Application of Lean Techniques and BIM in Building Deconstruction

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Acknowledgment

I would like to dedicate to my parents, my brother whose bless and kindness have been always the sunlight of my life and to my father, whose soul is inspirational to entire in my life. Furthermore, I should be grateful for having family and friends for their commitments throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.

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Topic: Application of Lean Techniques and BIM in Building Deconstruction

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Background

Lean construction and application of BIM are modern requirement of building construction or demolition. Construction industry is consuming more raw material day by day (Horvath 2004). Therefore, waste of energy and materials are increasing by leap and bound. As per European Commission in 2016, 25-30% waste generated by construction and demolition activities. Saved materials from such activities are hardly using back into the material supply chain (Hosseini et al. 2014).

Integrated Lean-BIM application on building construction is successfully done by Arayici et al. 2009, Sacks et al. 2010, Arayici et al. 2011 and Dave et al. 2013. However, the research, analysis, and execution of Lean-BIM interaction for deconstruction projects is yet to explore. There are some works which have been partially, directly, or indirectly concerned with deconstruction. Such as Environmental and Economic modelling through stochastic simulations from recycled coarse aggregates from precast plants by Azúa et al. 2019, combining life cycle assessment and Building Information Modelling to account for carbon emission of building demolition waste (Wang et al. 2018), and forecasting demolition waste generation using chi-squared automatic interaction detection method by Cha et al. 2017, a review to evaluate the transition towards cleaner production in the construction and demolition sector of China by Ghisellini et al. 2018 (Mohamed Marzouk, 2019). The BIM potential on deconstruction is explored by Cheng et al. 2015 to analyse the waste minimization, BIM based deconstruction plug-ins by Akbarnezhad et al. 2014 and 4D deconstruction scheduling by Ge et al. in 2017 is notable. (Ahmed Elmaraghy, 2018)

The aim of this research would be analysis and exploration of Lean-BIM combination in buidling deconstruction process. The focus will be examine the explored interaction between Lean techniques and BIM tools and understand it with resource perspective as well.

Research Questions

This topic is going to find the following research questions:

1) What are the extensions or verification of lean principals in the deconstruction process?
2) How to measure economic efficiency of Lean -BIM matrix for Deconstructability?
3) Evaluate the market potential lean-BIM approach in demolition projects with respect to materials and stakeholder.

Methods

Literature review and research works analysis will be playing an important role to fulfil the thesis goal. Work sampling study, Construction planning methods such as Balance charts, Line of balance, Critical Path Method will be analysed.

To fulfil the aim of research and finding the research questions a theoretical concept will be worked out. For validation of the concept a survey of contractors, project consultants, architects, engineers based on questionnaires will be done. Additionally, interviews would also take place.

Time Scale

Feb- March 2020	Conceptual draft for Research Proposal
April-May 2020	Finalize the Master thesis Proposal
June- August 2020	Usage of Research proposal to gain Internship and survey
September- Nov 2020	Data Collection
Dec- Feb 2020	Discussion, Limitation, and constraints related to proposal
March-May 2021	Work Progress of Master Thesis

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June-July 2021	Submission of Master Thesis
September- 2021	Final Thesis Presentation

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Signature of the Supervisor

Abstract

Lean principles and Building Information Modelling (BIM) technology is working remarkably in the construction of a building. Lean promotes waste reduction, transparency, collaboration and adds value to the industry. On the other hand, BIM facilitates a platform for sustainable construction from commencement to completion. However, the existing building is not able to match the pace of the current trend. Therefore, the demolition and deconstruction industries are also growing. Although, demolition pushes more waste generation whereas deconstruction encourages the reuse and recycling of rescued materials. As demolition is not the solution when there is scarce of resources already at the same time not eco-friendly at all. Deconstruction emerges as a new solution for both issues.

This research draws attention to the interaction of Lean and BIM to get optimum benefit from a deconstruction of existing buildings which has completed their life. This study also investigates the role of Lean-BIM interaction in the financial perspective of deconstruction. In order to explore synergies between Lean and BIM, academic and industry-based research works are reviewed. Subsequently, interviews and questionnaires are conducted to get a pragmatic overview. Circular economy and Lean-BIM techniques are also studied to understand the economic perspective of deconstruction and dismantling the market.

Integration of Lean-BIM is studied for deconstruction processes and its economical potential. The result of the thesis is that several interactions between Lean and BIM can provide a methodology to execute deconstruction which has a favorable economic potential. However, at present deconstruction is financially not cost-effective. Thus, the first deconstruction and later integrated form of Lean and BIM are less explored, and they are still in nascent form in the architectural, engineering, and construction (AEC) industry.

This research paper aims to contribute a distinct approach for improvement in the deconstruction process and circular economy.

Keywords: Lean techniques, BIM, Deconstruction, Lean-BIM interaction, circular economy

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List of Abbreviations

2D	Two Dimension
3D	Three Dimension
4D	Fourth dimension
5D	Fifth dimension
6D	Sixth Dimension
AEC	Architectural, Engineering and Construction
BIM	Building Information Modelling
CAD	Computer Added Design
DfD	Design for Deconstruction
EU	European Union
HVAC	Heat Ventilation and Air Conditioning
NGO	Non-Government Organization
UTS	University of technology, Sydney
WHR	Whole House Reuse
WMA	Waste minimization Act

CHAPTER 1: Introduction

1.1 Introduction

A building is a non-living structure, however, often considered to have life. A lifecycle Analysis, life-cycle management, life span, lifetime and many more terminologies are using by professionals for physical structure. Architectural historian James Stevens Curl notes ‘life spent without any contemplation of death is the logical and inevitable end for all.’ [1]

In other words, all the buildings have their age whether in the context of function, trend, technologies, or values. Usually, after achieving those purposes, demolition is the last stand. The overall demolition of physical structure generates 50% of construction waste in the present time[2] and specifically in the European Union (EU) demolition waste amount is 25-30% of total waste generation.[3] Some metropolitan area like Hong Kong uses their debris from construction for landfilling. It is quite rare to reuse the building elements rather than professionals reuse those element’s materials in buildings to some extent. Deconstruction appeared as a solution for the problem of demolition debris which is more sustainable and environment friendly as well.

Lean-BIM is already working for waste reduction in building construction sector. The need of the hour is to use it for the reduction of waste in demolition and deconstruction of the structure.

In this paper, modern technologies- Lean and BIM are focused on the deconstruction of a building. Lean techniques for waste reduction in construction and BIM for smooth building construction are well known in this industry. This research work will focus on identify and combining the application of Lean principles and BIM functionalities for the deconstruction of buildings. Furthermore, to explore the economic perspective of deconstruction concerning integrated Lean and BIM.

1.2 Scope of works and Limitation

[1] (Jacobs, et al., 2014)
[2] (Copland & Bilec, 2020)
[3] (European Commission, n.d.)

The research work will study the combination of Lean techniques and BIM functionalities for deconstruction. There will be few case studies based on Lean-BIM on institutional and residential buildings. Furthermore, explore the financial aspects of deconstruction. Involvement of dismantling elements in circular economy with the help of Lean and BIM interactions. To put an effort to emphasize on economic factors of the deconstruction market and the role of lean-BIM combinations. There is a various type of buildings for example institutional building, bridge, high rise tower, residential and so on. In this research work, the focused area will be institutional type including row housing, social housing, and individual residential units.

There is some software which features the deconstruction attributes. However, technical use of the software will not be part of the study. In addition, this paper is excluding the mathematical derivation for cost and estimations of building deconstruction. Under methodology, interviews and questionnaires are supposed to be taken from experts or experienced practitioners.

1.3 Aims and Objectives

The aim of this research is an analysis of Lean-BIM combination in a building deconstruction process. The focus will be examining the explored interaction between Lean techniques and BIM functions and to understanding the economical perspective of deconstruction. One of the objectives would be a financial perspective for deconstruction with the help of circular economy and Lean-BIM. In addition, figure out economic factors and measures for the deconstruction concerning lean and BIM technologies.

1.4 Research Questions

This paper will work on the application of both techniques for residential sectors. Furthermore, work on their potential has been important too. To be specific the research questions for this paper are:

- What are the extensions or verification of lean principles and BIM in the deconstruction process?
- How to measure economic efficiency of Lean-BIM matrix for Deconstruct-ability?
- Evaluation of the market potential for lean-BIM approached dismantling projects with respect to materials and stakeholders.

1.5 Methodology

The research work will be divided into three parts. The first part will be a literature review on lean-BIM identification and the second part will be to understand economical perception. The last and third part will be their analysis, review, and validations by case studies, interviews, and questionnaires. With the help of the above three parts, the research question will be answered.

To fulfill the aim of the research and finding the research questions a theoretical concept will be worked out. For validation of the concept a study of case studies, research work, and analysis will be done. Furthermore, interviews would also take place with experienced professionals in the deconstruction of buildings. In the end, the result analysis and framework will be addressed based on the overall study. Furthermore, the study will be summarized in the form of a conclusion and future recommendations. The following figure 1 below shows a flowchart of the methodology of this paper.

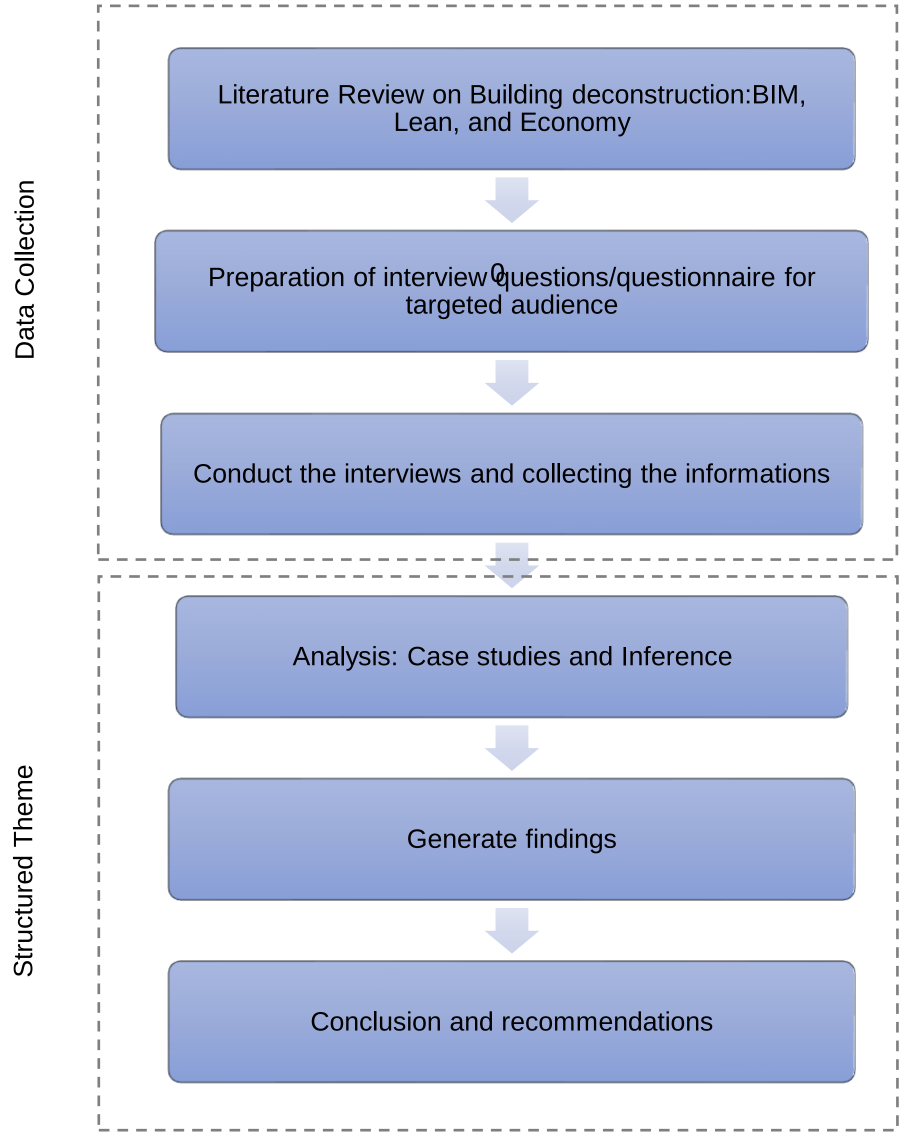

Figure 1: Flowchart of Methodology [4]

Additionally, complementary data or information related to research work would be added in the appendix at the end of the thesis report in order to get a clear and deep understanding related to the topics. The questionnaire form and Interview questions details will be mentioned with details as well in the appendix.

1.6 Thesis Organization

This paper is divided into 5 chapters. Continuing the introduction, the next Chapter 2 describes a literature review on the basics of deconstruction. Then lean techniques

[4] Own illustration, 2021

and BIM functionalities for deconstruction. This chapter also explores the possibilities lean and BIM combinations.

Chapter 3 explores the economical perspective of deconstruction with the help of lean and BIM and their connection with a circular economy. It also relates to those materials which affect the deconstruction economy and tries to figure out the parameters that affect the cost and respective market.

Chapter 4 tries to analyse the above studies and validate through case studies, expert's interviews, and questionnaires. In addition, based on the analysis explains the inference.

Chapter 5 generates finding by result analysis and framework. At last, summarizes the whole study in the form of conclusion and provides future research recommendation.

CHAPTER 2: Literature Review

2.1 Deconstruction

Deconstruction is an area of expertise belonging to the demolitionist. Nor is this simply about salvage operations, whose core categories are reuse, reclaim, recycle, destroy, dump as per Addis, 2006. Designing for deconstruction is about designing for a building to end well. According to Bougdah & Sharples, (2010), this depends on understanding ‘‘how the elements in the building are distributed, accessed and connected at the planning stage before the building is built”.

