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Deconstruction waste management through 3d reconstruction and bim: a case study

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Abstract

The construction industry is responsible for 50% of the solid waste generated worldwide. Governments around the world formulate legislation and regulations concerning recycling and re-using building materials, aiming to reduce waste and environmental impact. Researchers have also been developing strategies and models of waste management for construction and demolition of buildings. The application of Building Information Modeling (BIM) is an example of this. BIM is emergent technology commonly used to maximize the efficiency of design, construction and maintenance throughout the entire lifecycle. The uses of BIM on deconstruction or demolition are not common; especially the fixtures and fittings of buildings are not considered in BIM models. The development of BIM is based on two-dimensional drawings or sketches, which may not be accurately converted to 3D BIM models. In addition, previous researches mainly focused on construction waste management. There are few studies about the deconstruction waste management focusing on demolition. To fill this gap, this paper aims to develop a framework using a reconstructed 3D model with BIM, for the purpose of improving BIM accuracy and thus developing a deconstruction waste management system to improve demolition efficiency, effective recycling and cost savings. In particular, the developed as-built BIM will be used to identify and measure recyclable materials, as well as to develop a plan for the recycling process.

Keywords: Sustainability, Deconstruction, Recycling building material, Waste management, BIM, Reconstructed 3D

Background

Sustainable waste management has become one of the vital environmental issues and the construction industry is responsible for 50% of the solid waste generated worldwide (Commonwealth Commonwealth of Australia, 2011). Australians generated approximately 53.1 million tonnes of waste in 2010–11 (Australian Bureau of Statistics, 2014), an increase of 21.1% from 43.8 million tonnes of waste in 2006–07 (Australian Bureau of Statistics, 2010). This indicates that the volume of construction and demolition waste is continuously increasing over this period.

Of the 53.1 million tonnes of waste generated in Australia in 2010–11, 14.5 million tonnes or 27.3% came from the construction and demolition (C&D) sector in 2010–11 (Australian Bureau of Statistics, 2014). The growth of population, demographic elements and economic activities, such as the construction industry, which has been developing rapidly over the past few years, are the main factors causing the growth in the amount of waste generated in Australia.

The contributions of recycling and re-use of building material are significant in reducing waste and environmental impacts. This implies that the need for raw materials in new building projects is reduced since deconstructed materials are recycled and reused. Australian governments thus have formulated legislation and regulations, such as '*Construction and demolition waste guide –recycling and re-use across the supply chain*', which is one of the documents produced by the Department of Sustainability, Environment, Water, Population and Communities, aiming to maximise waste reduction in the construction industry. However, the principle of reducing waste cannot be applied in practice easily. The State of NSW and Environment Protection Authority (2014) reproduced an avoidance and resource recovery strategy 2014–21 and have set a new target to increase recycling of construction and demolition

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waste from 75% in 2010–11 to 80% by 2021–22. In order to achieve the new target, identifying the types of building material and locations, as well as estimating the quantity of waste accurately, are important before the demolition plan and waste management strategy are formulated.

Many researchers have also worked on solutions to the planning and management of construction and demolition waste. The main areas of research include developing C&D waste management tools and systems (Mercader-Moyano and Ramirez-de-Arellano-Agudo, 2013; Fatta, et al., 2003; Wang, et al., 2004). A common feature of these works is the combined study of construction and demolition waste management. The waste attributes from construction are different from those of demolition. Cheng, et al. (2015) claimed that construction waste is mainly generated due to improper design, poor procurement and planning, inefficient material handling, residues of raw materials and unexpected changes in building design. Demolition waste results from the demolition or refurbishment of building or infrastructure excluding Listed Waste, Hazardous Waste or Radioactive Waste. The debris varies from insulation, electrical wiring, rebar, wood, concrete and bricks. Some hazardous materials such as asbestos cannot be recycled or reused.

The second category of research focused on the demolition waste sorting process (Huang, et al. 2002 and Poon, et al., 2001), recycling and re-use of building materials (Corinaldesi, et al., 2005; Rao, et al., 2007 and Corinaldesi and Moriconi, 2010). However, to recycle and re-use significant volumes of materials from deconstruction of buildings is a challenge, due to cross-contamination of wastes, technological barriers, and the considerable time and cost involved.

The third category of research applied Building Information Modelling (BIM) technology for construction and demolition waste management (Cheng, et al., 2015; Park, et al., 2014; Hamidi, et al., 2014). BIM is a process integrating and managing all of the information over a project's life-cycle, including planning, design, construction, operation of a building facility and deconstruction (Wang et al., 2015; Wang et al., 2016). BIM not only provides a set of interrelated and cross-referenced information, but also creates a 3D visual interface from a 2D drawing and integrates time as 4D, as well as costs as 5D information assisting management decisions of different stakeholders and needs. It is identified that BIM contributes to improve planning, scheduling, productivity, the reduction of project duration and waste-related costs and materials in construction projects (Krygiel and Nie, 2008). Rajendran and Gomez (2012) suggested that waste could be minimized through designing-out-waste by using BIM tools.

Previous researches mainly focused on construction waste management. However, the uses of BIM on deconstruction or demolition are not common; especially the fixtures and fittings of buildings are not considered in BIM. The development of BIM is based on two-dimensional drawings or sketches, which may not be accurately converted to 3D BIM models.

This research answers the following questions:

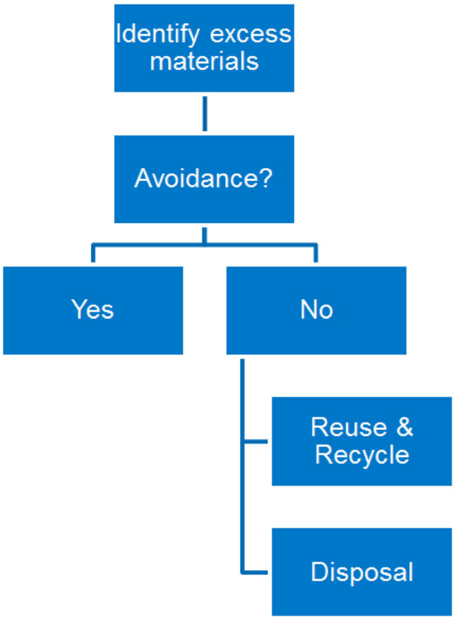
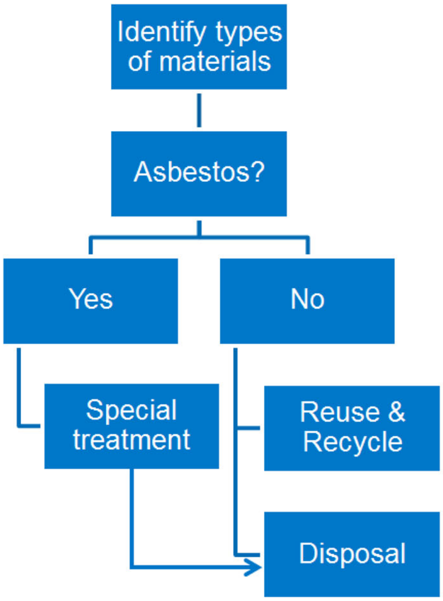
- How can BIM be used to identify different building materials (location and quantity) in a deconstruction project?
- How the reconstructed 3D model and BIM-based waste management system is built, as well as what are the benefits of the resultant estimating methodology?

