WHAT INFORMATION IS NECESSARY TO ASSESS THE ENVIRONMENTAL IMPACTS OF DECONSTRUCTION?

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ABSTRACT

4D modeling - the simulation and visualisation of the construction process - is now a common method used during the building construction process with reasonable support from existing software.

The goal of this paper is to examine the information needs required to model the deconstruction/demolition process of a building. The motivation is the need to reduce the impacts on the local environment during the deconstruction process. The focus is on the definition and description of the activities to remove building components and on the assessment of the noise, dust and vibration implications of these activities on the surrounding environment. The outcomes of the research are (i) requirements specification for BIM models to support operational deconstruction process planning, (ii) algorithms for augmenting the BIM with the derived information necessary to automate planning of the deconstruction process with respect to impacts on the surrounding environment, (iii) algorithms to build naive deconstruction activity schedules.

Keywords: 4D modeling, deconstruction, demolition, environmental impact, process planning

1. INTRODUCTION

Deconstruction of old, unfeasible buildings becomes increasingly necessary worldwide due to limited space in cities and limited adaptability of the building stock with respect to demographic and economic changes and increased building standards (cf. Couto and Couto (2007); Kamrath (2013); Kamrath and Hechler (2011); Shaurette (2010); Thomsen et al. (2011)).

Deconstruction activities can cause emissions, which have a major influence on the impacts on the local environment and on human beings, such as noise, dust and vibrations. Furthermore, hazardous substances included in old buildings impact the environment (cf. Amato et al. (2009); Anumba et al. (2003); Chu et al. (2011); Hu et al. (2004); Kamrath and Hechler (2011); Kim et al. (2013); Lippok and Korth (2007); Moser (1992); Shaurette (2010); Usman and Said (2012)).

Hence the planning of the deconstruction process, as an essential and challenging activity of deconstruction project management, should consider these emissions and hazardous substances, besides technology choice, work task definition and the estimation of required money, resources and time (cf. Trinidad et al. (2004), Trinidad and Aranda-Mena (2004), Chu et al. (2011))

The aim of this paper is to examine the information required in BIM models to support operational deconstruction process planning by considering the impacts on the local environment during this process. Hence the results of the research will be a requirements specification, or model view definition, for demolition works.

2. 4D MODELLING

A common method used during the building construction process is 4D modeling, which is the simulation and visualisation of the construction process with reasonable support from existing software. In 4D modeling, 3D CAD building elements are linked to construction activities, including information about activity durations and scheduling possibilities (cf. Trinidad and Aranda-Mena (2004)). Hence 4D models can support construction project managers in planning construction activities, prior to their actual execution on site, by visualizing and analyzing the construction process and respective conflicts due to technical, sequential, spatial and resource constrains (cf. Dawood et al. (2005)). The key assumption in this paper is that 4D modeling can effectively support the planning of deconstruction activities as well.

Deconstruction processes show major differences to construction of new buildings with respect to the impacts on the local environment due to emissions of noise, dust and vibrations as well as hazardous substances (Shaurette (2010)) and these environmental impacts are usually not considered in 4D models.

The work described in the paper builds on previous 4D modeling work by the Center for Integrated Facility Engineering (CIFE) group at Stanford University (e.g. Fischer and Drogemuller (2009)), the Centre for Construction Research & Innovation at the University of Teeside (e.g. Chavada et al. (2012)) and CSIRO (Commonwealth Scientific and Industrial Research Organisation) (e.g. Trinidad (2004); Trinidad and Aranda-Mena (2004); Trinidad et al. (2004)).

The base assumptions of the work are that the following are available:

1. A fully instantiated BIM model of the building;
2. Information on the available construction equipment, resources and methods;
3. High level descriptions of the proposed work methods to be applied during deconstruction;
4. Site and surrounding conditions.