Demolition and deconstruction are mostly interchanged in the architectural, engineering and construction (AEC) industry by stakeholders often. Although there is a huge difference between demolition and deconstruction. Deconstruction is a process of restoring architectural order from deteriorating acts or from wrong architecture. Thus, it is an architecture that gives new life to those materials or elements when it has completed its life-span with earlier structures. Many professional organizations defined deconstruction in different ways such as the US national institute of Building Sciences refers to Deconstruction in their ‘’whole building design guide’’. As per Keller and Burke, (2009) it is defined as the systematic disassembly of building generally in the reverse order of construction in an economical and safe fashion for the purposes of preserving materials for their reuse. Based on project, location, and regulation it can be divided into three types: Partial, Complete and Hybrid Deconstruction. Where hybrid maintains a balance between waste disposal, reuse and recycle of the recoverable materials. [5]

There are two types of deconstructions: Structural and Non-structural. Under structural deconstruction professionals salvage materials used for strength purposes such as bricks, stones, wooden-beam, wooden-column, etc. Whereas, in non-structural salvaged materials mostly related to interior elements for example door, windows, braces, accessories, finish material like tiles, door-window frames and so on. [6]

[5] (Delta Institute, 2018)
[6] (NAHB Research Center, Inc. Upper Marlboro, MD, 2001)

The following table 1 below elaborates the difference between demolition, non-structural and structural deconstruction based on several factors like definition, required lump-sum time, safety level and possibilities of disassembly.

Parameters	**Demolition**	**Non-Structural Deconstruction**	**Structural Deconstruction**
Definition	Tore down the physical structure to clear the site for new structure as soon as possible	Extraction of building elements not affecting the structural stability of the building	Extraction of building elements completely integrated in the building and with structural function
Time	Few days	Few days	Weeks/months
Cost	Low	Medium	High
Equipment	Expertise required for operating cranes, excavators, wrecking balls	Simple tool needed professionals are usually not required	Requirement of mechanical tool is highly needed professionals could be required
Safety concern	High	Standard	High
deconstructiveness	None	High	Variable

Table 1: Differences between demolition, non-structural and structural deconstruction [7]

Some buildings need to deconstruct or demolish because of obsolescence. However, deconstruction is not only about the recovery of building components at the end of life rather a developing process that makes a building to be easily assembled and disassembled. Which has multiple benefits in the construction and demolition industry in the modern era. [8]

Buildings always are planned for changing technological advancement, functional and life-cycle including maintenance. Then, why not plan for deconstruction? Experts and professionals need to identify the appropriate methods, tools, and principles. The flexibility can be maximized during pre-construction phases. Post-construction makes it difficult and costly. Additionally, timely application of mentioned ways can be eco-

[7] (Bertino, et al., 2021)
[8] (Akinade, et al., 2017)

friendly as well as economically. In one word, it could be sustainable. Lean-BIM duo has the potential to make deconstruction sustainably feasible.

2.1.1 Challenges in Deconstruction

Interchangeability of deconstruction with demolition is one of the well-known challenges though demolition cannot be ignored while having deconstruction. There is a massive difference between deconstruction and demolition which is mentioned in Table 1. Other main challenges are as follows:[9] [10] [11]

- Most of the occasion this term is explained as an environment friendly activity but not explored much in terms of financial benefits.
- Did not highlight the sequencing of the digital dismantle method for Building elements.
- Incorporation of deconstruction concepts during the design phase by architects/developers.
- Skilled labours requirement
- Valuation of antique materials from historical projects
- Quality control of extracted materials
- Lack of availability of training Centres
- Labour intensive industry
- Object based recovery methods and equipment
- Uses of composite materials which is tough to extract additionally that makes those elements under toxic category
- Unexplored application of BIM and Lean for dismantling process

Above mentioned points are few challenges in this sector though this list could be increased or decreased depend on the projects and different variables. Even country to country the list can change a little bit because of material related challenges, policies related, and possibly available resources related to deconstruction practice. However, these challenges are not permanent and could possibly resolve with proper guidance

[9] (Bohne & Wærner, 2014)
[10] (Chini & Buck, 2014)
[11] (Delta Institute, 2018)

and regulations. This research paper would try to provide some solutions through which some of these challenges can be sorted out. Apart from challenges, deconstruction has many benefits which make it a unique solution to new building problems.

2.1.2 Benefits of Deconstruction

The Life cycle of a building: Production, operation, and maintenance, Demolition. However, the introduction of deconstruction changes this cycle and extends the life span of the building elements. An only required step is to replace demolition with a deconstruction of the buildings. It will not only increase the life but the value of the extracted elements as well. It has sustainable features which means it contains social, environmental, and economical values. It has several social and environmental values, but economical values are still debatable though some projects proved economically viable, the numbers are less. Apart from direct environmental and social benefits, other benefits are the following:[12] [13] [14]

- Reduction of the disposal cost of a building
- Reusing and recycling of the construction materials
- Stimulation of local economies with new industries and employment generation
- Reduction of composite material that means the reduction of toxic waste
- Avoidance of dangerous material disposal in soil by landfilling
- Redevelopment efficiency would increase
- To save vernacular architecture style by reusing of harvested elements
- Construction and Demolition waste reduction
- Resource development by boosting circular economy
- Encourage innovation through design for deconstruction
- Encourage sustainable development

[12] (Delta Institute, 2018)
[13] (Zahir, 2015)
[14] (Rios, et al., 2015)

Above mentioned points are few benefits of building deconstruction, this list can be increased if the awareness and audacity of stakeholders related to such initiative would increase.

2.2 Organizational role in Deconstruction

Several organizations are intensively engaging with deconstruction and circular economy which can positively or negatively affect the dismantling and demolition sector of AEC. Their role will be vital in the promotion of lean-BIM as its development is still in the early phase as discussed in the above sections. These organizations can be a platform where constraints and conflicts could be identified. Some of the stabled organizations are:

Government Authorities

Demolition and deconstruction of a building require permission from regional authorities/ municipalities. They specify the standards and specifications regarding that. Since, it is an interest of environment, community, and economy the role of authorities is much more needed. A government prepares specific target-based policies and laws related to deconstruction such as safety and health of workers, hazardous material extraction and waste disposal are some examples. The German Waste Wood Act from 2003 and act for promoting cycle waste management [15], the Waste minimization Act 2008 in New Zealand, The New Zealand waste strategy 2010 are some laws implanted for such purposes. There are some voluntarily and legally binding agreements are also done by many countries related to deconstruction regulations. Paris agreement 2015, UN led clean sea campaign 2018 are some initiatives to regulate and monitoring the deconstruction and demolition in the construction and demolition industry. [16]

Statutory Organization

An organization that established by implementing law in the respective government system. Although it sets up by law, it is not governed by the government system. Under

[15] (Höglmeier, et al., 2013)
[16] (Zaman, et al., 2018)

this, those organizations come which are helpful to make bylaws related to construction, deconstruction, and demolition. The National Green Building Standards (NGBS) and Environment Protection Agency (EPA) in the USA,[17] NBCC in India are some examples that also specify the usual construction and demolition codes.

Non-profit Organization

To assist the deconstruction process, various non-profit based organizations are involved, and they are doing an outstanding job in this sector. As they are not concerned to make commercial profit, they go for even high-risk projects. If the projects get the success that turns into a standard for future projects. 'Delta institute' a US based organization is working in this sector since 1998.[18] Several reports and research work published by them are benchmarks today. 'Rekindle' is another NGO that works in New Zealand whose WHR, Christchurch a row housing deconstruction work set an example for deconstruction project.[19]

Community/Volunteers

Since deconstruction has social and environmental values, several communities step forward to help government, NGOs, and other organizations as such projects. Above mentioned WHR project of New Zealand succeeded with the help of the local community, artists, and volunteers.

Professionals/Experts

Professionals and experts are those who are going to design, execute and manage the dismantling works. If they show interest and lean towards this underdeveloped concept or recycling, implementing the reused materials, it is possible that the deconstruction project will accelerate in high pace. Several research and study could encourage them and the process which has high social and environmental values might be evolved as a high return project. As the resources are scarce, it has high

[17] (US Environmental Protection Agency, 2006)
[18] (Delta Institute, 2018)
[19] (Zaman, et al., 2018)

possibilities to turn into a commercially beneficial project. (Economic views discussed later in Chapter 4)

2.3 Lean Principles for Deconstruction

Lean is not a new concept for the construction and demolition industry though less explored in the deconstruction sector. Lean is a process of combination of ends, means and constraints. Here, ends mean requirements of end-users whereas means represent the method and medium apply to achieve the target and constraints explain the barrier or challenges such as location, costs, and scheduling. There are no specific findings as Lean Deconstruction principles, so the author's effort is to find techniques of lean construction useful for deconstruction processes. [20]

There are 16 principles under lean which can be utilised for deconstruction processes for residential structures.[21] [22]

I. *Early Planning and structure for the decision-making*: This principle helps to make early planning on building elements to be extracted for reuse as it is, restoration or any other value-addition. The planning phase is also helpful for finding the target customers and stakeholders which reduces the chaos and inevitable errors.[23] [24]

II. *Consider all option:* Under this, experts can find more options to extract salvaged in an efficient manner. Each project in deconstruction use to be unique and complex so exploring all possibilities would be helpful like in construction.[25]

III. *Transparency and Decentralized decision making:* It allows clear and honest decisions regarding the process and is helpful for the inhabitants who are going to affect directly or indirectly. Digitalization is the new definition of transparency and a web portal will play a vital role.

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[20] (Marzouk, et al., 2019)
[21] (Marzouk, et al., 2019)
[22] (Oskouie, et al., 2012)
[23] (Sacks, et al., 2010)
[24] (Tsao & Hammons, 2014)
[25] (Sacks, et al., 2010)

IV. *Selection of appropriate technology:* Wrong selection of technology for the right purpose brings the wrong outcome. To ensure right technology for the process is important for the salvaged elements to value addition.

V. *Ensure comprehensive requirements capture:* For value addition professionals need to ensure comprehensive requirements capture. It will provide a detailed overview of building elements that will ultimately help end-users with a decision.

VI. *Focus on concept selection:* Right concept leads in the right direction otherwise there is a possibility of delay, cost disbalance, wrong detailing and so on. Therefore, concept selection before detailing and go further steps is very important.

VII. *Ensure requirements flow-down:* To check the flow of process effortlessly one after another is required for deconstruction process.

VIII. *Verify and validate:* Following the principle confirms the verification of elements obtained from deconstruction, the followed steps adopted technology, etc. in order to meet consumer satisfaction.

IX. *Go and see for yourself:* This one instructs for sit visit. Professionals can evaluate better by personal visit and estimation, or overview of the salvaged items possibly achieve high accuracy.

X. *Pull from downstream:* A principle that depends on the earlier principle of early planning for decision making because the market analysis is important here. Pull from downstream means in the context of deconstruction is dismantle those materials or elements which is highly in demand between end-users. This is not viable for all projects, so a selection of this model over the push model is required market analysis.

XI. *Reduce variability:* This principle instructs to avoid fluctuation in workflow and quality control, since the process of dismantling varies from element to element and material to material. It can help to achieve concrete methodology and accurate scheduling for the deconstruction.[26]

XII. *Reduce cycle time:* It interprets the dismantling of elements should be done one after another i.e., consecutively. It will help in the processing of elements and reduction of time wastage during the work-process.

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[26] (Oskouie, et al., 2012)

XIII. *Collaboration:* this principle talks about the collaboration between the execution team and the plan formulation team. Coordination is required to salvage the appropriate items.

XIV. *Flexibility:* It is required while dismantling as new details or new instructions related to items issued. There should be a time span where during the process and after the process should be incorporated for quality and selling, respectively.

XV. *Standardizing the process:* This canon conveys to identify the pattern in a process to simplify the complexity of deconstruction steps in a variety of housing projects.

XVI. *Institute continuous improvement:* It says a logbook should be maintained for various purposes such as on-site activities updating, documentation of steps, inventory update etc. There should be a document for a lesson learned reporting from a project. A manual book to record everything for decisions and communications.

Thus, above mentioned canons are noted as a lean technique that makes the deconstruction process more sustainable than traditional demolition methods.[27]

2.4 BIM for Deconstruction

BIM is the most widely used tool in construction. Its applicability in construction makes it favourable and lucrative for deconstruction. Though, there is very little research worked happened for these purposes. BIM is defined as the “digital representation of physical and functional characteristics of a facility” (as per NBIS, 2015). Need of the hour is to imply this definition for dismantling of physical structure rather than demolishing that for landfilling. Although, some of the BIM functions are utilizing in this industry but not explored intensively. Present time, in construction and demolition industry generating tons of data that is relevant for all the stockholders. There are lots of fluctuations in tdeconstruction sector, BIM can be useful to minimize those

[27] (Marzouk, et al., 2019)

uncertainties. In this section of research work, the author tried to put the functionality of BIM applicable or currently practicing in deconstruction works.[28] [29]

There are 8 main functionalities identified related to BIM for deconstruction.[30]

I. *Data Capturing:* It is required for collecting data from various ways such as photogrammetry, laser scanning and high-tech sensors. With the help of these data, the generation of real time model is feasible.

II. *Modelling:* Under this, a 3D model of an existing structure is possible. BIM tool with a point cloud data enables the visualization of a form of structures. Their compatibility is so high that it creates a model quickly with high precision. It helps to maintain integrity as it can identify the missing data or check the clashes between different BIM models.

III. *Collaboration:* It provides a platform where data sharing i.e., information and communication become possible for stakeholders. It works as a central hub for information which ultimately pushes towards discussion and decision making. Interoperability between different BIM tool makes it more effective.

IV. *Object based programming:* This one is usually for existing BIM models of the project. If there is a need to introduce more data whether manually or from an external library, object-based programming facilitates additional parameters.

V. *Re-use of model data for predictive analysis:* Under this function, BIM allows the model to plug-ins facilities for data processing. Thus, the model data is reused for deep analysis for further extraction of information.