In particular, this research fills the gap by developing a BIM-based system for managing demolition waste including fixtures and fittings with a reconstructed 3D model. This research goes on to discuss the different processes of construction and deconstruction waste management and to demonstrate the importance of developing demolition waste management from deconstruction, in particular for deconstruction of buildings built before 1990. Reconstructed 3D models and BIM-based waste management systems will also be described and a pilot case study will be analysed followed by the conclusion.

Characteristics of construction and deconstruction of wastes

Construction and deconstruction are different in terms of process and waste creation (Refer to Table 1). The waste created from a construction can be from excavation for underground construction, road planning and maintenance materials, geotechnical engineering works and worksite waste materials. Additionally waste can be created from all the materials from operations or worksite construction, repairing, propping, accretion, expansion or renovation activities (Donovan, 1991). Deconstruction waste is debris from structural and non-structural demolition of a building. The main feature of deconstruction is that there may be hazardous materials such as asbestos waste contained in the deconstruction process. Based on Commonwealth of Australia (2013), asbestos products were used in commercial, industrial and residential house buildings until the late 1980s. All forms of asbestos were totally banned from 31 December 2003 and asbestos-free products were gradually used. For example, houses built before the mid-1980s are highly likely to have asbestos-containing products. Houses built between the mid-1980s and 1990 are likely to have asbestos-containing products; and those built after 1990 are unlikely to have asbestos-containing products. Most of the buildings that required demolition were built before 1990. Asbestos-containing products can be found from roofing, insulation, exterior

Table 1 Difference between construction and deconstruction waste

	Construction	Deconstruction
Definition	Construction is the act or process of building something such as an office building or road.	Deconstruction refers to carefully dismantling pieces of a building in order to salvage valuable building materials.
Purpose	To develop a building or infrastructure	To demolish a building or infrastructure
Process	After design, the construction process includes breaking ground, excavation, foundations, utilities, framing, roofing, a weather resistant barrier, rough plumbing, mechanical systems, lighting and electrical, air sealing, insulation, drywall, siding, flooring, tiling, painting, cabinets and shelving, finish plumbing, finish electrical and lighting, certificate of occupancy.	Developing a list of contacts for collecting recycle and re-use material; identify hazardous materials such as lead paint and asbestos; conducting 'soft-strip' of the non-structure deconstruction for removing all appliances, windows, doors, and other finishing materials; structural demolition starting at the roof and working down to the foundation; storing, sorting and building an inventory list of materials and sending it to the collectors.
Waste creation	a) Excavations from underground constructions (Fatta, et al., 2003); b) road planning and maintenance materials such as asphalt and all pavement materials such as sand, gravel, metal and material coming from road dismantling and renovation and underground hydraulic and electrical installations and repairing activities (Fatta, et al., 2003); and c) geotechnical engineering works and worksite waste materials that consist of wood, plastic, paper, glass, metal, wires, pigments, enamels, covers, glues, and all those material coming from operation or worksite construction, repairing, propping, accretion, expansion or renovation activities (Donovan, 1991).	Debris from structural and non-structural demolition of a building or infrastructure such as soil, gravel, pieces of concrete, lime-cast, bricks, overlay plates, gypsum, sand, dressed stone, porcelain, etc.
Waste management		

and interior wall cladding, water or flue pipes, insulation on hot-water pipes, domestic heaters and stoves, textured paints, decorative ceiling coatings, and so on. The construction of buildings after 1990 is generally asbestos-free in Australia, and as a result, waste management strategies are different for construction and deconstruction.

Waste minimisation and estimation methods

Understanding the difference between construction and deconstruction provides guidance for developing tailor made waste management strategies. The demolition of a building produces a large quantity of different types of solid waste. For many existing buildings, the original design and building documents might not be found. Some of the buildings were renovated and possible different building materials were used. To identify what building materials have been used and where the materials are located in the demolished buildings are challenging. Additionally the decision on the method of demolition and recycling of building material relies on the information regarding the type and quantity of waste. An accurate quantification of demolition waste is essential for effective waste management. From this information the contractor applies his own experience to estimate the number of trucks needed and the transport frequency (Cheng and Ma, 2013). Overestimating the number of waste pick-up trucks could result of a waste of space and increase logistics costs. Underestimating the pick-up quantity could cause trucks to be overloaded and cost increases due to penalties. Figure 1 depicts a typical demolition process.

The various ways of waste minimisation of construction and demolition have been the subject of previous studies. Medibodi, et al. (2014) suggested the use of prefabrication and procurement management for minimizing concrete waste. Waste reduction rate was 52% (Jaillon, et al. 2009) and 70% concrete waste reduction (Lawton, et al. 2002) if prefabrication was used. However, no evidence was provided for waste reduction on deconstruction in the literature.

Accurate estimation of waste quantity is critical for demolition decision programs, waste management and logistics scheduling. The existing waste estimation methods include 'Waste Index' (Poon et al., 2001), 'Global Index' and 'Component Index' (Jalali, 2007), material stocks and flows from a region (Cochran and Townsend, 2010), quantities from related construction databases (Solis-Guzman, et al., 2009 and Llatas, 2011), physical layout forms of materials (Lau, et al., 2008) or accounting tools. The main drawbacks of the listed estimation methods are identified as their inaccuracy and the difficulty of implementation in practice (Cheng and Ma, 2013). For example, Poon (2001) introduced a method called 'Waste Index' for estimating the quantity of demolition waste generation in Hong Kong. He categorised the existing building records held at the Planning Department by age groups. He then derived the yearly gross floor areas (GFA) using the measured site area times number of storeys to measure the quantity of waste for the buildings belonging to the identified category. His work calculated the total waste produced in the demolition buildings for each category considered. Based on the work of Poon (2001), Jalali (2007) constructed a 'Global Index', which estimates waste in unit amount, or area of activity, by the given type of building material. However, the building materials used for each of the buildings were not separately identified and measured. In addition, the building data was based on the original records, renovated buildings and the actual building materials including fixtures and fittings at the time of demolishing were not taken into account. Since the recycling and reuse rate varies from site to site and from contractor to contractor (Cheng, et al., 2013), the measurement of waste of gross floor areas may not be useful for developing waste management strategies for a single deconstruction project. The developed 'component index' (Jalali, 2007) is difficult to implement in practice as it depends heavily on the use of detailed spreadsheets and labor-intensive manual measurements and updating (Cheng, et al., 2013).