The work undertaken by CSIRO in the CRC for Construction Innovation (Trinidad et al. (2004)) was a proof-of-concept to demonstrate that construction sequencing could be partially automated. The focus was on the major structural components of the building. There were many more subtle considerations that were ignored. The output was a naive Gantt chart that could be used as a starting point for human manipulation. The technical process was:

1. Scan the Industry Foundation Classes (IFC) file and add a supports relationship to the building components. For example, column21 supports beam15, beam15 supports slab05. This required some reasoning on the model in identifying the lowest building components;
2. Build a partial ordering based on the supports relationship. The major ordering was on building storeys, with various possibilities available within a storey;
3. Attach construction activities, with associated resources including duration estimates, to the building components;
4. Sequence the construction activities;
5. Export the construction sequence to Microsoft Project;
6. Export the building component geometry to VRML;
7. Combine the sequencing data and geometry in CommonPoint and view an animation of the construction process.

The refinements to this process incorporated in this work are:

1. Expanding the range of building components beyond major structural components;
2. Using the concept of shearing layers (Brand (1994)) to further partition the building component types to improve the sorting method;
3. Adding information about the attachment methods between the various types of components.

The shearing layers consist of – site, structure, skin (building envelope), services, space plan (interior layout) and stuff. The excavation aspects of site, structure, skin, services and the internal walls and fittings/fixtures within space plan are considered within this work. The contents of buildings which are easily removable are excluded.

3. A SCHEMA FOR DECONSTRUCTION

A proposed schema for deconstruction activities is shown in Figure **1**. This schema should be considered to be in a draft state as the full schema has not yet been tested in a software implementation. The attribute types have also been left as the default for the Unified Modeling Language (UML) software.