VI. *Rapid evaluation and simulation of deconstruction alternatives:* This function will be helpful to visualize the sequencing of deconstruction activities for the projects as it is used for steps of construction activities. BIM can detect clashes between elements when it will be salvaged from building to destination. This

[28] (Marzouk, et al., 2019)
[29] (Oskouie, et al., 2012)
[30] (Marzouk, et al., 2019)

one will automatically quantify the elements obtained from the site as well as it will give an estimation of waste materials from the deconstruction. A simulation of dismantling sequence through virtual reality makes the process safer and more assessable.

VII. *Automatic generation of reports:* BIM can provide reports while executing several objectives of dismantling steps on-site. These reports will contain results and outcomes of data to processed data. The best part is real time updates with respect to BIM model updating and site events.

VIII. *Online e-based communication:* It can fulfill various functions and objectives. The dismantling process could be elaborate online or on the web portal which can work as a reference for the workers as well as this can be connected via augmented reality. Moreover, it can provide a common platform for customers which can strengthen the pull model plus boost the circular economy. There will be more possibilities to update the on-site information with the BIM model with the help of an e-based medium by getting feedback from workers.[31]

Above mentioned functionalities are applicable to the deconstruction industry.[32] These would be useful with a combination of lean techniques while incorporating dismantling steps. In order to get these, there are much software in the market such as Autodesk, Autodesk Revit, Tekla structure, ArchiCAD, Graphisoft, schedule planner and ArchiCAD and so on.[33]

2.4.1 BIM Software

There is some tool of BIM which already used for deconstruction or partial deconstruction of the building. Some of them added separate deconstruction features and few software utilize their existing features for the deconstruction sequence design

[31] (Marzouk, et al., 2019)
[32] (Marzouk, et al., 2019)
[33] (Akbarnezhad, et al., 2014)

development. A few renowned software which has potential to implement for dismantling are mentioned below.

Tekla structure

Tekla structure is proficiently used for structural modelling in building construction. It is used for structural disassembly of the building also as it contains structural components of a building. In Tekla, the developer included one attribute named 'deconstruction' where the component which supposed to be dismantled are detailed as shown in figure 2 below. The tab facilitates the component details and is helpful in modelling while deconstruction of a building. [34]

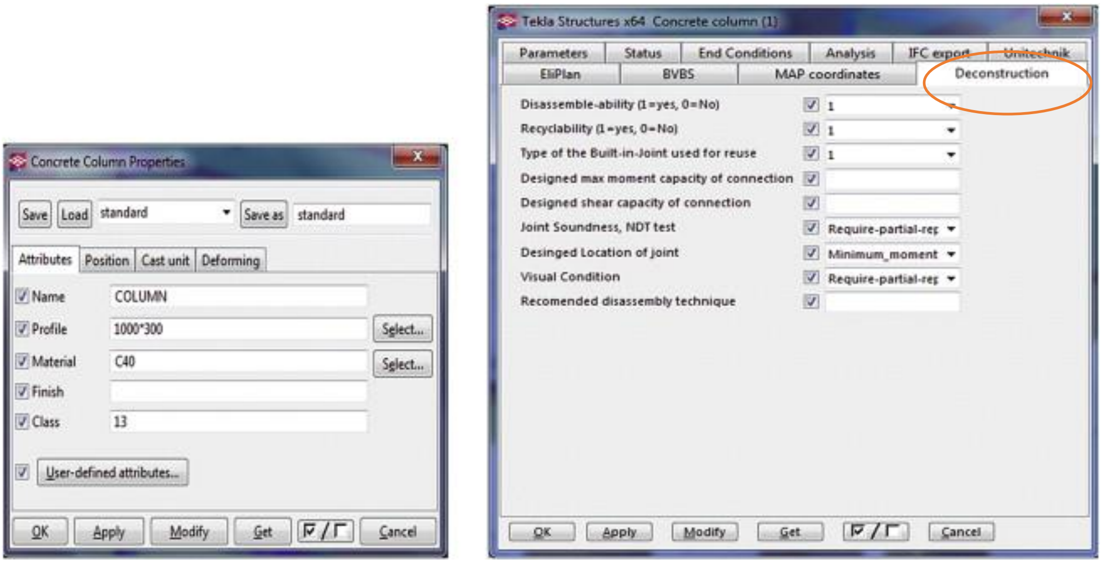

Figure 2: Deconstruction Tab is added in the Tekla structures Software [35]

Revit

It is popular among professionals for construction work though it has deconstruction features as well. It is applicable for both structural and non-structural deconstruction. The design for deconstruction tab is there in the figure below of Revit software. The Revit has 3D, 4D, 5D and 6D functionalities that means with visualization there are scheduling, cost estimation and budgeting, life cycle analysis of the model respectively. Interoperability and collaboration specialities of this software make it useful for

[34] (Akbarnezhad, et al., 2014)
[35] (Akbarnezhad, et al., 2014)

dismantling processes as an example for 6D, it functions with add-in Tally make it more relevant for the purpose (Refer Appendix A, page 71). [36]

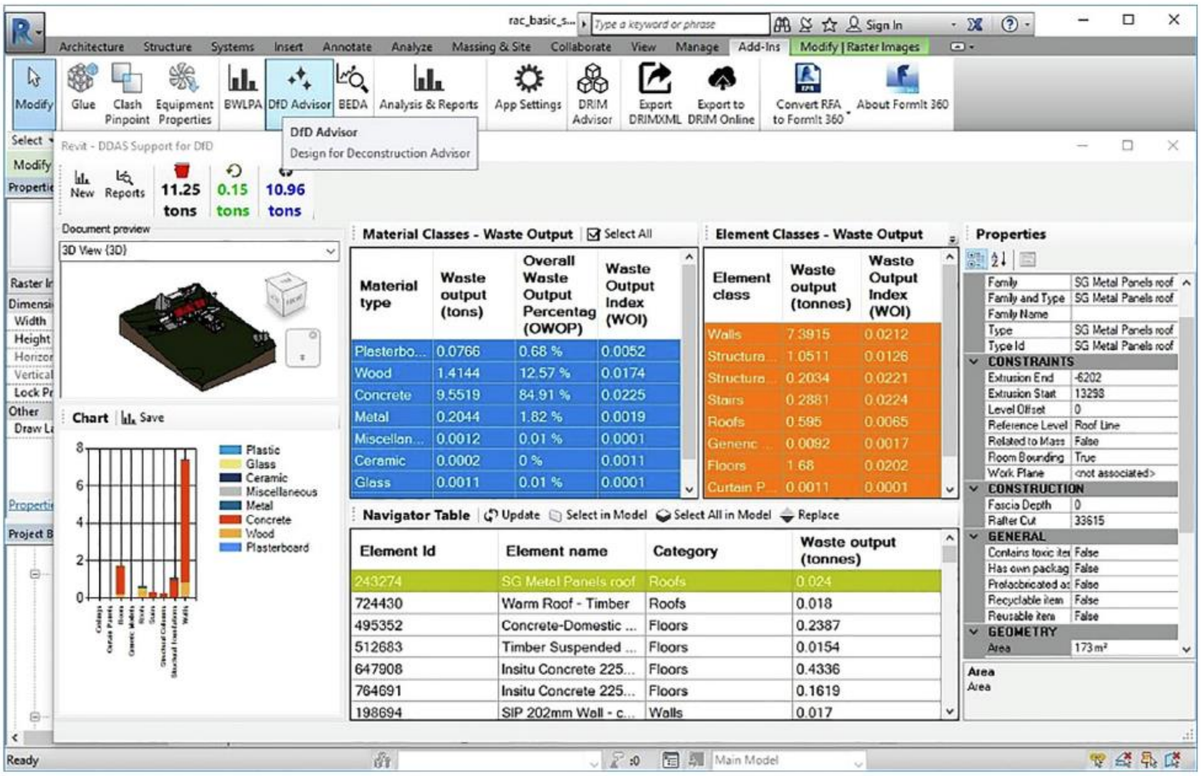

Figure 3: DfD (Design for deconstruction) advisor feature in Revit 2017 [37]

ArchiCAD

This software is useful for architecture and civil engineering which also assist in preparing a schedule, assigning task, tracking as well as helpful in cost estimation. Its useability for deconstruction could be like building construction such as scheduling, navigation, 3D modelling etc. This software also has an interoperability features so, it can support quantity take-off for cost estimation as well.[38] [39]

[36] (BenjaminSanchez & Haas, 2018)
[37] (Akanbi, et al., 2019)
[38] (Eastman, et al., 2011)
[39] (Akbarnezhad, et al., 2014)

2.5 Combination of Lean-BIM

Lean and BIM made several combinations with each other to execution of deconstruction for residential buildings. There are some shreds of evidence rediscovered through literature study. In the following table there are lean principles viable with BIM functions that are applicable for deconstruction processes and evidence where these combinations are already applied. The following tables illustrate the details and evidence.

Lean Principles	**BIM Functionalities**	**Evidence/Reference**
Early Planning	Data Capturing	Tool like scanner accumulate data in real time which gives insight to a planner [40]
	Modelling	A Model use for analysis and discussion [41]
	collaboration	Collaborative environment: a common platform for all stockholders [42]
	Re-use of model data	Assessing the deconstructivity by reuse of data [43]
	Rapid evaluation & simulation	Simulation reveals different scenario and help to fix the strategies [44]
	Online/e-communication	Helpful to understand the demand of end-users for professionals & communication
Consider all options	Modelling	Different perspective and available options [45]

[40] (Ge, et al., 2017)
[41] (Eastman, et al., 2011)
[42] (Eastman, et al., 2011)
[43] (Oskouie, et al., 2012)
[44] (Ge, et al., 2017)
[45] (Eastman, et al., 2011)

	collaboration	Collaborative environment: a common platform for all stockholders [46]
	Re-use of model data	Assessing the deconstructivity by reuse of data [47]
	Rapid evaluation & simulation	4D scheduling, deconstruction sequencing and safety measures [48] [49]
Transparency and Decentralization	Data Capturing	Data from site visit, comparison from reports
	Modelling	Model available for all stakeholders
	collaboration	Common platform so, unhidden [50]
	Rapid evaluation & simulation	Conflict detection, 4D scheduling, assigned responsibility [51]
	Online/e-communication	Digitalisation through BIM, web shop for salvaged elements etc.
Selection of Technology	Data Capturing	Digitalisation of work process, laser scanning, using drone, BIM software
	Modelling	3D model tools such as Revit, AutoCAD
	Rapid evaluation & simulation	Visual simulation of dismantling steps and Virtual reality for deconstruction [52]
	Online/e-communication	Synchronization of on and off-site process using e-communication
Comprehensive Requirements	Data Capturing	Accurate information of salvaged which ignites thorough requirements, building conditions, inspection [53]

[46] (Eastman, et al., 2011)
[47] (Oskouie, et al., 2012)
[48] (Eastman, et al., 2011)
[49] (Ge, et al., 2017)
[50] (Eastman, et al., 2011)
[51] (Eastman, et al., 2011)
[52] (Eastman, et al., 2011)
[53] (Böhler, 2004)

	Modelling	Model maintenance and its integrity in order to ensure full-fill of needs and enhance efficiency [54]
	collaboration	BIM collaboration tools ensure comprehensive project requirements, compliance of the project outcomes [55]
	Object based programming	Deconstruction based programming to cover requirements. [56]
	Re-use of model data	As per requirement interoperability and plug-in facilities with existing model.
	Rapid evaluation & simulation	4D scheduling, simulation and virtual reality can open new possibilities [57] [58]
Concept selection	Data Capturing	Collected data use for concept formulation
	Modelling	Available model use for new concept or alternative [59]
	collaboration	Stakeholders of project can discuss on different or viable concepts
	Re-use of model data	Strategies for salvaged to follow up the assessment and evaluation [60]
	Rapid evaluation & simulation	Visual simulation of dismantling steps and Virtual reality help to develop new concepts

Continue….

54 (Eastman, et al., 2011)
55 (Gu, et al., 2008)
56 (Akbarnezhad, et al., 2014)
57 (Eastman, et al., 2011)
58 (Ge, et al., 2017)
59 (Eastman, et al., 2011)
60 (Eastman, et al., 2011)

Lean Principles	BIM Functionalities	Evidence/comments
Ensure Requirements flow-down	Modelling	Changes in model update all the parts make it smooth workflow [61]
	collaboration	Synchronisation of data possible due to collaboration BIM tools [62]
	Rapid evaluation & simulation	Simulation gives vision and help to plan the further steps; adaptability of quantification and assessment improve its feasibility for smooth working [63]
	Online/e-communication	To prioritize the salvaged elements for end user by web shop and scheduling accordingly
Verify and validate	Data Capturing	Comparison before and after of salvaged extraction
	Modelling	Assessment visually through modelling
	collaboration	Interoperability in BIM tools allow verification and analysis [64]
	Object based programming	BIM data can export to external applications as per object for validation [65]
	Re-use of model data	Export to external application makes eligible for reuse of model data [66]

[61] (Eastman, et al., 2011)
[62] (Eastman, et al., 2011)
[63] (Akinade, et al., 2017)
[64] (Pazlar, 2008)
[65] (Akbarnezhad, et al., 2014)
[66] (Pazlar, 2008)

	Rapid evaluation & simulation	Enhance the accuracy [67]
	Online/e-communication	With e-communication and web portal validate the salvaged elements process
Go and see yourself	Data Capturing	Site visit helps to cover missing data and detection of collected digital information
	Modelling	By seeing on-site reveals the direction of modelling or clash detection
	Rapid evaluation & simulation	Stakeholders can see the bigger picture or interested outcomes and virtual reality can make it more realistic while decision making [68]
	Online/e-communication	Present time update of salvaged elements by site inspection could be alternative [69]
Pull from Downstream	collaboration	Smoothing the production flow by work break system through BIM collaboration [70]
	Re-use of model data	BIM enables the plug-in of different model data in order to get required extracted elements [71]
	Rapid evaluation & simulation	Tracking of strategy as per demand and alternative plan could execute by simulation and assessment, ensuring