In recent years, Building Information Modeling (BIM) is an emergent research topic recommended for construction and demolition (C&D) waste estimation and management (Cheng and Ma, 2013; Park, et al., 2014; Hamidi, et al., 2014 and Cheng, et al., 2015). Cheng and

Fig. 1 Traditional demolition process

Ma (2013) developed a system for C&D waste estimation, disposal charging fee calculation and pick-up truck planning. The research did not include specific methods to minimize and manage C&D waste. Hamidi, et al. (2014) proposed a BIM-based demolition waste management system and Park, et al. (2014) developed a BIM-based C&D waste database by analysing the construction material classification system and data available in the ARCHICAD library in Korea. The research focused on establishing of a BIM-based demolition waste (DW) database, but failed to investigate demolition of existing buildings that have not previously used BIM technology. Cheng, et al. (2015) investigated the potential of eliminating the major causes of C&D waste generation using BIM technology for supporting integrated building design and construction processes. They claimed that BIM can minimise the amount of C&D solid waste by improving the quality and accuracy of design and construction through reducing design errors, rework and unexpected changes.

Most of the previous research introduced potential use of BIM to minimise C&D waste but have not provided a specific method to minimize and manage C&D waste using BIM (Liu, et al. 2011; Porwal and Hewage, 2012; Rajendran and Gomez, 2012; Cheng and Ma, 2013; and Ahankoob et al., 2014). Additionally, a typical BIM is used for planning, design and construction. Its features include structural, mechanical, electrical and plumbing (MEP) details. However, a BIM does not include details of fixtures and fittings of buildings, in which some of the material can be recycled and re-used.

Another challenge is to establish whether the building materials are recyclable. Materials include concrete, timber and glass that can be recycled; whereas some of the old buildings contain hazardous materials such as lead paint and asbestos that cannot be recycled. Based on the identified 'can be recycled' and 'cannot be recycled' materials, appropriate demolition and recycling methods for each type of material can be introduced. The next section explains how the reconstructed 3D model and BIM is developed for deconstruction projects.

Research methods

The method used for developing deconstruction waste management systems is the use of reconstructed 3D model and BIM. The Reconstructed 3D model is used to build the detailed 3D model of an actual building purely based on data collected by sensors such as images from a camera. The purpose of including a reconstructed 3D model into the management system is to achieve data visualization and improve the accuracy of BIM. That is to say that the type of building material and locations, as well as the connections between the building materials can be visualized through the reconstructed 3D model. Demolition of existing buildings involves complex activities. Often, original building and facility drawings of old buildings have been lost and this makes demolition operations difficulty. On the other hand, re-drawings or sketches of the building structure are two-dimensional (or 2D) making 3D visualisation more difficult. Static is one of the problems of 2D drawings, which are not able to be understood the space relationships among structures, facilities and rooms. The introduction of 3D technology allows people to see what a building will look like and feel a connection to a particular space. Thus, an accurate model can be built. Additionally, BIM can present 3D graphics with sections of building data, but it is not able to show the actual buildings and walk through the buildings. By combining BIM with interactive visualization, managers can understand which materials are placed where; identify the areas of demolition that need attention or special treatment. Safety measures can be taken and the amount of waste can be predicted. Managers can make better decisions and develop tailor made demolition plans and waste management strategies in order to save costs and achieve reuse and recycle targets.

Figure 2 denotes the process of developing demolition and waste management plans. Compared to the traditional demolition process shown in Fig. 1, this method includes reconstructed 3D and BIM before quantity take-offs.

Obtaining drawings or sketches

Original building structure and mechanical, electrical and plumbing (MEP) drawings are the very basic information needed for understanding what the building materials are, where they are and their quantities. If the original drawings have been lost, a building survey is needed to provide sketches of the building so that the demolition can be planned and the resultant material quantities estimated. The more detailed the drawings are, the richer the data information for developing the BIM for the building.

Reconstructed 3D model

As discussed above, a reconstructed 3D model can provide dynamic visualisation of the buildings and assist with accuracy of constructing BIM, as well as help demolition planning and waste management decision-making. The 3D reconstruction algorithm is based on bundle adjustment techniques. The sensors used for collecting data can be RGB cameras or RGB-D cameras. The common features observed from neighbouring frames are extracted and matched. The matched features and the camera poses are then estimated using an optimization technique. Necessary constraints are taken into account in order to improve the estimates. For

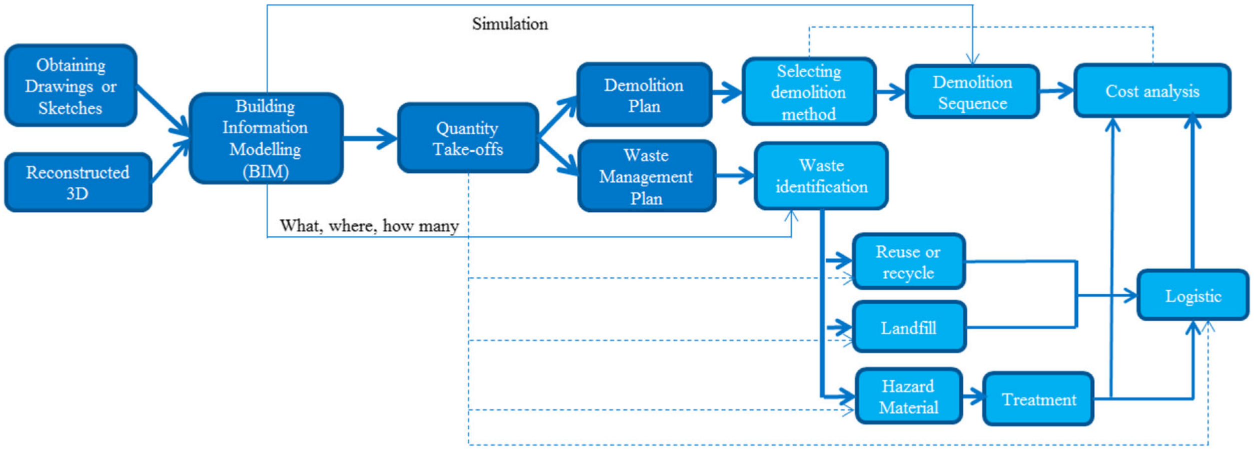


Fig. 2 Developed deconstruction and waste management process

example, in Wang et al. (2017), RGB-D sensor is used to generate a globally consistent model in complex indoor scenes. The first step is to generate a rough 3D model using hierarchical intra-chunk and keyframe bundle adjustments. Next, planar elements are detected in the selected keyframes and the planar constraints are incorporated into the global optimization. Global consistent point cloud and high-quality mesh models are then built by integrating all the depth images and reducing noise through Truncated Signed Distance Function volume. Figure 3 presents one of the reconstructed 3D point cloud using camera for a classroom. Brick walls, glass windows, concrete built celling and the floor with debris and even the prints on the blackboard can be identified.