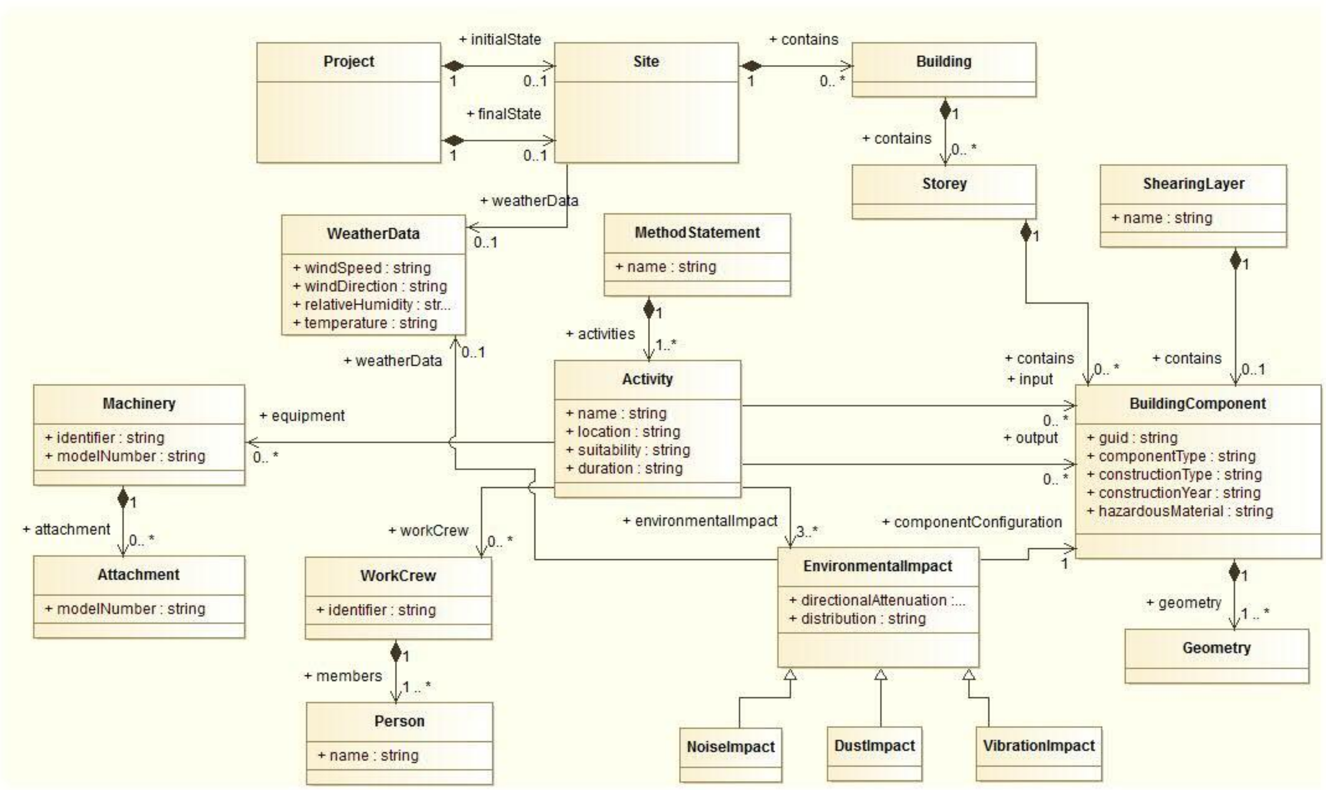

Figure 1: Deconstruction Schema

The representation of the BIM model, with a project containing sites, sites containing buildings, buildings containing storeys and storeys containing building components follows the IFC containment hierarchy (buildingSMART, 2013), except for the addition of *initial state* and a *final state* attributes to project. These allow explicit definition in a clear way of the state of the building both at the start of the project and on completion. As explained below, the characteristics of the weather influence the environmental impacts. These are attached to the site object.

Most of the objects in Figure **1** have direct mappings to IFC objects, except for *MethodStatement*, *EnvironmentalImpact* and *Attachment*. The *MethodStatement* object is used to store the high level definition of the proposed deconstruction method. This is normally defined around the method proposed to remove the major structural components, such as "progressive wrecking" of low-rise structures with excavators or front-end loaders, or floor-by-floor for tall buildings, which are over a certain height (Illingworth (2000); Diven and Shaurette (2010)). The *EnvironmentalImpact* object provides the storage for the various types of impact which provide a contoured spatial distribution of the particular impact for the analysed conditions as would be required to capture the information in Figure 3. *Attachment* allows a single type of construction plant to be configured with different attachments for distinct activities (Figure 2). For example, an excavator digging into soil with a ripper attachment will make much less noise than the same excavator breaking up concrete with an impact hammer.

BuildingComponent is given a wider meaning in deconstruction than for construction. The output of a deconstruction activity could be a bulk material, such as crushed concrete or scrap reinforcement bars, which do not fit the common concept of a *BuildingComponent*.

4. DECONSTRUCTION ACTIVITIES

4.1 Deconstruction activity description

In general there are two levels to describe the deconstruction process. On a strategic level it can be distinguished between different deconstruction strategies due to the differentiation of activities, from the simple, mostly undifferentiated building demolition to the differentiated removal of single building layers and elements (cf. Schultmann (2003); Schultmann and Rentz (2002)). On the operational level it can be distinguished between different deconstruction activities (cf. Schultmann (2003); Schultmann and Rentz (2002)), including different deconstruction techniques, such as cutting, crushing, gripping and chipping, and applied machinery with respective attachement. The focus of this research is on the operational deconstruction process.

The choice of a single deconstruction activity is influenced by different factors. It can be distinguished between technical, organizational, economic, environmental and safety factors (cf. Abdullah and Anumba (2002); Anumba et al. (2008); Kourmpanis et al. (2008); Lippok and Korth (2007); Mur and Muzeau (1979); Schultmann (2003); Schultmann and Rentz (2002)).

- Technical factors include building characteristics, such as statics, material, element thicknesses and deconstruction height, and surrounding conditions, such as space constraints on site and around site.
- Organizational factors encompass available machinery, respective attachments as well as the available number of human resources and their skills and experiences.
- Economic factors include different costs related to machinery, human resources and activity durations.
- Environmental factors take into account hazardous substances, emissions of noise, dust and vibrations as well as deconstruction materials.
- Safety is a cross-section dimension, which touches factors of all previous dimensions.