[67] (Eastman, et al., 2011)
[68] (Ge, et al., 2017)
[69] (Marzouk, et al., 2019)
[70] (Marzouk, et al., 2019)
[71] (Akbarnezhad, et al., 2014)

		the levelling of production by 4D simulation [72]
	Online/e-communication	Prioritize the required extracted elements in order to fulfil pull flow, proficient resources management on site could also be possible with minimum inventories during dismantling; At the end smooth flow of information [73]
Reduce variability	Data Capturing	Accurate building and salvaged data because of digital documentation and tool like laser scanning.
	Modelling	Eliminate the misinterpretations and immediate clash detection because of different digital model [74]
	collaboration	Coordination between different process and model maintain the integrity and reduce variation amongst project needs
	Re-use of model data	Reuse of BIM model or data by exporting or plug-in for various purposes to maintain the accuracy [75]
	Rapid evaluation & simulation	BIM 4D simulation optimizes assessment and reduce variation in productivity, human error, quantity take off etc. [76]

[72] (Ge, et al., 2017)
[73] (Marzouk, et al., 2019)
[74] (Eastman, et al., 2011)
[75] (Akbarnezhad, et al., 2014)
[76] (Ge, et al., 2017)

	Automatic generation of reports	Because of BIM, updating of data is easy and it enables instant change in the all-important documents [77]
	Online/e-communication	It reduces the delay between activities and cycle time of salvaged elements, gives visual ideas of process for dismantling and quality controls, timely delivery approach
Reduce cycle-time	Data Capturing	Digital scan, point cloud reduce the time of activities while collecting data
	Modelling	Generation of as built model eliminate the extra time [78]
	collaboration	Distribution of workload, monitor and revise while in progress of deconstruction
	Re-use of model data	Reuse of BIM model or data by exporting or plug-in for various purposes like accuracy, cycle-time etc. [79]
	Rapid evaluation & simulation	Reduction in variation of productivity and ultimately reduces the cycle time
	Automatic generation of reports	Helps to avoid manual error while updating the documents, quick and detailed results
	Online/e-communication	Visual representation of process, on time delivery of required elements, priority-based execution of deconstruction

[77] (Eastman, et al., 2011)
[78] (Marzouk, et al., 2019)
[79] (Akbarnezhad, et al., 2014)

Continue…

Lean Principles	**BIM Functionalities**	**Evidence/comments**
Collaboration	Data Capturing	Meeting for early start get positive outcome by site data [80]
	Modelling	BIM platform act as a central hub for different parties [81]
	collaboration	BIM assures the smooth flow of the process, production, and reliable platform
	Re-use of model data	BIM model data facilitates the early decision for involved stakeholders [82]
	Rapid evaluation & simulation	Evaluation and simulation helpful for stakeholders at various stage and strategy [83]
Flexibility	collaboration	BIM collaboration platform provides smooth workflow, alternative, revision, and operation with maintenance
	Object based programming	BIM allows additional parameters as per dismantling steps or salvaged materials [84]
	Re-use of model data	Can exported to external applications for analysis, assessment, verification etc. [85]

[80] (Eastman, et al., 2011)
[81] (Eastman, et al., 2011)
[82] (Eastman, et al., 2011)
[83] (Ge, et al., 2017)
[84] (Akbarnezhad, et al., 2014)
[85] (Akbarnezhad, et al., 2014)

	Rapid evaluation & simulation	Instant change, alternate and update is possible, which helps for planning process [86]
	Automatic generation of reports	Rapid updates reflect immediately in all documents [87]
Standardizing the process	Data Capturing	Accuracy achieving by digital data and avoiding unnecessary data set a parameter for further process and project
	Modelling	BIM model helps in the quick assessment, clash detection etc. to make process simple and make monitoring easy
	collaboration	This platform facilitates break downing the dismantling steps in order to understand and reference for future [88]
	Object based programming	As per need, required programming and as-built model suitable solution to complex data and available forms [89]
	Re-use of model data	Plug-in model Data using for deconstruction assessment and recovery potential of salvaged elements [90]
	Rapid evaluation & simulation	This BIM features insight stakeholders to identify the scenario for salvaged elements/extraction [91]

[86] (Ge, et al., 2017)
[87] (Eastman, et al., 2011)
[88] (Eastman, et al., 2011)
[89] (Marzouk, et al., 2019)
[90] (Akbarnezhad, et al., 2014)
[91] (Eastman, et al., 2011)

	Online/e-communication	Updates, performance measure, activities/sequences, and transparency in real time
Institute continuous improvement	Data Capturing	Digitally documentation before execution
	Modelling	Identifying common errors in model to avoid for future project [92]
	collaboration	"Feedback loops" in collaborative modelling process for future improvement [93]
	Re-use of model data	BIM facilitates data interoperability to different application which can reuse for further improvement [94]
	Rapid evaluation & simulation	It sets parameter in eyes of stakeholders which should put in the logbook [95]
	Online/e-communication	Real time update, productivity measures and records through digital platform work as a reference point for future projects [96]

Table 2: Lean-BIM combinations with reference [97] [98]

Thus, above mentioned table shows the combination of Lean-BIM for deconstruction for all type of buildings. However, research and study will be analysed for institutional building type. Now, there will be validation through case studies in next chapter.

[92] (Marzouk, et al., 2019)
[93] (Marzouk, et al., 2019)
[94] (Akbarnezhad, et al., 2014)
[95] (Marzouk, et al., 2019)
[96] (Marzouk, et al., 2019)
[97] Own Tabulation, 2021
[98] (Marzouk, et al., 2019)

CHAPTER 3: Economical Perspective

3.1: Economic Potential

In the construction and real estate industry, every construction is itself a unique project. In the context of building deconstruction, it opens several dimensions. In such scenario, financial viability depends on many factors as well as differs from one project to another. As it is clear that deconstruction and demolition are not same and not interchangeable. Then, cost comparison between them is highly required to acknowledge. Under demolition, materials used in the building is turning into debris and use that for landfill which is less time taking as well as cost effective with compared to a building deconstruction.[99] [100] So, net cost for deconstruction is higher than the demolition. However, gross cost for building deconstruction is lesser than demolition though it takes more time though again it will depend on projects. Other long-term cost-benefits are included in deconstruction such as job creation, longer life-cycle of materials and waste minimization. Which in terms of monetary value is more effective than waste disposal and demolition.[101]

Deconstruction cost based on various factors as such mention above these are Labour cost, human resource, material extraction/disposition, project duration and estimated profit and so on. Other variables on which cost fluctuates are: [102]

- facility to store recovered elements
- BIM software's license
- higher insurance for work force
- disposal transportation
- management of hazard/harmful materials
- BIM and on-site training cost for work force
- local and regional market and demand for used materials
- materials' conditions
- landfill fees

There are also several factors where monitoring and control can help to reduce the expenses of deconstruction. These are:[103]

- good selling price of the recovered materials

[99] (Michigan State University Center for Community and Economic Development, 2017)
[100] (Zaman, et al., 2018)
[101] (Delta Institute, 2018)
[102] (Rios, et al., 2015)
[103] (Rios, et al., 2015)

- applying different partnership model for fund/investment
- subsidies available by government authority
- tools/equipment-based savings
- tie up with software companies
- lease agreement for storage facilities

As per Delta Institute, there is a minimum 25% materials reusable whereas, 70% reusability of the harvested materials are estimated is some cases.[104] These percentage could increase with recycling of the materials as concrete structure is unavoidable in institutional projects.

Now a days, cost of landfilling and waste disposal are also increasing in spite of government are putting restriction and tough regulations related to it. In Netherlands, as per law reusable building materials are prohibited to disposal for landfilling.[105] In New Zealand, Waste Minimization Act (WMA, 2008) implemented to reduce the waste and reorganize the resource management.[106] Which encourages practitioners for building deconstruction as a tool to waste management. The workers safety and their health facilities would also make deconstruction industry lucrative and can attract professionals as promising jobs.[107]

Some pilot projects based on deconstruction proved financial feasibility such as "WHR, New Zealand" a row housing project. However, it was included the aftermath of deconstruction such as auction of by-product developed by harvested materials. With the help of community help they reduced the labour cost.[108]

Another case in one of the cities of the USA named New Orleans, in 2005 after a natural disaster hit the city almost 2,75,000 homes were destroyed. Out of those four houses deconstructed as a pilot project and claimed 38% to 75% was the rate of harvested materials by weight. The lump-sum $60,000 entered back in the local economy as a derived product from the salvaged lumber. In addition, the deconstruction cost revealed to $3.80 per square foot whereas the demolition rate was $5.50 per square foot. As per the Hazel Denhart's report, deconstruction emerged as

[104] (Delta Institute, 2018)
[105] (Van den Berg, et al., 2021)
[106] (Zaman, et al., 2018)
[107] (Kneebone & Lipscombe, 2017)
[108] (Zaman, et al., 2018)

an efficient industry for New Orleans.[109] Thus, there are possibilities to regulate and control the cost of deconstruction though the need is to support from various sources.

3.2 Circular Economy and Lean-BIM Tactics

Now, the world realized that the resources on earth are limited. So, global attention towards the circular economy is not only a new trend but a need also. The idea behind circular economy is to reduce the use of virgin resources and keep reused the resources till their actual end-of-life.[110] Under circular economy, the reusable materials from building go back to the construction purpose after going through the deconstruction in this context. The figure 4 below represents this clearly.

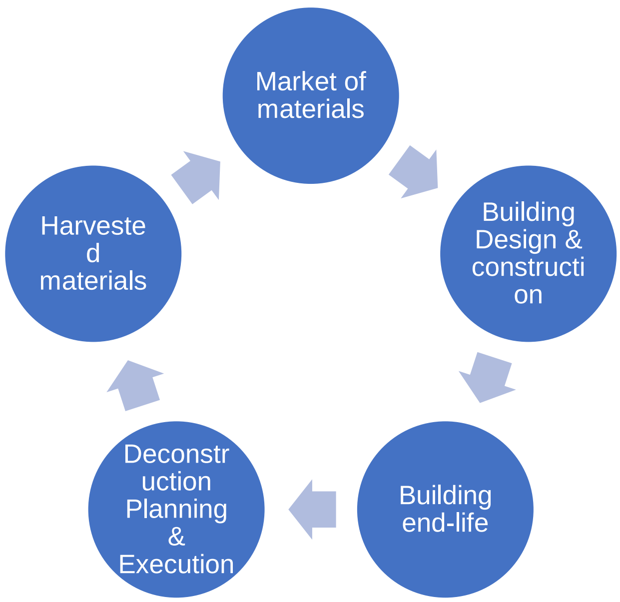

Figure 4: Circular Economy of construction materials [111]

The deconstruction concept perfectly suits this concept where it can work as a material bank for the other building projects. The WHR project of New Zealand mentioned in the above section had developed new products from the salvaged. Dismantling of the buildings work as an input for the circular economy as well as output and create a loop.

[109] (Denhart, 2009)
[110] (Copland & Bilec, 2020)
[111] (Akanbi, et al., 2019), Note: own illustration

On the other hand, demolition follows a linear economy. The number of building disassembly will rise the salvaged will be increased. Consequently, initial price of the harvested building material will be lower, and material resources will be in abundance which may boost the market. It can be a transitional phase from “cradle to grave” to “cradle to cradle gain” concept where reused and recycle will be normal practices in the AEC industry.[112]

Application of BIM with Lean theories can improvise the circular economy along with deconstruction. For the purpose of eliminating waste and delay decisions, early planning of lean techniques can be applied with the help of data capturing. As mentioned regarding BIM, laser scanning and object recognition can identify the possible recoverable materials from the building. To get more accuracy, verification and validation is highly required which can be executed through BIM which can check the degree of reuse and recycle of salvaged materials. To check recovered material performance Akanbi, et al. (2018) developed a Whole life Performance estimator which is based on BIM. A pre-deconstruction audit of the project with evaluation and simulation, the constraints and conflict can be identified during deconstruction planning to execution. As a result, quality resources will be injected into a market. However, due to high technology application operational costs and trained personnel demand could be skyrocketing.[113] There are various factors in BIM which directly or indirectly affect the cost of the projects. The following Table 3 elaborates the factors of BIM which can influence the implementation with Lean in a project.

Factors	**Role**
Pre-deconstruction survey	Data capturing
Interoperability of BIM software	Design, execution, and management
BIM software licence	To operate BIM functionalities
Training to staff	same
Equipment to support BIM function	To support BIM
Cybersecurity for BIM tools	e-Safety and e-security
Copyright and Publishing	Collaboration and communication

[112] (Rose & Stegemann, 2019)
[113] (Copland & Bilec, 2020)

Client awareness and demand	To incorporate in design to monitoring
Supporting facilities (Net connection, electrical power, good network etc.)	To support work on BIM

Table 3: BIM factors and their role affecting cost and Lean applicability [114]

Storage for extracted materials is not directly connected with lean/BIM and economy though facility management of that storage is vital in this respect. As storage is highly recommended by experts to quality control of the deconstruction outcomes and Lean-BIM approach is a proven game changer for facility management in several studies. Therefore, a process balance between Lean-BIM and circular economy for deconstruction is advantageous for the market and the construction sector.

3.3 Materials for Deconstruction Market

There are some building materials which has huge potential to merge into the market again after building disassembly. Those materials have been used more often and in massive quantities. Furthermore, if these materials are extracted tactfully then it exactly works as a secondary resource or material bank with high resale value.[115]

A higher percentage of C&D waste is concrete, timber and plasterboard. Structural materials such as steel are recyclable at least if not reusable. In New Zealand, the amount of C&D waste of these materials is timber highest 38% of total landfill waste whereas concrete and clean fill is 25%, plasterboard is 18%, metal reported 6%, paper-3%, glass and plastic both 1% which need to divert.[116]

Every region has its own challenges and solutions regarding building materials for reuse to recycle harvested from deconstruction. Different materials require different methods, tools, and techniques to harvest. Lean and BIM could be effective techniques to deconstruct them from the structure. There are some materials discussed which are unavoidable in construction apart of a region or building type.