Developing BIM and integrating with reconstructed 3D model

Together with the 3D Point cloud images, the collected data from drawings or sketches and Auto-desk Revit Structure are used to build a model. The modelling work involves three tasks (Tang et al., 2010): (1) modelling geometry information of building components; (2) assigning a BIM object category (i.e. wall, column, door or window) to a component and adding related properties such as material type, demolition cost, and recycling method; and (3) establishing relationships between components, for instance, *window1* is linked to *wall1.* Although there are numerous approaches developed for automating the creation of as-built BIM model, manual creation is still a dominated method in current practice

Fig. 3 An example of reconstructing 3D point cloud (A point cloud is a set of data points in some coordinate system. In a three-dimensional coordinate system, these points are usually defined by X, Y, and Z coordinates, and often are intended to represent the external surface of an object. Point clouds may be created by 3D scanners (Wikipedia))

especially in old building documentation. In this research, a semi-automated approach is applied to conduct the above three tasks. The major components such as walls and columns as well as large pipes and ducts are automated recognised from the point cloud model. Small size components (e.g. light fixtures and furniture) and hidden elements (e.g. rebar) are modelled manually according to old engineering drawings. In addition, most of the object properties (e.g. material and cost) are also manually added by BIM service providers. If there are inconsistencies between the old drawings and reconstructed 3D model, the point cloud images are used to decide which one is correct. For hidden elements, due to the lack of corresponding point cloud images, we can only rely on the as-built engineering drawings. If these drawings are incomplete or inexistent, personal expertise and experience will be leveraged to deduce the possible structures. Alternatively, other new approaches such as electromagnetic method and Ground-Penetrating Radar can be applied in detecting hidden elements such as rebar and pipe in concrete (Gibb and La, 2016; He et al., 2016).

As suggested by Cheng and Ma (2013), the Revit environment[1] allows users to manipulate whole buildings. Different types of building materials are input into a database, which includes material types, locations and measurements. In addition, the reconstructed 3D model in 4.2 will be integrated with the developed BIM so that the users can visualise not only the fixtures and fittings, but also the shapes of building materials behind the walls or columns, such as rebars (as shown in Fig. 4).

Quantity taking-offs

Types and the location of hazardous materials and their quantities can be identified. BIM can provide accurate quantity take-off and the total waste volumes (inert e.g., concrete and non-inert, e.g., wood) without additional time and effort. BIM also helps to estimate the amount of demolition waste, disposal charge fees and the costs of logistics. The number and size of pick-up trucks can be estimated and the benefits of disposal and recycling can be compared.

The quantity of each type of building materials can be extracted from the as-built BIM by material types and building levels. The measurements can be classified as numbers (e.g., number of doors or windows) and volume (cubic meters). Grand total can also be calculated automatically. All quantified materials can be exported to Excel if needed. According to Cheng and Ma (2013), the total volume of demolition waste, based on his methodology, was 15.8% different from the results using BIM.

Developing demolition and waste management plan

The use of demolition methods can vary with the site conditions, safety requirements, and cost; as well as time available for demolition and the need for site clearance for the new structure (Pranav, et al., 2015). BIM can provide accurate building information assisting in the selection of the demolition method and developing the demolition stages. The sequences and process of the demolition can be designed and simulated prior to the actual demolition implementation. For example the handling of hazardous materials (e.g., fire doors that contain asbestos) can be prioritised so that they are removed first. The benefits and costs of using different demolition methods can be compared and studied.

Waste can be distinguished from items of reuse, recycling, and disposal based on the types of demolished materials and waste management strategies can be developed accordingly. Figure 5 depicts the demolished material classes.

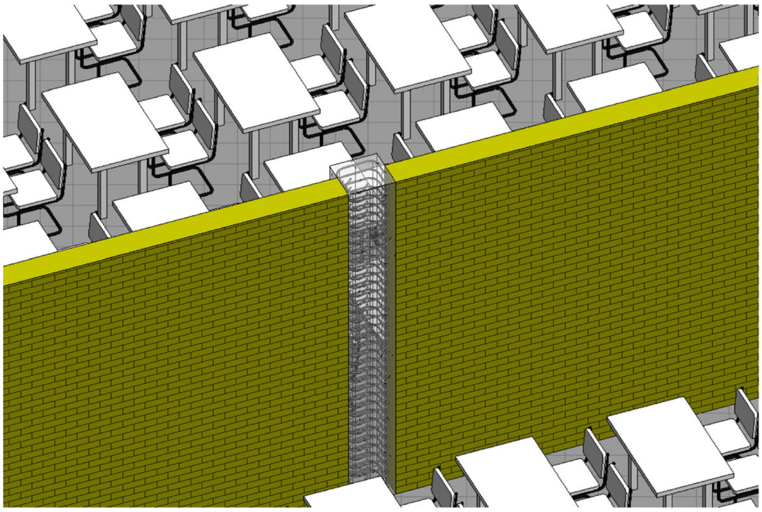


Fig. 4 Rebars behind the column in BIM

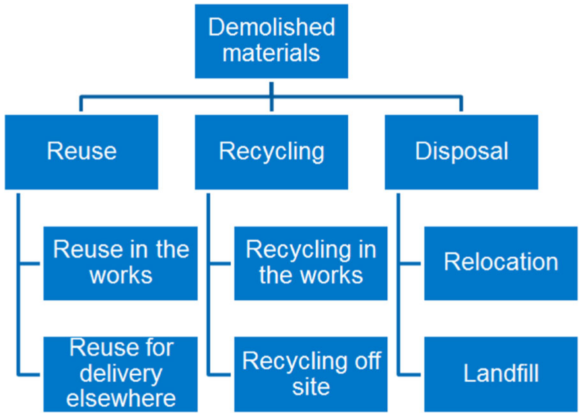


Fig. 5 Demolished materials classes

Case study - waste management with reconstructed 3D and BIM

Building 2 at the University of Technology Sydney was used as a case study. The building was built in 1978 and has completed its life cycle. As this is a prototype study used to test the developed model described in section Development of deconstruction waste management system with bim and reconstructed 3d model, level 5 of the building was applied as an example. The detailed process of developing demolition and waste management plans are shown in Fig. 6.

The first step was to obtain the drawings and engineering documents of the building's level five. Each of the types of material, specification, location and quantity of the material was then input to build the BIM. The BIM shows what, where and how much of each material there was.

At the same time, a 3D model of building 2 (exterior) was reconstructed by using the information of images taken from a drone (Refer to Fig. 7) and 3D classrooms were also reconstructed using camera images.

The developed BIM (as-designed) and the reconstructed 3D model (as-built) were combined and the virtual 3D model was then built. The information contained in the BIM is linked to the drawings and reconstructed 3D models. As shown in the Fig. 8, the column between the partition walls can be located accurately and the measurements of the column can be known. The benefits of the links are to provide visualisation and accurate identification of material locations and specifications.