Figure 2: Excavator with attachments

4.2 Activity segmentation

From the description of the different influencing factors, it can be concluded that especially for the technical evaluation of deconstruction activities detailed building characteristics are important. Hence, the use of BIM, including 3D CAD building elements, can be advantageous for operational deconstruction process planning. Table 1 shows requirements specification for BIM models in the form of important attributes of 3D CAD building elements with respect to the major technical issue related to the selection of deconstruction activities.

Table 1: BIM model specifications with respect to the major technical issue of deconstruction activities

Attribute of the 3D CAD building element	Major technical issue of the deconstruction activity
Building element geometry	Selection of possible deconstruction techniques
Major material of the building element	Selection of possible deconstruction techniques
Height of building element above ground	Determination of the machinery size/type
Connections to other building elements	Ability to separate the component from its surrounds
"Support" relationships between single building elements (statics)	Sequence of deconstruction activities Selection of possible deconstruction techniques

4.3 Impacts on the local environment

Detailed building characteristics are important for the environmental evaluation of deconstruction activities. Besides the choice of machinery, respective attachment and deconstruction techniques by the deconstruction company within the technical possibilities, the extent of impacts on the local environment due to environmental factors, including hazardous substances, emissions of noise, dust and vibrations as well as deconstruction material, are directly influenced by the building characteristics. Empirical studies related to this topic are currently performed within a research project by the French-German Institute for Environmental Research (DFIU) at the Karlsruhe Institute of Technology (KIT) in collaboration with other research institutes and the deconstruction industry.

Table 2 shows important attributes of 3D CAD building elements with respect to the environmental issue related to deconstruction activities.

Table 2: BIM model specifications with respect to the major environmental issue of deconstruction activities

Attribute of the 3D CAD building element	Major environmental issue of the deconstruction activity
Building element geometry	Influence on the extent of generated of noise, dust and vibrations through attenuation by the building fabric
Major materials of the building element	Influence on the extent of generated of noise, dust and vibrations Determination of incurred deconstruction material and its quality due to recycling possibilities after the actual deconstruction process
Height of building element above ground	Influence on the extent of generated of noise, dust and vibrations (e.g. through falling elements, influence on the distance that noise travels)
"Support" relationships between single building elements (statics)	Determination of the deconstruction material quality due to recycling possibilities after the actual deconstruction process
Construction age of the building element	Identification of possible hazardous substances

As previously the extent of impacts on the local environment due to the deconstruction process are functions of

1. Detailed characteristics of the existing building to be deconstructed,

2. Deconstruction activities influenced by the deconstruction company within the technical possibilities.

4D modeling, which links exactly these two components, construction activities and 3D CAD building elements, can effectively support the planning of deconstruction activities, including the consideration of impacts on the local environment due to emissions of noise, dust and vibrations as well as hazardous substances.

Figure 3: New Hampshire Coliseum - controlled demolition ("http://en.wikipedia.org/wiki/File:NH-Colliseum.gif**)**

5. ALGORITHMS FOR 4D DECONSTRUCTION PROCESS PLANNING

5.1 Specifications of building elements to be deconstructed

The deconstruction process and respective applied activities are influenced by certain building attributes and surrounding conditions. Especially

- The materials of the major building elements;
- The age of construction/renovation and;
- The building height;
- The available equipment and resources;

The surrounding environment, such as closeness of adjacent structures, available areas on site for storage, etc. are important for the deconstruction process (cf. Anumba et al. (2003); Schultmann (2003); Schultmann and Rentz (2002)). Hence, from a top-down perspective the overall building to be deconstructed has to be classified due to these parameters. As the focus of this study is on the operational deconstruction process with changing single deconstruction activities throughout the overall process, a bottom-up approach is required by defining the single building elements to be deconstructed. The single building elements to be deconstructed can be defined in different ways related to the applied deconstruction strategy. It can be distinguished between the following classifications:

- Single building components, such as slabs, beams, walls, columns;
- Different layers of a building, such as structure and envelop/skin (Brand (1994)) and respective composition of a single building component, for instance, the envelope layer includes the surface of a wall, such as plasterboard, and possibly insulation , such as mineral wool, and the structure layer includes the wall carrying structure, such as brick;
- A combination of diverse building components with respect to the story (slabs, walls, beams within one story) or also over few stories.