[114] (Obi, et al., 2021)
[115] (Copland & Bilec, 2020)
[116] (Zaman, et al., 2018)

Metal

It is one of a prime material of a building structure that can extract with different processes depends on the structure type for reuse to recycling. Reinforced concrete is using as a widely common way to use in the building so, pulverize, crushers and heavy-duty magnets are some tools used to remove steel bars from that. Nowadays several automatic machines are available in the market to remove screws, bolts and braces which can also be useful to disassemble the steel structure like truss roof. [117]

With the help of lean techniques and BIM of early planning for deconstruction, right selection of technology and tool waste can be reduced from the structure and steel elements could be harvest without many damages. The extracted steel has a high potential for recyclability but is challenging to reuse. Because every project has its own requirement, size, and dimensions so, different structure needs different type and specification which is quite tough to match with recovered steel. In this case BIM would be more useful as it can store object data and facilitate online or e-information to another user. This way a huge amount of energy and cost can be saved. [118]

Masonry

This material achieves highest quality and most widely reuse in the construction. Though it is usually a labour extensive manual dismantling. Bricks have 70-90% possibilities to reuse. In this case, Lean-BIM have less applicability but help to quality control, data collection and monitoring the process. The major challenge is use of Portland cement which is hard to remove from the bricks and probability of damages increase. Whereas lime-based mortars are easy to remove from the bricks. Contractors have possibilities to increase the profit by selling the components to reclamation yards or to recycle facilities. It could be useful for the owners who can avail the tax benefit by donating these to Non-profit organization. [119] [120]

[117] (Zahir, 2015)
[118] (Chini & Buck, 2014)
[119] (Zahir, 2015)
[120] (Bohne & Wærner, 2014)

Wood

The most extensively used materials in Europe, USA, Canada, Japan and many more. So, timber as a waste has high percentage. Such as in Japan, wood waste is 32% of total C& D waste used either landfill or burn, in Norway this amount is 14.3% but in New Zealand and USA that is 38% and 51.5% as mentioned above.[121] [122]

It varies from location to location and the way of wood use. Wood used as a building material in different forms such as lamination, clean stubs, impregnated wood, glued with plyboard and chips. Due to this variation (chemical uses, glue, paints) of wood uses, they are hard to use as it is. Modern requirement of timber elements is very specific like thermal features, moistures, and dimensions. Lean-BIM can highlight the variation in demand, and it is possible that delivery of such elements where it is most required. Lean would be more effective to reduce the waste generation in this scenario. Furthermore, changing the way of assembling wooden structure like using nails and screws would be more effecting during deconstruction phase. Resale value of wooden in the market is much higher than any other materials. Moreover, product development after adding value the harvested wooden has also monetary value in the market. WHR project of Netherland mentioned in earlier section is best example of that. In the given figure below of that product express the multiple uses of the wood elements.[123] [124]

Figure 5: Products from harvested Material, WHR, Christchurch (New Zealand) [125]

[121] (Bohne & Wærner, 2014)
[122] (Chini & Buck, 2014)
[123] (Zahir, 2015)
[124] (Zaman, et al., 2018)
[125] (Zaman, et al., 2018)

Concrete

Concrete structure constructs mostly at the site, framing cast-in-situ except prefabricated concrete structure. Therefore, deconstructing these elements from building need equipment like automatic cutting machine, drilling etc. Depends on the scale of a project thermal lances is also applicable. Usually, concrete is applying in the building without mixing many pollutants though it is not always additive free. Sometime, heave metals in paint falls concrete under toxic waste. By using Lean-BIM combination, concrete material can be recovered for recycle purpose by defining the object-based planning and labelling the building component using BIM. It will be helpful to reduce the harvesting time and transport to the destination as transporting is costly and if there will be a need to store then the deconstruction of this material become more expensive than virgin materials. [126] [127]

3.4: Impact of DfD (Design for Deconstruction)

In the deconstruction process, the main aim is to recover a building element without many damages and minimization of waste as much as possible. So that, waste generation during treatment for salvaged elements could be reduce and get maximum resale prices. Other alternative might be using those harvested materials as a source of new building materials. Which again work as a low material cost for that region and construction. The Design for deconstruction is a one of solutions to make it feasible and can attract the diverse market players.[128]

There are some considerable factors and principles which help to construct a building on this concept. These are:

- *Materials selection*: Selection materials are quite important for DfD as those materials should have potential to reuse after life of the building, environment friendly and low maintenance features. The material variation should be less to check higher useability and lesser complexity.[129]

[126] (Zahir, 2015)
[127] (Bohne & Wærner, 2014)
[128] (US Environmental Protection Agency, 2006)
[129] (US Environmental Protection Agency, 2006)

- *How to assemble the building components*: Fitting of building elements are reliable as well as easy to dismantle. Nails, bolt, fasteners, and mechanical connector should include whereas glue and chemical should be avoided. Modular and prefabricated components are based on such ideas.[130]

- *Wholesome building system*: How the building services like heat, ventilation and air conditioning (HVAC), plumbing and electrical supposed to be integrated are important. A differentiated arrangement in the building makes it easy to maintenance/repair and afterlife easy to disintegrate from the structure. [131]

Based on above mentioned principles a benchmark is studied in to understand how a building design changes with respect to deconstruction concept at early phase. In addition, later discussed how Lean-BIM interaction can play role to affect the cost of deconstruction.

Benchmark: Chartwell School, California (USA)

The school building designed almost all the interior wall removable that means that was not part of structural portion. The building services like electrical, firefighting, cables are placed on utility raceway which is running through corridor as shown in the following figure 6. The modular frame was used for simple assemble and to save material and optimal use of components size as shown in the figure 7. Furthermore, interior wood panelling also installed which were attached with clips, nail and c-channels as shown in the figure 8 below.[132]

[130] (US Environmental Protection Agency, 2006)
[131] (US Environmental Protection Agency, 2006)
[132] (US Environmental Protection Agency, 2006)

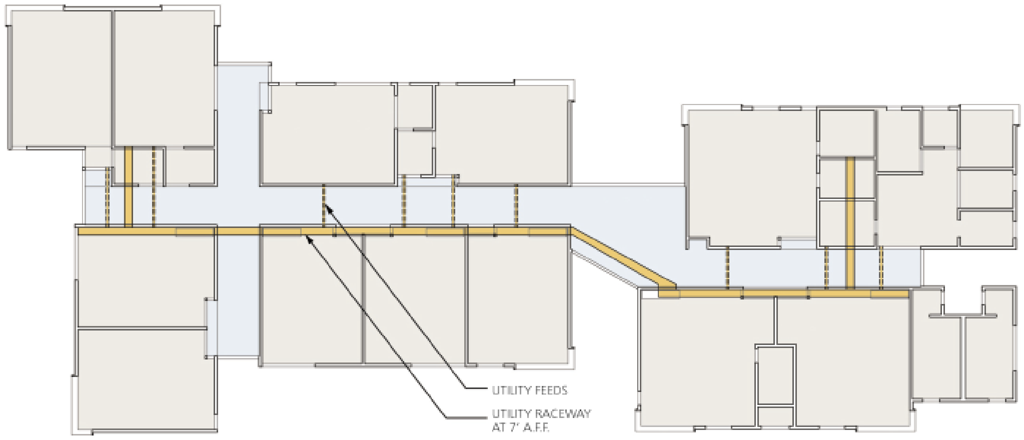

Figure 6: Utility raceway through corridor, Chartwell school plan [133]

Figure 7: Typical wooden modular frame of classroom[134]

[133] (US Environmental Protection Agency, 2006)
[134] (US Environmental Protection Agency, 2006)

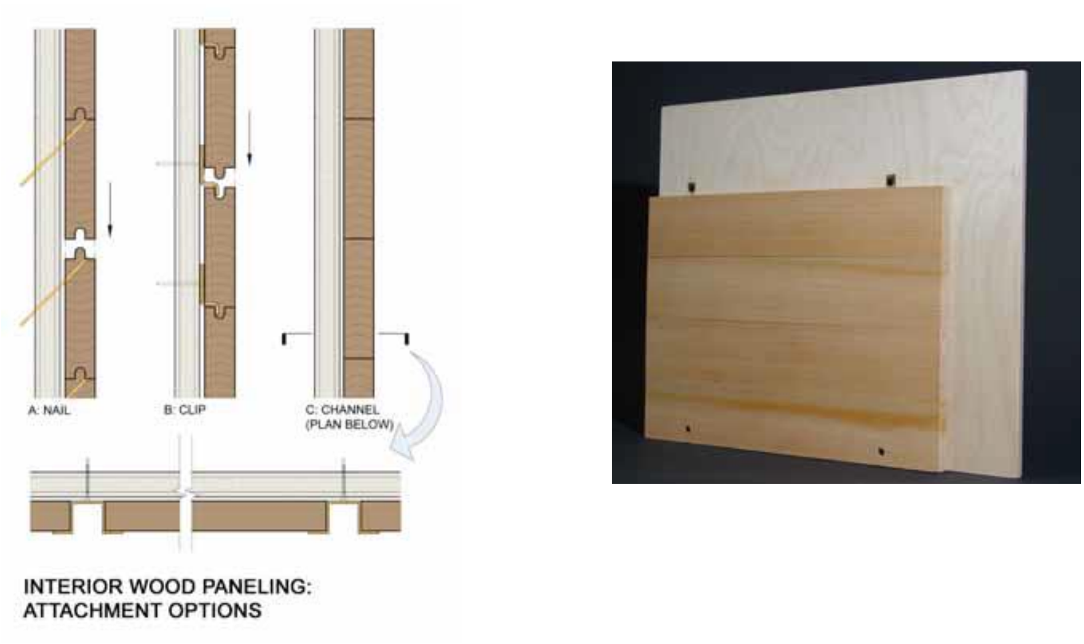

Figure 8: Interior wooden panelling joints; plan and section with site illustration [135]

3.5 Lean-BIM interaction based economical parameters

As building materials are the driving force of deconstruction market so, it is required to find out which parameters affect the material extraction with respect to Lean-BIM. According to Akbarnezhad, et al., (2014) economical parameters for materials extraction could be Recyclability, reusability, structural elements, handling the equipment, geographic location, and available conditions.[136]

Recyclability

Under BIM there are many tools which has material specification-based library which help to figure out the recyclable potential of the recovered elements from deconstruction. In addition, there are ways to indicate such materials like binary system where 0 means non-recyclable and 1 means cyclable. Lean-BIM could be deciding factors to relocate these at desirable market. A digital soft library with mentioned features of recyclability is developed in Singapore.[137]

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[135] (US Environmental Protection Agency, 2006)
[136] (Akbarnezhad, et al., 2014)
[137] (Akbarnezhad, et al., 2014)

Reusability

The reusability features of building components depend on life cycle of a material, deconstructibility from the building, and ability to reassembly. With the help of remodelling, it could be possible to draw that whether harvested element is able to reconnect with new component of building or not. BIM facilitates such attributes for connecting components.[138]

Structural Attributes

One of most challenging parameters, as structural requirement for different structure is different which depends on several specification like force, momentum, size, and requirement. Tekla structure has such features which provides detailed specification of components like beam-column. Further development of deconstruction has potential to make this feature profitable.[139]

Handling and Installation

This is required for handling the harvested material intact. While selection of technology, it would be required to know how to handle and move components from one place to another and BIM functionalities would be helpful to decide where to put the fixing points for re-assembly.[140]

Geographic coordinates

It could be helpful to find nearest recycling or modular manufacturing hub. Moreover, connecting location coordinates with BIM facilitates communication and collaboration with stakeholders to deploy the recoveries. Singapore used this attribute and estimated the transportation cost from project site to that hub successfully. [141]

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[138] (Akbarnezhad, et al., 2014)
[139] (Akbarnezhad, et al., 2014)
[140] (Akbarnezhad, et al., 2014)
[141] (Akbarnezhad, et al., 2014)

CHAPTER 4: Lean-BIM Analysis

4.1 Case study

There are two case studies are selected based on availability of data as well as utilization of Lean and BIM for the deconstruction. To validation of the Lean-BIM combination for the dismantling of an institutional building author's observation on study and comparative analysis in next section are also mentioned.

4.1.1 Building 2- University of Technology, Sydney (UTS), Australia [142]

Deconstruction is applicable to the building because of various reasons. In this case, it applied when building completes its life cycle. However, the other important point was location of the building 2 which is in the middle of high-rise structure and near to Broadway. The details of this case study are:

Location: Building 2, UTS, Australia

Built: 1978

Building Type: Concrete Structure, Institutional building

Use Of BIM: Yes, for waste management.

Use of Lean: Yes

Deconstruction: 2016, 4 &1/2 – months

Lean techniques are used before conceptualising the application of BIM for deconstruction such as information regarding drawings, used materials, site conditions and suitable methods for dismantling of level 5 of the building as a standard model.

Role of Lean-BIM:

Under early planning, information collected such as building plans, engineering detailed drawings. The data also collected using drone and used Revit software as a BIM tool to recreate a 3D model as in the figure below. The other supporting data like

[142] (Ge, et al., 2017)

materials, quantity, location, specification etc. helped as an input for BIM development. The dangerous or anti-eco materials were identified in order to dismantle them with full attention. BIM helped out to understand the waste would increase if they used demolition methods such as implosion. Inspection (Table 4) and detailed work plans scheduled before starting the process because of risk and safety of people and personnel were included. Extracted materials were differentiated in different type (recycle, reuse, disposal) to place them as per their utilization.

