.g., missing exchange requirements, information lost in the enrichment process). Figure 5 shows part of the results of the MVD for disassembly planning for buildings.

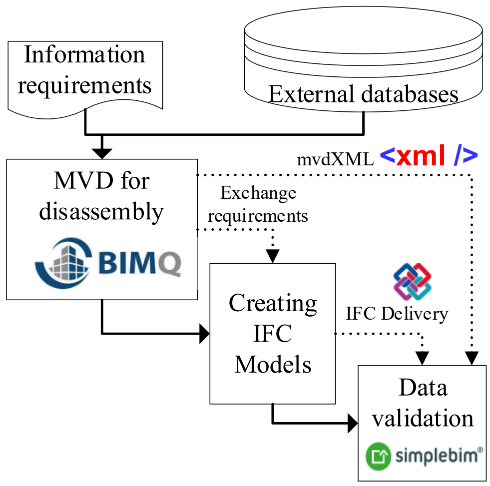

Figure 4. Disassembly planning MVD development and validation (*MVD-Model View Definition, BIM-Building Information Modeling, IFC-Industry Foundation Classes, mvdXML-MVD data format, BIM-Q-commercial software for supporting Building Information Modeling use case requirements, simplebim- Open BIM IFC application for verifying data accuracy)

4 Conclusions and future work

This research explores the necessity for standardized information in disassembly models of buildings within the BIM framework. Efficient management of asset data is essential for informed decision-making throughout all stages of a building's life cycle, including its End-of-Life phase. This paper introduces a formal specification of a MVD for disassembly planning. This approach aims to

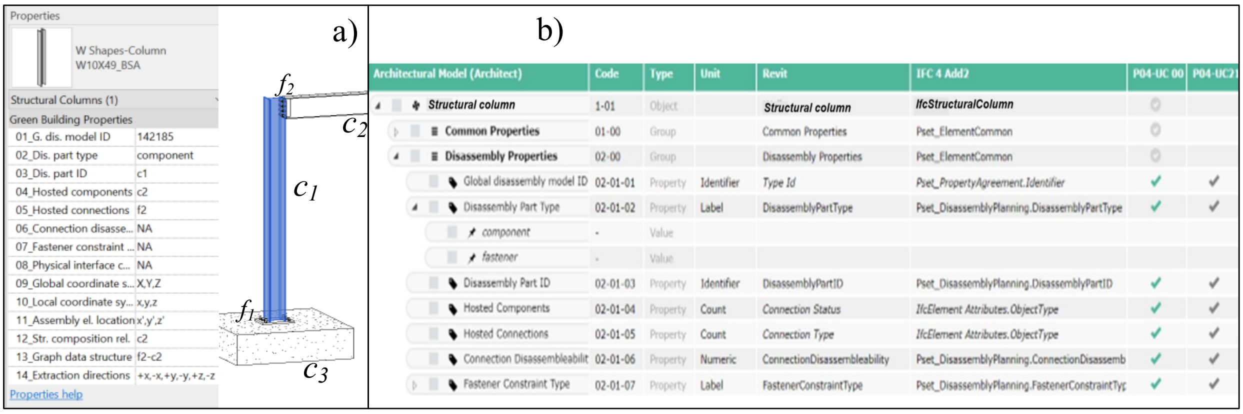

Figure 5. MVD for disassembly planning: a) BIM disassembly planning parameters, and b) MVD information package using the BIM-Q interface

enhance the adoption of building disassembly by minimizing the effort associated with planning tasks. The framework outlined in this research has the potential to address the current technical obstacles that hinder the systematic and standardized implementation of disassembly planning in the construction industry.

A future phase for this study involves creating an automated semantic enrichment engine for disassembly models based on BIM. This strategy aims to enhance the generation of accurate and thoroughly semantically enriched BIM disassembly models. One drawback of the suggested approach is the substantial volume of data that needs to be incorporated into a BIM model at a component level. The high Level of Detail (LoD) may pose computational challenges, especially for large building assemblies. Nevertheless, it might be feasible to apply this approach for subassemblies of buildings. Future advancements in computational technology could make high LoD assessments technically feasible for complete building assemblages.

This study offers a contribution to the field due to key factors that distinguish it from alternative solutions. First, unlike some alternative solutions which may focus on specific aspects of disassembly planning, this paper presents a holistic approach leveraging BIM MVD. It considers various crucial factors such as material properties, structural integrity, spatial relationships, and environmental impact, offering a comprehensive framework for disassembly planning. Second, the BIM MVD proposed in the paper promotes data interoperability and standardization, which are essential for seamless communication and collaboration among stakeholders involved in disassembly projects. This ensures that relevant information is accurately exchanged and utilized throughout the lifecycle of the building, leading to more efficient planning and execution. Finally, the BIM MVD framework presented in the paper is designed to be scalable and adaptable to different types and scales of buildings, making it suitable for a wide range of applications. Whether dealing with small-scale structures or large-scale complexes, the approach can be tailored to meet specific project requirements and constraints.

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