The 4D modeling approach within this research is based on single building elements, as detailed selective deconstruction, where every single material is separated during the deconstruction process is still limited in praxis due to time and space constraints and for the combination approach the component-based activity assessment can be aggregated to a certain degree.

5.2 Specification of component-based deconstruction activities

Deconstruction activities are defined as a combination of the deconstruction technique, the applied machinery and the respective attachment. The type and size of the attachment is determined by the other two components. The technical suitability of the deconstruction technique and the machinery size is dependent on different building element attributes and has to be analyzed separately before the activity as a combination can be applied. Furthermore, the type of machinery is influenced by the deconstruction technique.

5.3 Deconstruction activity related resources

Each deconstruction activity requires certain resources, including labor and equipment. For the suitability of component-based deconstruction activities required machinery and attachment had been assigned to each activity. Hence, essential equipment is already determined. In the following human resources, number of workers and their skills, as well as related required duration of the activity has to be estimated. Field work and empirical studies about required activity-related human resources, durations and costs are described in Rentz et al. (1998) and Schultmann and Rentz (2002).

Equally to construction, usually there are resource constrains, such as limited time, number of workers and available abilities of these workers, during the deconstruction process. Furthermore, space can be limited as well (Trinidad et al. (2004)), especially in cities. Space constrains can influence the choice of activity with respect to machinery size and deconstruction technique. Nevertheless, these issues are not further specified within this study.

5.4 Deconstruction activity related impacts

Like resources, emission levels for noise, dust and vibrations can be assigned to deconstruction activities. Furthermore the recyclability of deconstruction material can be described due to the applied technique by the size category of material pieces and the possible material sorting level.

The level of influence of the different attributes influencing the emissions, such as machinery and their size, deconstruction technique as well as the material and height of the component, have to be further analyzed by detailed measurements on deconstruction sites, while placing the measurement equipment as close as possible to the emission source (this is especially the case for noise and vibration measures). Furthermore expert opinions can help to quantify the influences within certain ranges.

To make a statement about the impacts on the local environment, the activity-related emission levels can be the basis for the simulation of noise, dust and vibration impacts.

Besides the emission data the required information source to predict the impacts on the local environment are wind maps with average local wind speeds and directions, land register maps to define the surrounding conditions (building density, area roughness and possible ground barriers) as well as topographic maps to define ground materials, which can be possible ground barriers as well, such as solid rock.

The approach of this study to nominate possible hazardous substances focuses on relevant primary hazardous substances in building materials, such as for instance asbestos. As these hazardous substances are introduced through the raw material and the production process depending on the production period, they are assigned to the type of building component, its material and its year of construction (cf. BayLfU (2003); DEMEX et al. (2006); DEMEX et al. (2004); Lippok and Korth (2007); Rötzel (2009)).

As a result, diverse factors influence the operational planning of the deconstruction process. Based on the schema for deconstruction activities introduced in Figure 1, Figure 4 shows decision dependencies within the deconstruction process and related environmental impacts.