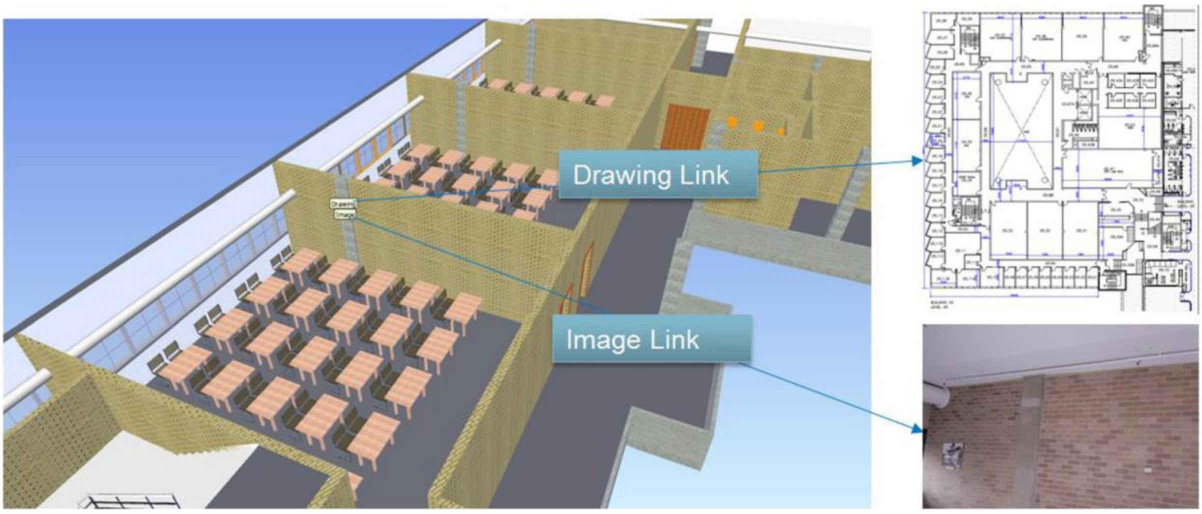

Figure 9: Integrated 2D and 3D under BIM modelling[143]

[143] (Ge, et al., 2017)

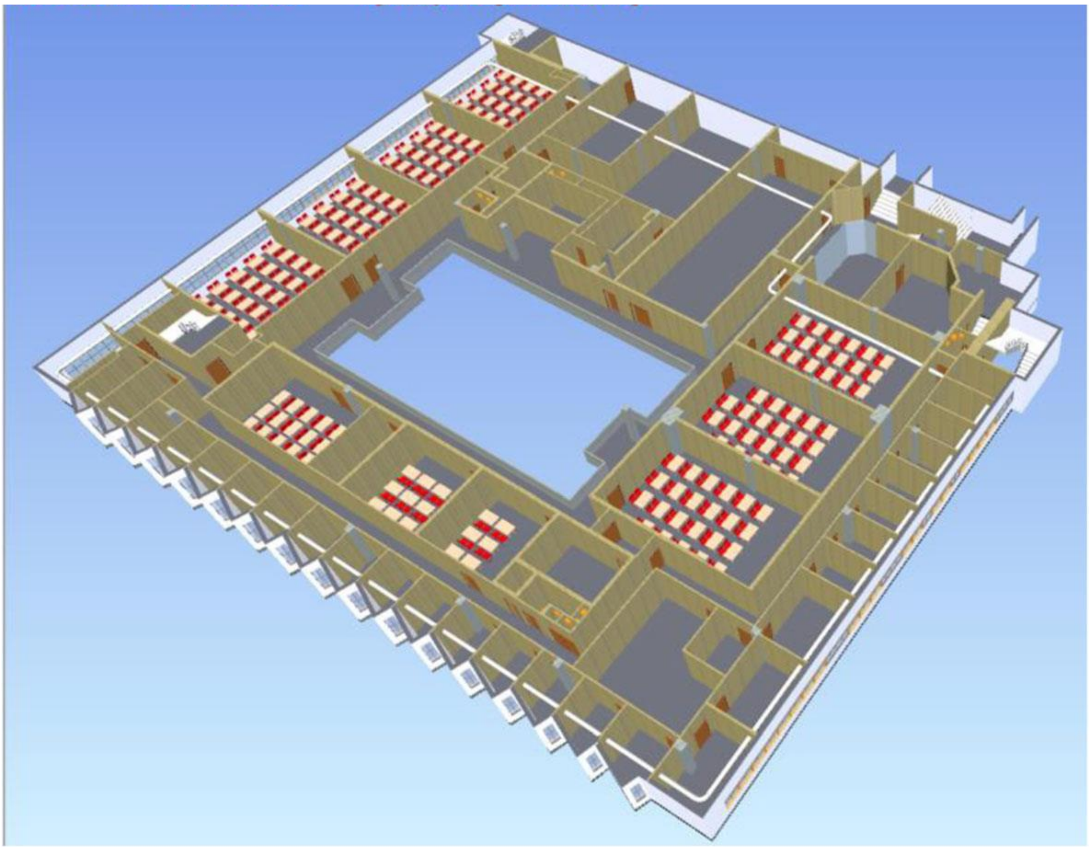

Figure 10: BIM based Model for deconstruction simulation[144]

Dismantling steps were simulated during planning with scheduled phase through BIM and 3D model as shown in figure 10. It visualized not only the fixture and surface of wall but the materials inside the upper layer of wall. Based on simulation, contractor and subcontractor assessed the required labours, machines and time consumption including lump-sum cost estimation. For example, in the Table 5 wall details and estimation process of wall material are shown. Where, the material type, list of materials and the unit price are mentioned which helped contractor to assess the overall cost. [145]

Items	**Notice(days)**
Before Service interruption to the building	3
To mark trees in order to save them or preservation	3
Inventory of the building	3
To check structure after extraction of roof and external claddings	3
To check underground work and excavations	3

144 (Ge, et al., 2017)
145 (Ge, et al., 2017)

Site inspection after the deconstruction process	3
After restoration of services to the building	3

Table 4: Schedule of Inspection, UTS[146]

Material	Type	Phase	Volume(m3)	Cost ($/m3)
Asbestos	Hazardous	Phase 3	0.42	300
Bricks		Phase 7	508.92	300
Concrete Masonry Unit	Interior wall 100 mm	Phase 7	10.06	300
Concrete Masonry Unit	Exterior wall 200 mm	Phase 10	180.48	300
Gypsum Wall Board	Exterior wall 200 mm	Phase 10	18.05	300

Table 5: Extracted wall salvaged materials estimation process [147]

Further salvaged materials are listed and assessed manually as per useability such as recycle, reusable and disposable (Refer Appendix A, page 72).

Author's Observation:

The following figure 11 is explaining the few techniques applicable under Lean and BIM for the management of deconstruction during the execution.

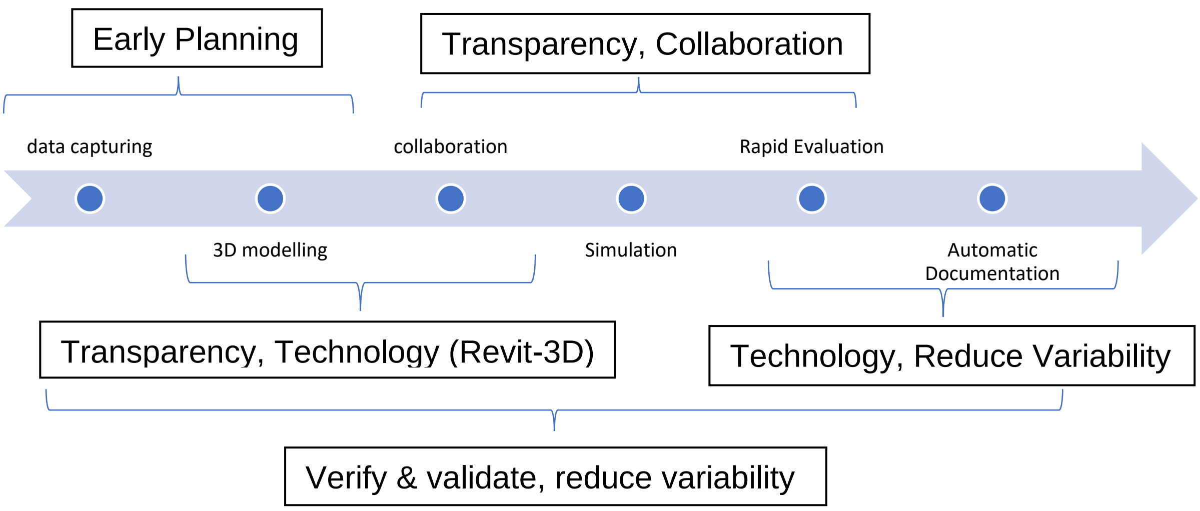

Figure 11: Lean-BIM applied in Building 2, UTS[148]

[146] (Ge, et al., 2017)
[147] (Ge, et al., 2017)
[148] Own illustration, 2021

Few techniques of lean observed during the entire deconstruction process. However, the actual aim was waste management and experts used deconstruction as a tool to handle that. In addition, they saved time, reduced noise pollution, dust, and maximized the recyclable salvage. [149]

4.1.2 Nursing Home, Netherlands[150]

This building was planned for temporary nursing home so, building design was based on prefabrication and modular concept. The elements of building whether structural or non-structural such as façade were supposed to be use it again as a building material. The project details are as follows:

Location: Netherlands

Life span: 5-6 years

Area: 2400 sqm

Building Type: Prefabricated Institutional building

Use Of BIM: Yes, for reusable the elements

Use of Lean: Yes

The lean principles and BIM functionalities used during the dismantling process. Although, deconstruction was in the mind of designers and experts however, during design phase of construction BIM was not used intensively.

Role of Lean-BIM:

The first step for the deconstruction process was to collect data of the existing building to early planning. To collect the data, site inspection and audio recording from the site observer included. Deconstruction schedule prepared to reduce variability and incorporated to site activities such removing panels, removal of cables and so on.

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[149] (Ge, et al., 2017)
[150] (Van den Berg, et al., 2021)

Parallelly, data analysis with the help of BIM started by experts to sort out the contradictions. Project manager used spray paint to point out the delicate element at the building for site workers. Inventory of such elements were noted through BIM, and it was done because of contradiction between drawings and built structure. 3D model also developed to identify the delicate elements and to resolve the conflicts. It helped to recognise the problem and solution for roof and wind bracing in the structure. The Figure 12 below shows how the 3D fulfils the various purposes like connecting two floors, wind bracing, staircase, and sizes.[151]

BIM helped foreman to draw a logical conclusion for dismantling sequences. For, façade stripping, project manager labelled that as it was module element. A special attention was required to reuse it for school project (it was decided). Here, object-based treatment was planned, certain codes and tools such as drawings and machinery list were prepared. A virtual environment created to do some demo before the actual process, BIM model experts added 3D texts, used colour code, and enabled the virtual navigation. Another concern was to store the salvaged elements and transferred it to the destination (in this case school site). Therefore, task allocation and channelising the labour force were important from the deconstruction site to the construction site. A schedule was drawn in paper as well as in BIM with combination of 3D and 4D though that did not work practically. Because workers and team were not so familiar with the 4D deconstruction sequences. The figure 13 below shows the 4D dismantling sequences by representing different colours. [152]

[151] (Van den Berg, et al., 2021)
[152] (Van den Berg, et al., 2021)

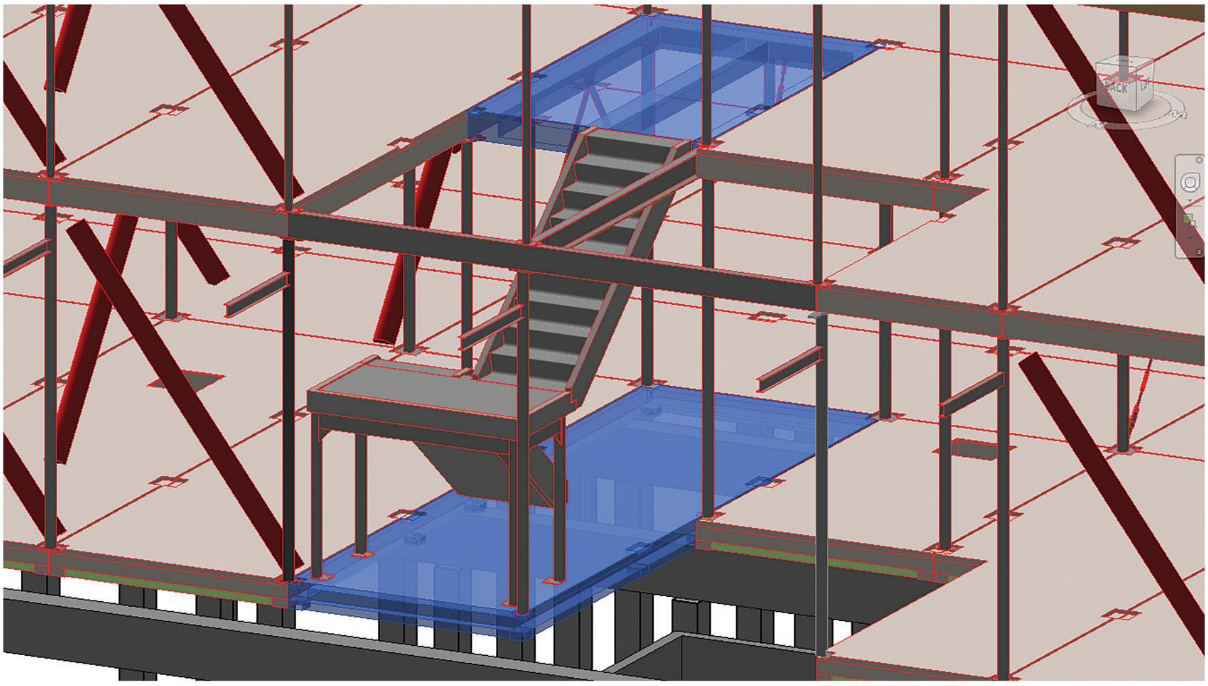

Figure 12: 3D modelling of building showing connecting floors and bracings[153]