Next step was to determine what materials were used, where they are and their quantities. The hazardus materials were first identified because they need to be treated and demolished specially. Simulations of the demolition process have also performed in the developed BIM (Refer to Fig. 9). The simulations consist of not only demolition sequences, but also scheduled number of days required for demolition in each of the phases. As a result, labour required costs and quantities of demolished material and number of trucks required for transporting the demolished material could be estimated.

Table 2 shows an example of wall material take-off, in which phase demolitions will occur, volume of materials, unit cost and total demolition costs are included. Given the accurate information provided by the BIM and reconstructed 3D model, demolition and waste management plans were developed.

Demolition plan

Before the demolition plan is developed, understanding of the building materials, site conditions, the built environment of the building to be deconstructed are important for selecting an appropriate method of demolition. Pranav, et al. (2015) proposed the use of controlled demolition work and found that waste can be minimized and recycled. In addition, the use of controlled demolition is quite an economical and time-saving method as compared to conventional methods. They also found

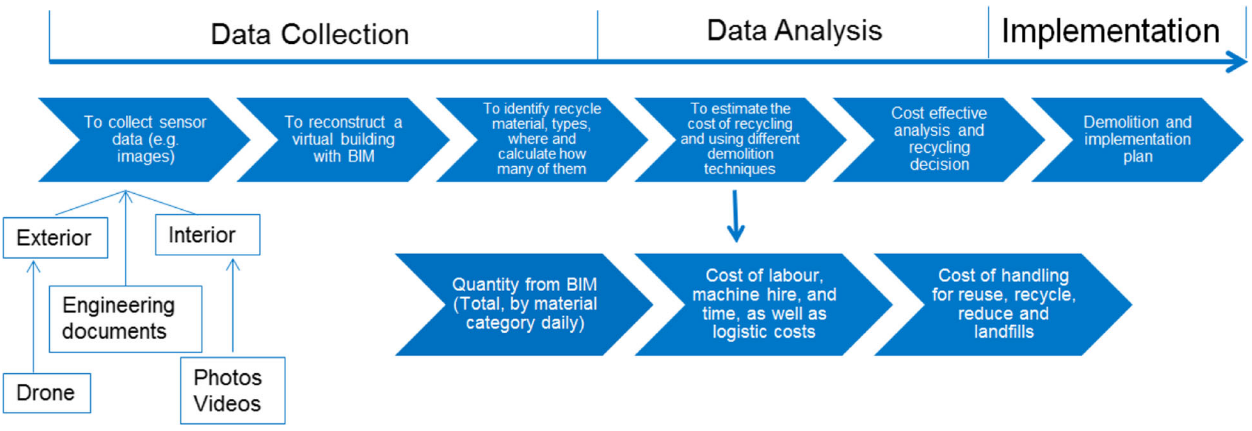


Fig. 6 Steps of developing demolition and waste management plans

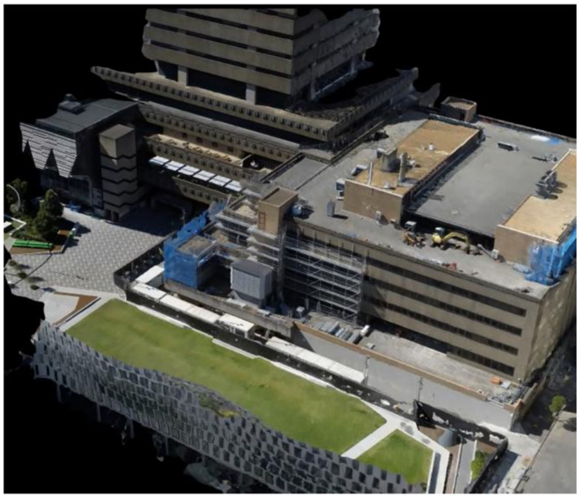


Fig. 7 Reconstructed 3D model using Drone

that the reuse and recycling of waste can be increased when their proposed demolition method is used. Explosion deconstruction is an effective and efficient method of deconstruction as both cost and time (up to 80%) can be reduced with the majority of the time being spent in the preparation period and the clean-up following the implosion (Pranav, et al. 2015). However, the implosion method of demolition contains high risks and results in most of the building materials not being reused and recycled. Table 3 depicts the advantages and disadvantages of popular demolitions methods.

In view of the goal to maximize recyclable materials and in light of the fact that the area to be demolished was part of an existing building the contractor used the selective demolition/strip out method.

UTS Building 2 is located at the centre of Sydney CBD surrounded by high-rise buildings and busy traffic on Broadway. Implosion methodology is therefore counter indicated as it could cause harm to people and the surrounding buildings. Control method of demolition by stripping the structure and applying machinery to the building deconstruction is more appropriate.

Demolition and scaffold permits must obtained from the authorities before starting demolition. Each person must obtain health and safety certificate and attend induction training before accessing the building site.

Inspections and detailed work plans need to be done before stripping work and demolition begins. Table 4 shows the schedule of inspections.

The work plan consists of the method of protection and support for adjacent property, locations and details of necessary service deviations and terminations, confirmation of the sequence of work, government planning requirements and execution and the safe use of mobile plant, including consideration of suspended structural members and wheel loads of tipping or loading vehicles (Richard Crookes Construction (RCC), 2016).

A hazardous substances management plan and register need to be prepared. A dilapidation record must be kept and submitted to the owners of each adjacent property in order to assess any damage and subsequent need for making good arising out of the demolition work. On-site stockpiles need to be arranged for demolished materials for recycling in the works.

Demolished materials must be classified by recovered items for re-use in the works, for delivery to the principal, demolished material for recycling in the works or off site, dismantle for relocation and demolished for removal.