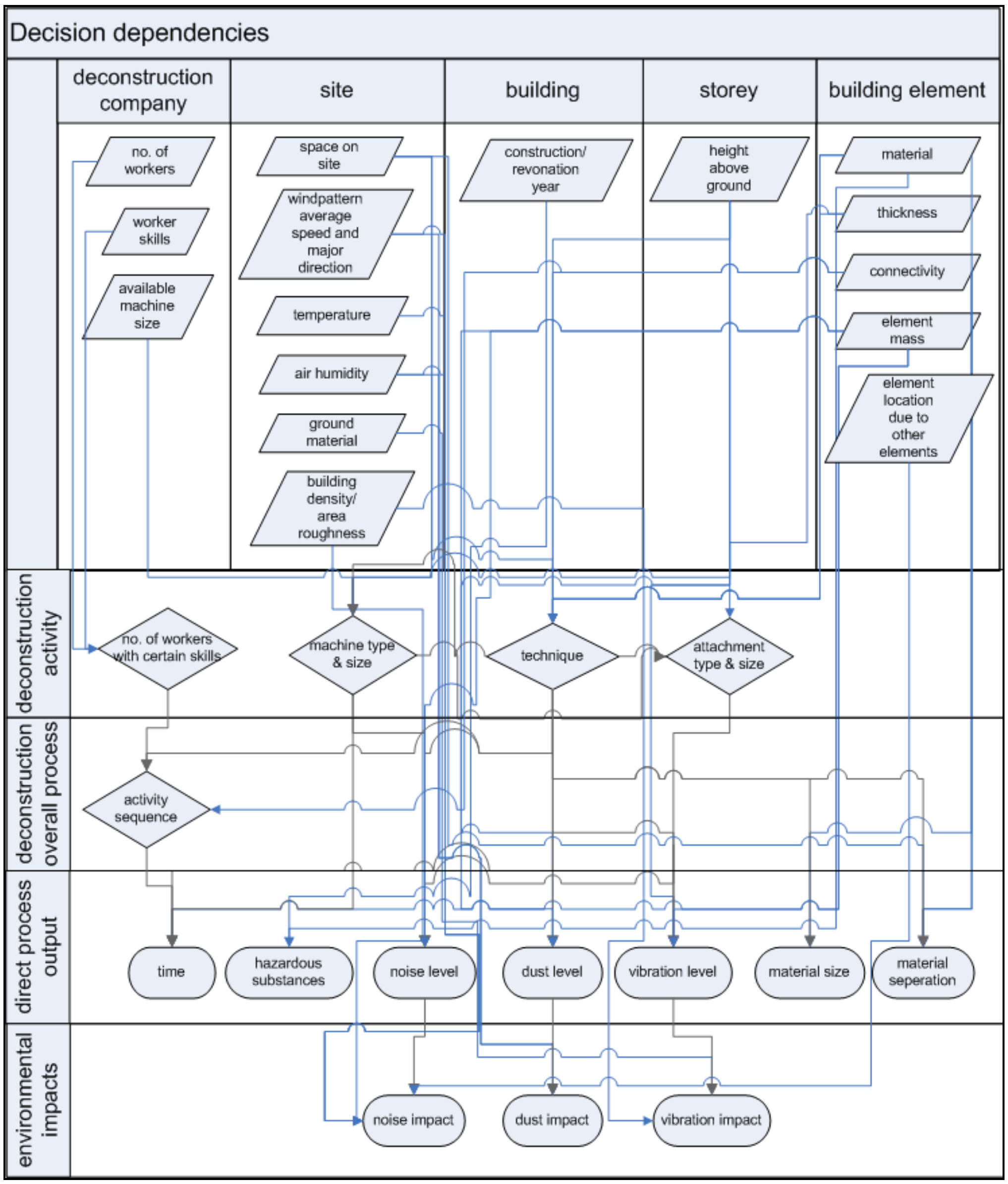

Figure 4: Overview of decision dependencies within the deconstruction process and related environmental impacts

6. CONCLUSION AND FUTURE WORK

The deconstruction process shows major differences to the construction process, especially with respect to environmental impacts, such as noise, dust and vibrations as well as hazardous substances. An approach to semi-automating aspects of activity planning for the deconstruction of buildings were described. These aspects were captured through an object model, description of the algorithm and an analysis of decision dependencies for the deconstruction process. These capture the current state of research across several projects within the two institutions collaborating on this research. These deliverables are still under development as the outputs of the contributing projects are refined. Immediate tasks to refine this work include:

1. Refinement of the environmental impact models and validation of the models proposed in this paper through encoding this information in databases;
2. Extension of the existing implementation of the planning algorithm to support the consideration of environmental factors.

In the longer term a model view definition of the deconstruction process will be defined as an interface to the IFC model. This is likely to require extensions to some existing IFC objects and the addition of some new objects.

The planning algorithm used within the software only produces very naive results, the intention being to remove the drudgery from planning and then allow humans to value-add. Adding more “intelligence” to the process would improve this process, but is not the focus of this current work.

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