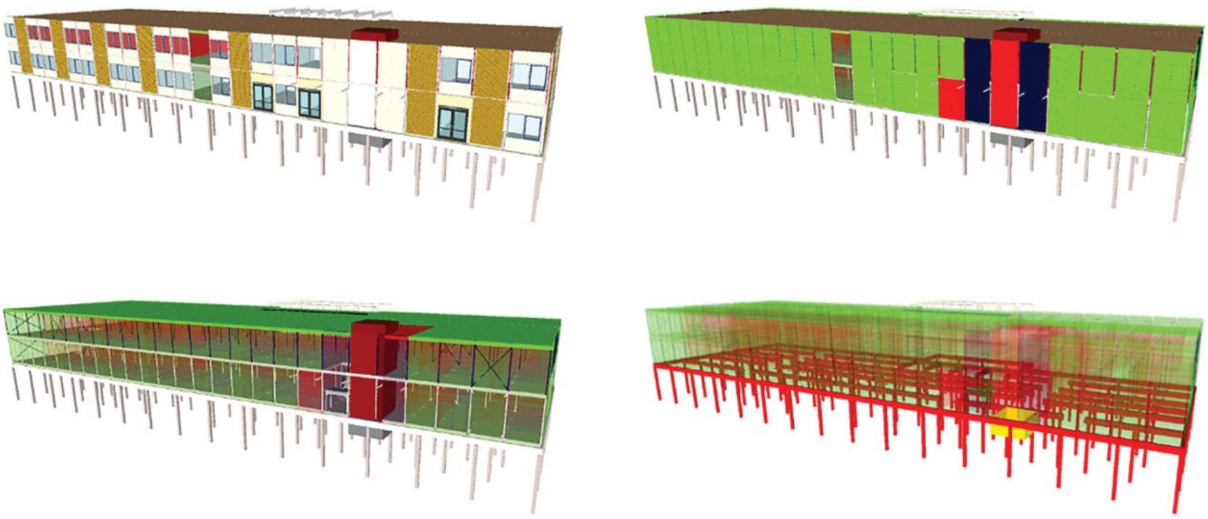

Figure 13: Deconstruction sequences showed by colours with combination of 3D and 4D[154]

153 (Van den Berg, et al., 2021)
154 (Van den Berg, et al., 2021)

Author's Observation:

The following figure 14 is explaining the few techniques applicable under Lean and BIM for the management of deconstruction during the execution.

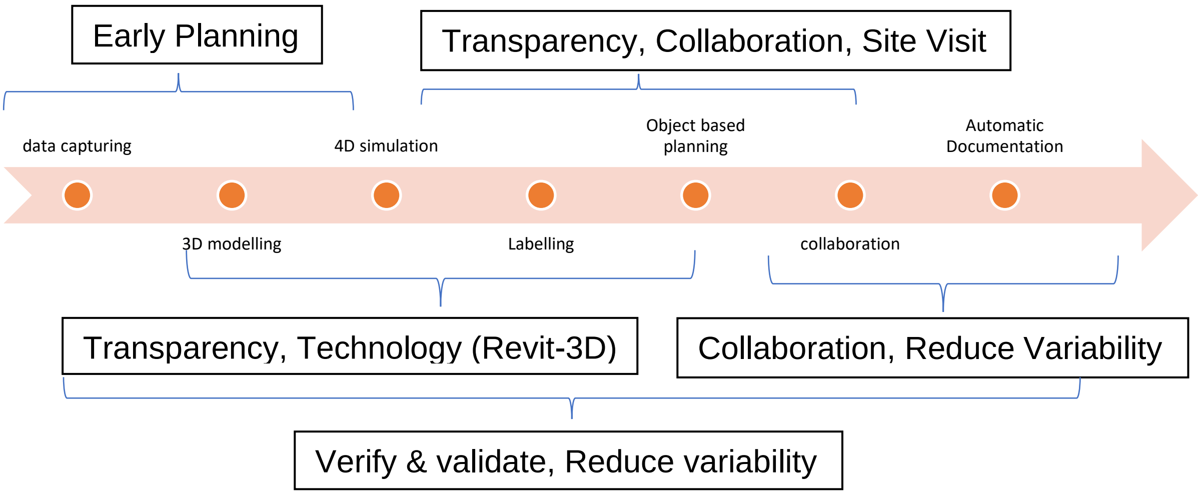

Figure 14: Lean-BIM applied in Nursing Home, Netherlands[155]

It was a unique project as it was modular cum prefabricated structure and while designing BIM was not applied. Whereas, during deconstruction lean and BIM used intensively to reuse the extracted materials for the other project. It makes this project unique as well as challenging. Staff training and non-standardised use of BIM was missed. A 4D model failed to fulfil its purpose although it had potential. [156]

4.2 Comparative Analysis

The above-mentioned case studies proved that use of Lean-BIM have not fully utilised for a project though at some extent it was applied, and their outcome can be seen. There were several conflicts between BIM and conventional work system though, those conflicts and the future contradiction will be helpful to evolve the BIM and lean techniques. Awareness and vocational training were missing at some extent for example in the Nursing home case study 4D model did not succeed as it was planned. Some information was missing too from the case studies which could transform the

[155] Author, 2021
[156] (Van den Berg, et al., 2021)

outcome such as transportation of extracted materials, storage for salvaged materials, risk factors and damages while deconstruction processes. The table 6 summarize the overall applicability in above mentioned case studies.

Case study	**BIM** / **Lean**	Data capturing	Modelling	Collaboration	Object based planning	Reuse of model data	Evaluation & Simulation	Automatic Documentation	online/e-communication
Building2 UTS, Australia	Early Planning	✓	✓	✓	×	×	×	×	×
	Transparency	✓	✓	✓	×	NA	NA	✓	×
	Technology	✓	✓	✓	×	NA	✓	✓	NA
	Collaboration	✓	✓	✓	-	NA	✓	✓	✓
	Verify & validate	✓	✓	✓	✓	✓	✓	✓	×
	Reduce Variability	✓	✓	✓	-	×	×	✓	NA
Nursing Home, Netherland	Early Planning	✓	✓	✓	✓	×	×	×	×
	Transparency	✓	✓	✓	✓	×	✓	✓	×
	Technology	✓	✓		✓	✓	✓	✓	✓
	Collaboration	✓	✓	✓	-	✓	✓	✓	✓
	Verify & validate	✓	✓	✓	✓	✓	✓	✓	×
	Reduce Variability	✓	✓	✓	-	✓	✓	✓	×
	Site Visit	✓	✓	-	-	-	×	-	×

NA: Data not available, (-): Not applicable, (✓): applied, (×): Not used

Table 6: Comparative Analysis of case studies [157]

4.3 Interviews and Questionnaire

An interview and questionnaire are taken to understand the current deconstruction practices with the help of lean and BIM. The interviewee 'Shashank Singh'(SS) is working in the "Aecom" an American based multinational engineering firm. He is an Assistant Project Manager in Austin, Texas (USA) and has experience in construction as well as deconstruction in the institutional building (specifically school). The interview helped to provide awareness related to dismantling techniques, software, and BIM functionalities along with the challenges and advantages of BIM and lean during deconstruction process. In addition, gave insight regarding storage and reusability of

[157] Own tabulation

the salvaged material. Questions were based on BIM uses in deconstruction and lean techniques applicable for deconstruction as it is a type of production (material). The aim was to get vision of lean and BIM utilization for deconstruction. To understand financial related view of the experts and pragmatic solutions.

- How BIM is playing role, how far lean beneficial in this context?
- What is the status in practice and market?
- How much cost effective it is?

With some challenges, Lean and BIM are playing good role in dismantling of building. It enlarged the material reusability perspective for the future projects. Since, it is not going on mass scale so, trading of extracted materials is still debatable. Mostly, the extracted materials are reused in either same project as a renovation or reconstruction. As per interviewee's thought, it has more social or emotional values. The Client wants to reuse the elements of earlier building in new construction to get same face values. Practicing deconstruction is not easy with BIM compared to Lean as BIM is not as developed for that as it is for a construction. However, it uses makes work accurate and within timeframe. As per economical point of view it is quite expensive and sometime extracted material turn into waste due to improper storage and mishandling. Interviewee also mentioned about some BIM tool which need to evolve and could be helpful in near future. Those are augmented reality, BIM lens, plugins for Revit related to deconstruction process. Some of Important questions and answers are given below which are more relevant to get the ideas. (Refer Appendix A, page 72 for other questions).

Q) Which information do you need before applying Lean/BIM for the deconstruction?

SS Response: A Planning is most important before taking any steps related to that. So, detailed design of the building is highly required including materials and services related information. Images and videos of the site/building then check availability of tools for formulation of dismantling steps. Storage facility for salvaged elements is another requirement. Because most of the time material quality degraded due to lack of storage facilities. To figure out scope of the salvaged after extraction whether utilization in other project or reuse in the reconstruction of same building.

Q) Is currently, the deconstruction methods and processes are flexible/smooth?

SS Response: Not exactly, as projects are complex and unique so, there is not any standard process or tool developed for, specifically deconstruction. BIM is developed a lot now a days but still there is not any precise tool for dismantling of the whole building. We usually plan these BIM features or Lean principles if there are any possibilities to imply that. However, when these techniques fit to dismantling work then it gives some positive edge like smooth workflow and flexibilities in conceptualisation and alternatives.

Q) What are your expectations from BIM and Lean in the near future?

SS Response: First, awareness regarding utilization of BIM and Lean techniques for the purpose of building deconstruction should be more focused. At certain point I am not expecting from Lean principles as these principles are useful and playing well to standardise the deconstruction processes, but BIM needs more development in the field of deconstruction and demolition. BIM tools need to have a user interface that is friendly for non tech savvy workers. Too much sophistication prevents it from being used widely. Organizations responsible for implementation of Lean principles need to conduct more workshops to increase awareness among industry professionals.

The questionnaire was also prepared, and that is mentioned in Appendix B, page 75 though that did not work. It was intended to get some acknowledgement from experienced in deconstruction projects. The survey was replied from 9 professionals including architects and civil engineers. None of them had experienced§ with deconstruction, neither directly related with demolition of the building projects. It reflects this topic is unexplored and using lean and BIM are quite a new concept in the current practice.

4.4 Inference

Lean-BIM matrix is a practical approach for deconstruction of the building. ‘Verify and validate’, ‘reduce variability’ and ‘cycle time’ have more interaction with BIM functions.

The function which has less BIM interaction with lean does not mean anything less with that combination rather it expresses accurate and pinpoint relations. These combinations are showing the good possibilities of applicability in deconstruction. The result could be decision making, unused, and negative depends on the project type, scale, and location.

Furthermore, current practice in the field is very scarce and at limited applicability. Even though, above case studies and interviews are a little aligned with the combined use of lean techniques and BIM functionalities. Some of BIM and lean functionalities are not fully explored such as object-based planning in UTS, Australia case study, online updating of BIM data, the plug-ins related and post deconstruction management. However, feasibilities of Lean-BIM implementation are based on project type and scale. In case study 2, Nursing Home at Netherland, due to lack of training and not acquaintance with BIM, 4D application failed drastically even theoretically that was matured enough.

In addition, the survey is done with the help of questionnaires that completely failed to acknowledge the theories with practicalities. So, it is tough to assess that till what extent these are applicable. Although, number of interviews and survey participants are not enough to infer above expression. However, it proves that the subject is still in early phase of development or has not been explored much.

CHAPTER 5: Results, Conclusion and Recommendation

5.1: Results and research answers

The take home lessons from these Lean-BIM analysis and economical perspective study are elaborated in the following sub-sections.

5.1.1 Result analysis

Integrated Lean-BIM

There are 85 times Lean and BIM interacted with each other where there are 18 lean principles noted and 8 BIM functions. From inference of above chapter, it is clear that “verification and validation”, “reduce cycle time”, “reduce variability”, and “process standardizing” possess high integration than any others. Under lean principles from early planning to destination delivery, it integrates the wholesome of a project. Verify and validate facilitates the smooth flow to a project continuously by verifying and validating. It has potential to control and monitoring the dismantling process and ensures harvested materials are intact to meet requirement of end users.

The next most interactive is to reduce cycle time with BIM which depicts all the process related to BIM reduce the cycle time of all the events connected with building deconstruction. It might be helpful to reduce time for initial data capturing which is usually a time-consuming process. With the help of simulation, an inform decision and visualization make sure the running time should not exceed much for disassembly procedures. Likewise, the principle reduces variability also reduce the differences between multiple events to execute dismantling on time. It detects the conflicts, variation and communicates to stakeholder with the support of BIM tools. Process Standardizing is also interacting with various BIM which simplifies the process through work break system and makes the complex dismantling into simple form. Which is helpful to understand and to execute a project disassemble for the foremen and team. Because data entry, source and clashes between different BIM tools make the dismantling methods complex. It disintegrates the complexity from design phase of dismantling to the end of a project along with collaboration and communication.

Moreover, other BIM facilitation which coordinated more with Lean were Early planning, comprehensive requirement, and institute continuous improvement. They express the entirety of a project with detail to achieve the objectives.

An outline of BIM functions from data gathering through automation is a distinct approach for an initiative like deconstruction. It supports secondary events and information through vast range of examining processes, plugins, and interoperability with other tools. Thus, it associates with the series of lean principles and produces smart outcomes for deconstruction projects.

Among the functionalities of BIM with lean techniques, some have been fewer transactions such as “pull from down-stream”, “Site supervision”, “selective technology”. However, that does not reduce the importance or applicability. Moreover, these complement the entire process of dismantling.

Economic Outlook

There are factors like pre-deconstruction audit, staff training, landfilling cost etc. which affect the cost of deconstruction most. Lean-BIM factors are watering the budget which can be short out with proper management.

The most affecting factors among Lean-BIM are BIM training and awareness programmes for team and upcoming professionals. It can be costly for a while nevertheless; in long run it will reduce the cost and time for future projects. Then it will be factor which would be helpful to boost this initiative. Plugin and interoperability are also required steps for smooth workflow which demand the financial support from big players. Likewise, cyber securities, recycle and reuse need government support in terms of law and policies. At present, contractors try to escape from that which brings huge penalties for deconstruction.