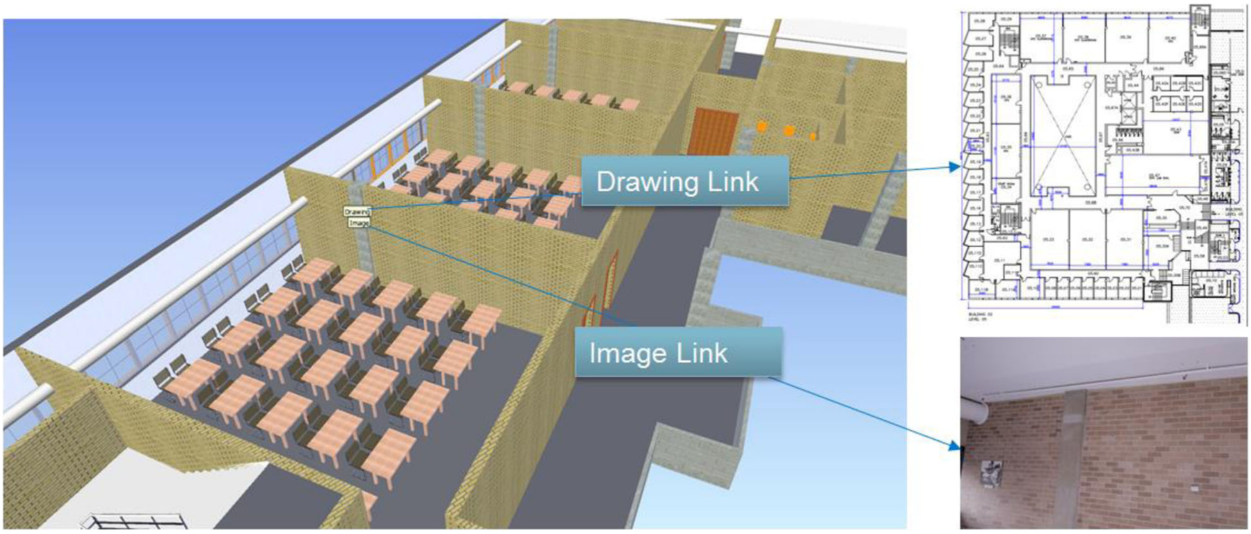
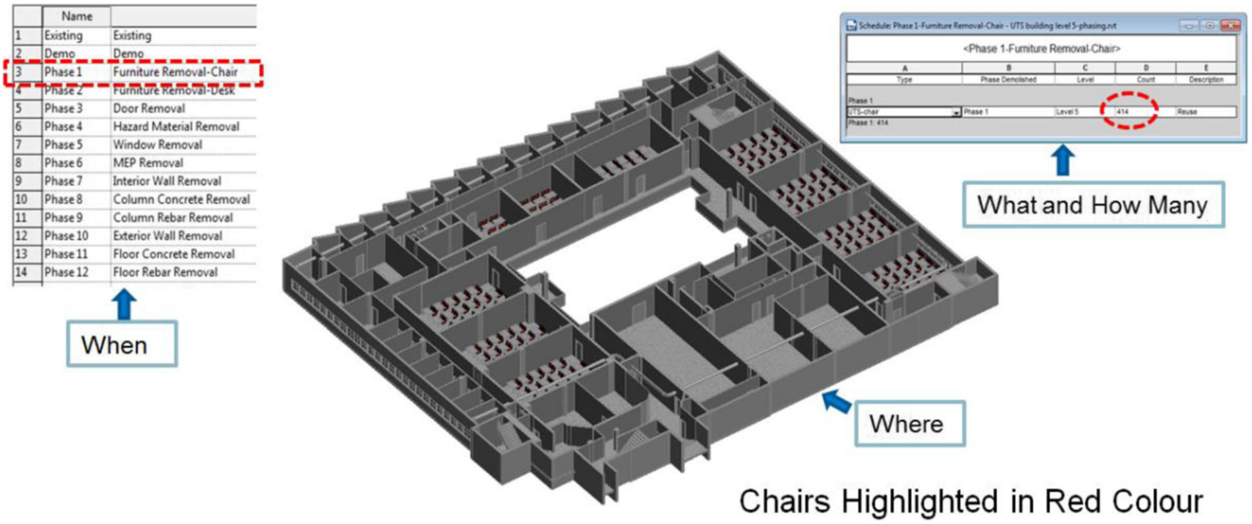


Fig. 8 Information links and integrated of 2D drawing, 3D and BIM



	Name	
1	Existing	Existing
2	Demo	Demo
3	Phase 1	Furniture Removal-Chair
4	Phase 2	Furniture Removal-Desk
5	Phase 3	Door Removal
6	Phase 4	Hazard Material Removal
7	Phase 5	Window Removal
8	Phase 6	MEP Removal
9	Phase 7	Interior Wall Removal
10	Phase 8	Column Concrete Removal
11	Phase 9	Column Rebar Removal
12	Phase 10	Exterior Wall Removal
13	Phase 11	Floor Concrete Removal
14	Phase 12	Floor Rebar Removal

Schedule: Phase 1-Furniture Removal-Chair - UTS building level 5-phasing.rvt

<Phase 1-Furniture Removal-Chair>

A	B	C	D	E
Type	Phase Demolished	Level	Count	Description
Phase 1				
UTS-chair	Phase 1	Level 5	414	Reuse
Phase 1: 414				

Fig. 9 What, where and quantity of materials and demolition process

The demolition steps are initially simulated through BIM (Refer to Fig. 10). As discussed, with the development of the reconstructed 3D model integrated with BIM, workers can visualise not only the surface of fixtures and fittings, but also the material behind the walls. Thus the decision of the demolition steps can be made. In the case of level 5 Building 2, after disconnecting all services, the first step was to remove the furniture (desks and chairs) and carpets for reuse if possible. The second step was to remove classroom or office doors. The third step was to remove and treat hazardous materials (e.g., fire doors) that are made from asbestos or material containing asbestos, flammable or explosive liquids or gases. The next steps involve removing windows, MEP, interior walls, concrete columns, rebar columns, exterior walls, floor concrete and floor rebar. Based on the simulated demolition sequence, contractors are able to estimate the numbers of workers, types of machine hired and time required accurately, as well as to ascertain costs of demolition and budget some contingency.

Waste management plan

Waste reduction and recycling is the environmental and social responsibility of the client and the contractor. The waste management plan must meet the government's regulations, and client's target KPIs, which is to generate

Table 2 An example – wall material take-off

<Wall material takeoff>

A	B	C	D	E	F
Material: name	Type	Phase demolis	Material: volume	Unit cost ($/m3)	Cost ($)
Asbestos					
Asbestos	Hazardous materials	Phase 3	0.42 m^3	300	124.874983
Asbestos: 26			0.42 m^3		124.874983
Brick, common					
Brick, common		Phase 7	508.92 m^3	300	152,675.861538
Brick, common: 60			508.92 m^3		152,675.861538
Concrete masonry Units					
Concrete masonry units	Atrium wall 100	Phase 7	10.06 m^3	300	3019.045148
Concrete masonry units	UTS-exterior-wall-240	Phase 10	180.48 m^3	300	54,142.794872
Concrete masonry units: 69			190.54 m^3		57,161.84002
Gypsum wall board					
Gypsum wall board	UTS-exterior-wall-240	Phase 10	18.05 m^3	300	5414.279487
Gypsum wall board: 57			18.05 m^3		5414.279487
Grand total: 312			717.92 m^3		215,376.856029

Table 3 Comparisons of popular demolition methods

Method	Description	Advantages/Disadvantages
Implosion	Explosives used to cause the building's support structure to fail and the building to collapse.	• Do not need BIM. • Construction material not separated. • Not a technique to be used to demolish only part of a larger building. • Creates a great deal of dust, vibration and noise.
Crane and ball	A heavy ball is swung into the building shattering its structure.	• Do not need BIM. • Height limitations. • Construction material not separated. • Not a technique to be used to demolish only part of a larger building. • Creates a great deal of dust, vibration and noise.
High Reach Arm	Demolition equipment, such as hammers and shears, are attached to an arm consisting of several sections or a telescopic boom.	• Do not need BIM. • Height limitations. • Needs a favorable building shape. • Not a technique to use to demolish only part of a building. • Creates a great deal of dust, vibration and noise.
Rope pulling	Cables and wire ropes are attached the structural members which are then pulled down using a winch or tractors	• Do not need BIM. • Needs a significant amount of surrounding room. • Construction material not separated. • Not a technique to be used to demolish only part of a larger building. • Creates a great deal of dust, vibration and noise.
Selective Demolition or strip out	This process allows the staged selective demolition of both the interior and exterior portion of a building. Interior equipment, walls, floor, ceilings and exterior components can be separated.	• BIM assists with providing maximum separation of waste types. • Achieves the highest production of recyclable material. • Can be used on part of an existing building and is the safest method for use in an urban environment were a building may be partially occupied. • Minimizes noise, vibration and dust. • Takes the longest and may be the most expensive.

(Source: Authors' summary)

at least 80% of recycling or reuse of construction and demolition waste (The State of New and Environment Protection Authority, 2014; UTS, 2016).

Waste management targets were developed to minimise waste volumes and the risks of causing harm to the environment and maximise operational efficiency and environmental performance. The aim of developing a waste management strategy is to avoid waste at the planning of deconstruction stage; secondly, to reduce waste during the deconstruction activities by using appropriate demolition skills; thirdly, to reuse materials wherever possible such as furniture, metal, etc.; fourthly, to recycle those materials sorted or stored on-site, e.g., wiring, used for different purposes; fifthly, to treat the materials and reuse them on-site; and finally to dispose of wastes that cannot be reused, recycled or treated for beneficial reuse.

Table 4 Schedule of Inspections (Source: Richard Crookes Construction, 2016)

Item	Inspection type	Notice
Services before disconnection or diversion.	Hold point	3 days
Trees specified to beretained before demolition.	Hold point	3 days
Contents of building before demolition.	Hold point	3 days
Structure after stripping and removal of roof coverings and other external claddings.	Hold point	3 days
Excavations remaining after removal of underground work.	Witness point	3 days
Site after removal of demolished materials.	Witness point	3 days
Services after reconnection or diversion.	Witness point	3 days

The sub-contractor is responsible to develop a waste management plan that meets the aim to achieve compliance with the Waste Management credit of the Green Star Education V1 rating tool required by the main contractor of the project and UTS. The principle of the waste management plan is to minimise the impact of waste on the environment and the public where practicable through reduce, reuse, recycle and disposal hierarchy of waste management. Reduce means to prevent and eliminate waste products, whereas reuse is to find a secondary use for the waste product. Recycle implies an alternative use for the waste product which may include reprocessing of the product, whereas disposal includes

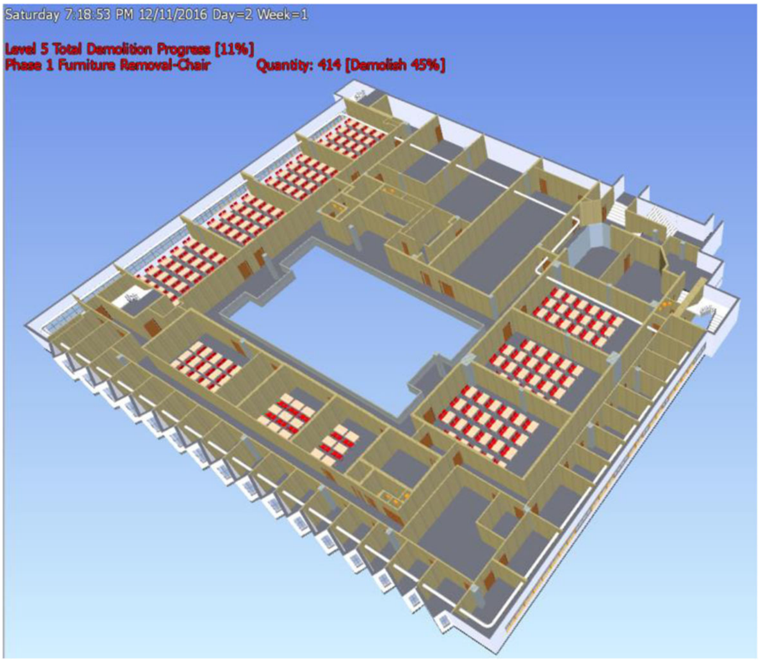


Fig. 10 BIM-based demolition simulation

treatment of the product, incineration or deposit at a landfill site.

The waste management procedure includes the planning identification of hazards, assessment and control.

Planning identification of hazards, assessment and control

Prior to commence the deconstruction project, the management team will use industry knowledge and experience, incident history, review similar projects completed, consultation with workforce to identify Hazards that have the potential to impact the successful completion of the project.

When starting the demolition, related personnel including estimator, project manager and site supervisor will complete an OHSE Hazard Identification and Risk Assessment for the site. By planning the process, the timing and resources necessary to achieve the desired outcomes will be determined and a platform for continual improvement can be provided. The key stakeholders at tender stage of project will be consulted and communicated with both formally (tender meetings) and informally (phone calls, etc.) to establish the context of the risk with regards to scope of works.

Results and discussions

The 3D reconstruction models ensure the BIM was built accurately. Based on the BIM, all locations of building materials were identified and quantified accurately and then classified as reuse, recycle and landfill, including hazardous materials that need to be treated specially. As BIM is used, all waste materials are recorded and identified by material name, volume, source, category, code, approval documents, data, time of waste collected, and receiving facility. Total waste collected, reused and the recycle rate etc. can be tracked. Table 5 is an example that records some of materials generated from the deconstruction of level 5 of the building and waste management classification.

Furniture such as chairs and tables were used for other parts of university and to furnish a new office for the main contractors. The old carpets were used between the walls that adjoin to the building 1 for breaking down

Table 5 Examples of waste generated from the deconstruction of level 5 of the building

Materials	Quantity	Reuse	Recycle	Disposal
Furniture (chairs)	414	y		
Furniture (tables)	207	y		
Carpet and underlay	2499 (m2)	y		y
Bricks	1017.81 (m3)		y	
Concrete (column)	42.42 (m3)		y	
Concrete (wall & floor)	690.41 (m3)		y	
Gypsum board (e.g. drywall)	36.14 (m3)		y	
General Doors	69		y	
Fire doors	8			y
Glass	1.17 (m3)		y	
Rebar	30.06 (ton)		y	
Asbestos	0.83 (m3)			y

the acoustic noise from the demolition. The main demolished materials are concrete and bricks.

The concrete (structure members) and brick (walls throughout the building) will be recycled. The recycled concrete can be used for road construction work and some new technique of recycling concrete has been developed. For example a technique developed by Choi, et al. Choi, et al. (2014) for the complete recycling of concrete based on microwave heating of surface modification coarse aggregate (SMCA) with only inorganic materials like cement and pozzolanic materials (silica fume, fly ash).

According to Business Recycling (2013), there was approximately 8 million tonnes of brick disposed of landfill and recycling in Australia in 2005. If all of this were commercially recycled, it would be the equivalent 'everyday' savings of over 1.5 million households' energy requirements for a month. Bricks can be reused in construction applications such as paving and landscaping. Recycling bricks result in no landfill fees and maybe lower transport costs thus cost savings for business. In the long term, recycling bricks can minimise the need for mining and quarrying activities to produce new bricks and diverts significant quantities of waste materials from landfill.

Demolition waste including ceiling tiles, general rubbish, tiles, windows, frames and materials generated from strip out works, as well as hazardous waste will go to its respective landfill locations. Most of the deconstruction materials were sorted and recycled off-site. This is because UTS is located at a central area surrounded by many buildings with busy traffic so that there is limited space for on-site sorting. During the stripping period, some of the materials were sorted on-site. Figure 11 provides an example of on-site sorted and stored recycle materials.

The actual waste generation activities are reported monthly detailing all waste generated from demolition by average loads per day and per tonnage. Tonnages reported will be accurate figures due to trucks being weighed on a weighbridge located at the tip site. Figure 12 shows an example of the reports of transport tonnage and waste management target measured by Greenstar.

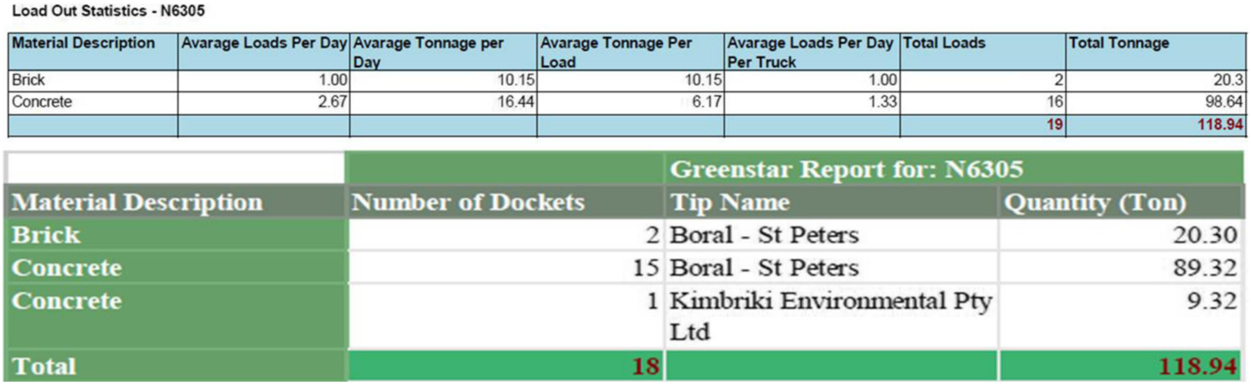
The estimation accuracy of labour costs and time required can be improved by using BIM and thus reduce the waste of energy and better managing logistics. Cheng and Ma (2013) concluded that more than 70% of the total fee can be saved if all the waste is sorted instead of sending it to landfill. According to a report prepared by BDA (2009) for the Australian government the estimated costs of the disposal of waste to landfill ranges between $45 and $105 per tonne of waste in urban areas.

It is estimated that the total weights of concrete, bricks and demolition waste are 18,000, 6400 and 750 tonnages respectively for the UTS demolition project. Assume $88 per tonne is used by taking the average and adjusting for inflation of 17.5% over the last seven years, the total savings for the waste management for the project can achieve $1,509,200, which is calculated by the following: (18,000 + 6400 + 750)*$88*70% = $1,509,200. This result indicates that a well-developed waste management plan is important.

Conclusion

This paper has investigated the use of reconstructed 3D model and BIM to improve accuracy of estimating for developing deconstruction and waste management plans. The paper has compared the difference in construction and deconstruction and outlined how the reconstructed 3D model and BIM are developed. The demolition and waste management plans for the deconstruction of

Fig. 11 An example of recycle material on-site sorted and stored



Load Out Statistics - N6305

Material Description	Avarage Loads Per Day	Avarage Tonnage per Day	Avarage Tonnage Per Load	Avarage Loads Per Day Per Truck	Total Loads	Total Tonnage
Brick	1.00	10.15	10.15	1.00	2	20.3
Concrete	2.67	16.44	6.17	1.33	16	98.64
					19	118.94

		Greenstar Report for: N6305	
Material Description	**Number of Dockets**	**Tip Name**	**Quantity (Ton)**
Brick	2	Boral - St Peters	20.30
Concrete	15	Boral - St Peters	89.32
Concrete	1	Kimbriki Environmental Pty Ltd	9.32
Total	18		118.94

Fig. 12 A sample report of load out statistics and Greenstar Report (Delta Group, 2016)

UTS's level 5 Building 2 were developed. It was found that the new methodology, as opposed to traditional methods, provides a visual demolition program and accurate estimation of waste.

Based on the research, the conclusions that can be drawn are: a) construction and deconstruction plans and waste management strategies are different; b) the use of reconstructed 3D model provides visual environment that ensures the accuracy of building BIM; c) the use of BIM provides accurate estimations of deconstruction materials and thus making waste management plans more accurate and timely; d) the accurate identification and estimation of deconstruction material assists in formulating tailor made demolition and waste management strategies. This improves rates of reuse and recycles and saves costs of deconstruction and logistics and avoids mismanagement. Based on the estimation, the cost savings of $1,509,200 for landfill can be achieved from the implementation of recycling activities.

This research is significant for the deconstruction industry by introducing a new methodology through user-friendly BIM tools with reconstructed 3D, in order to improve accuracy of estimation for environmental protection and increased rates of recycling. This study further support Byrne (2015) who summarized that BIM projects reduce risk and deliver cost, resource, quality and time efficiencies, as well as improve collaboration. The reconstructed 3D model provides visual environment that connects real life experiences and thus improves accuracy of BIM development. The developed methodology can also be applied to the new construction and whole of life management, i.e., from design, monitoring construction works to facility management. In addition, there are implications for the advancement of construction technology and standardisation of construction and deconstruction practice in the industry. The obtained data can be shared, stored and recorded for dispute resolutions, as well as for training purposes. There are also policy implications for environmental sustainability monitoring and management.

Further research can be extended from this pilot study to test the developed methodology into construction and infrastructure projects.

Endnote

[1] Revit is powerful BIM tool that lets end-users use the intelligent model-based process to plan, design, construct and manage buildings and infrastructure. As suggested by Cheng and Ma (2013), the Revit environment allows users to manipulate whole buildings.

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Authors' contributions
XJG Project leader, paper writing, data collection and data analysis. PL drone data collection, demolition waste management analysis, native English proof reading. JW BIM-related modelling, simulation, waste calculation and analysis. SH interior 3D model reconstruction from site images. XH exterior 3D model reconstruction from point cloud. CZ paper framework development and data analysis. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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