There are some universal materials like wood, steel, concrete, bricks etc. which has multiple reuse ability and recyclability. Lean-BIM application ensures the desirable management of those materials during dismantling. Adding value to the rescued elements could be one of the good solutions for industry as an improved value of the components. Alongside, present resources and means are available for DfD through which design development and establishing new market for secondary market is possible. The supply chain can also be developed in the future through the design for the deconstruction of buildings.

There are different types of projects and those require an implementation of the Lean-BIM synergies for deconstruction so that waste could be minimise, resources development and eco-friendly behaviour could be improvised.

Case studies and Interviews

To validate the Lean-BIM interaction for deconstruction the following case studies and interviews were done. First, Building2 UTS, Australia where multiple Lean and BIM sciences were used. This project faced challenge to gather information at early phase as it was not designed for deconstruction. Retrieving BIM data was also one of the issues so, many lean principles and BIM could not explore completely. Although “reduce variability” and “verify and validate” tried to replicate at maximum possibilities. Advance technologies such as augmented reality and 4D along with others were not used. Nevertheless, 3Dmodelling played multiple roles to deconstruct the project.

Another one was Nursing Home, Netherlands which theoretically sticks with advanced BIM tools. In this project, likewise, verify and validate and reduce variability played a vital role. Selection of technology and site visit were also included consequently, 4D application, dismantling sequences along with retrieving BIM model was successful development for the deconstruction. Though 4D action did not work due to non-familiarity with such operation by team. Overall, dismantling of Nursing home was proven as a successful project. Which validates the potential use of combined Lean and BIM. However, economic, social, and environmental values were missing.

Moreover, continuation of validation interviews and questionnaire were drafted to get insight from experienced experts. Unfortunately, questionnaire did not work and only one interviewee responded which were not enough to conclude any stances. However, the approach of interview was to get some vision regarding uses of lean and BIM for deconstruction. As per project manager, dismantling is challenging and not cost effective though he found social values from owner’s side. The challenges he pointed out were related to BIM application, storage, and awareness. Unavailability of participants for such survey proves how this deconstruction industry is in its nascent phase and ignored by professional players.

Lean-BIM deconstruction hypothesis for the Chartwell School, California: financial

To deconstruct economically, the first step for the school building would be to collect all the building drawing including component details and detailed utilities of the building. It will be helpful to capture the data for early planning of dismantling. Which could be helpful to minimise the survey cost and time for decision making. The site inventories could be reported with the help of available information under DfD and incorporate with BIM to reduce variability and for transparency. Remodelling and object-based planning with the help of Tekla structure and Revit could provide rapid dismantling sequences and possible alternate. Because of detailed information and modular components, scheduling and collaboration with professionals would be fast with optimal accuracy without much wastage. Quantity take-off and materials value estimation would be precise.

Before schedule project completion would save time, which can reduce the longer running cost of labour force, equipment, and additional facilities for team. Moreover, it would be helpful to create positive image of the developer/investor in the market. That popularity might encourage stakeholder for such projects. At the end, beforehand execution and planning would open door to find new market, storage, and reassessment of salvaged materials for present market values. Thus, it would be safer from currency fluctuation in the market. Though, it might not affect direct cost of disassembly of the project, but it would give that environment through which financial flow for the project will be smooth.

5.1.2 Framework of integrated Lean-BIM approach for Deconstruction

Based on Lean- BIM duo analysis and its economic perspective, framework for deconstruction of a building is suggested. This framework prefers the BIM functionalities with respect to the lean principles from assessment to end of the deconstruction of a project. It tries to explore the capabilities of Lean-BIM to assess the dismantling possibilities, degree of assistance in sequencing process, control, and monitoring. It allows the design professionals and contractors for early decision on methodology of deconstruction as well as transparency during the whole project execution. An effective flow of deconstruction is shown in the figure below.

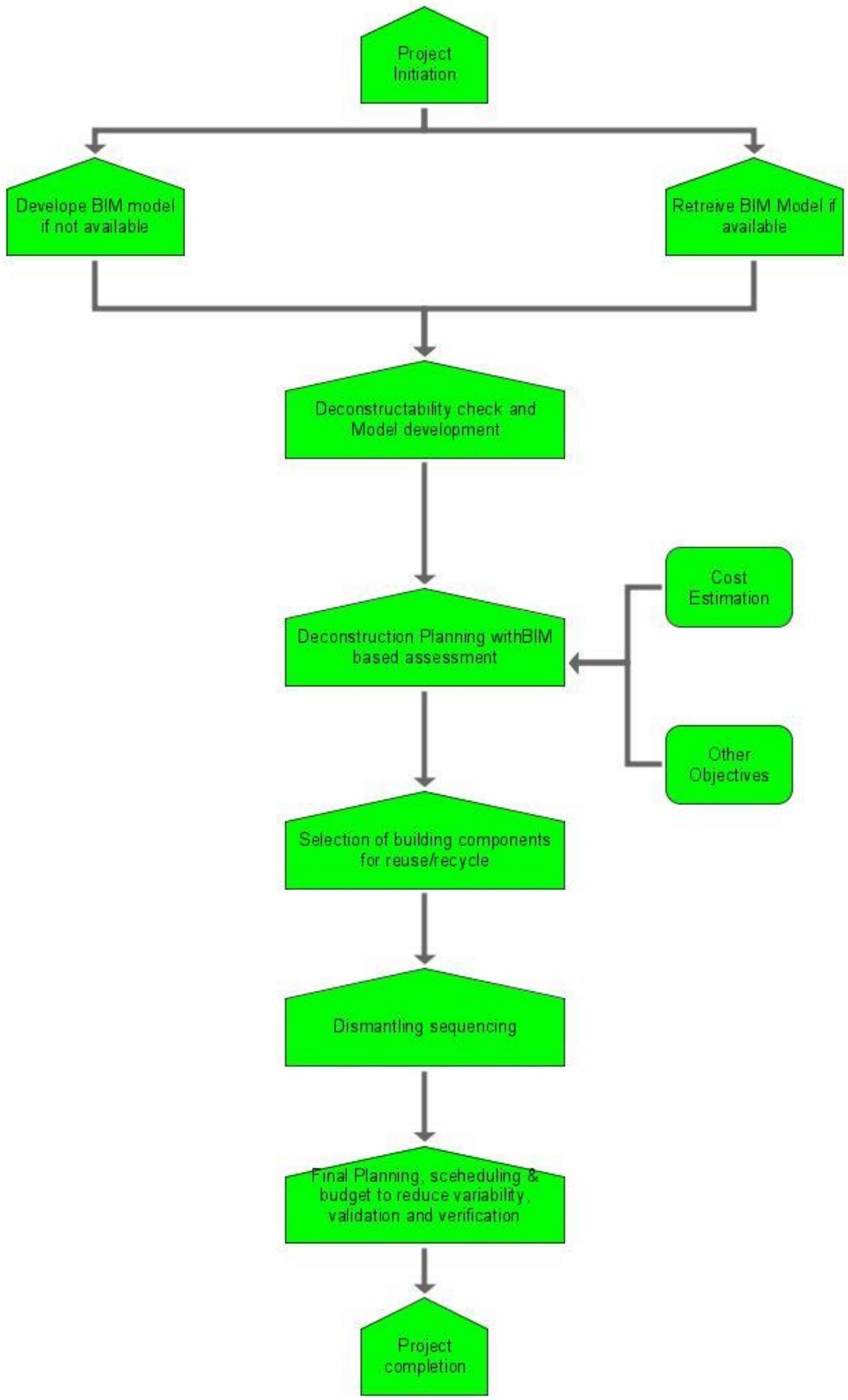

Figure 15: Conceptual deconstruction framework based on Lean-BIM application[158]

[158] Own illustration

Once project selection is done, the guidelines is required to check the feasibility of deconstruction and the achievable targets. A comprehensive requirement is important for the experts in order to go for deconstruction. Based on this collection of data and BIM model development is required. Deconstruct-ability check is prime aim at this stage then project can go further else it will be demolished.

Remodelling of the BIM data would help to assess the various objective like cost estimation, quantity take-off, environmental aspect, dismantling method selection, deconstruction simulation and automatic report generation. In this scenario, DfD projects can get foremost results.

To move further steps, selection of building components is vital as that will be final product for reuse, recycle or disposal. Here, the goal is to rescue the dismantled elements and keep them intact to utilise that optimally.

After finalizing the components, the BIM will play its role intensively. To dismantling sequences will be planned as per the building type, component type and available resources. Interoperability of BIM software, collaboration, object-based programming, simulation, and other functionalities will be utilised by architects and engineers. This phase would help to find other alternative to get high accuracy and excellent output.

With the optimal option, final planning would be proposed. The schedule for the dismantling would draw the detailed time duration for each process. And the final budget for project execution will be delivered including tools or equipment, storage and if there will be a provision for delivery then transport as well. At this phase Lean and BIM has high potential to replicate their useability. A technology selection to standardizing the process will be applicable including reduction of cycle time, collaboration with other stakeholders, business model selection like pull from downstream. The application of Lean-BIM can reduce the cycle time of disassembly furthermore, validation and verification through BIM make a project successful.

Thus, this framework can be a guiding principle for experts to dismantle the existing buildings by using lean techniques and BIM tools.

5.1.3 Research Answers

The first question is related to possibilities of Lean-BIM combination for deconstruction. The literature review and Lean-BIM analysis showed which lean techniques are workable for deconstruction along with BIM functionalities.

What are the extensions or verification of lean principles and BIM in the deconstruction process?

This study figured out 16 lean principles and 8 BIM functionalities with 85 coactions are applicable for building deconstruction. The following picture expresses the lean principles in central circle and how each BIM functionalities in outer circle related. Though, these two-dimension relation are not the limited interaction, and it can affect to other function of BIM as well lean techniques.

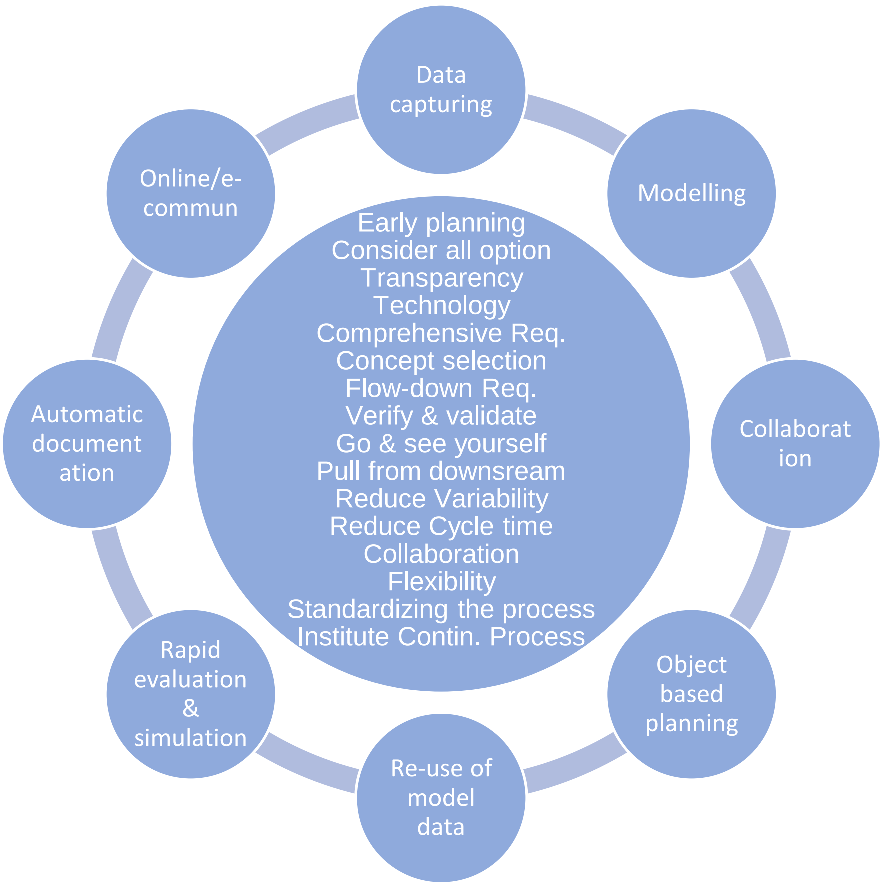

Figure 16: List of Lean techniques and related BIM functions[159]

[159] Own illustration

The next question is about the ideas to understand how Lean and BIM combination is effective for building deconstruction in terms of finance. How lean-BIM makes deconstruction economically feasible if it applies intelligently.

How to measure economic efficiency of Lean-BIM matrix for Deconstruct-ability?

The above study on lean and BIM functionalities proved that it is possible to apply efficiently for deconstruction, and it showed the potential that deconstruction is possible under budget. Furthermore, Lean-BIM combo helpful to improve the value of the components after extraction.

Lean-BIM facilitates pre-deconstruction audit where site inventory could be noted down is one of starting factors which state about the project and possible deconstruction outcomes. It provides information before starting the process and limitation along with scope and objectives of Lean and BIM application through retrieving the BIM model. After audit, Deconstruct-ability assessment by using BIM tools turn into deciding factor related to cost and estimation. At this pre-final stage, lump-sum cost estimation with the help of software would go. This stage will be deciding factors whether the building is fit for deconstruction or not along with how much initial investment would be required. Thus, it helps to take early decision, provide time span for deconstruction project management which has a high monetary value.

Using Tekla structure, Revit and Telly-in are some means through which evaluation of the amount of recyclable and reusable building components possible. It would be helpful for following pull from downstream model. Then, potential buyer can be identified, and high price could be achieved. Using harvested elements to correct place decrease the gross cost of deconstruction. This way building deconstruction could be economically efficient because the biggest challenge of this sector is finding destination for secondary materials.

Another way is to adding value in the recovered materials like in a WHR case of New Zealand. BIM is itself a medium to design and develop new objects and lean helps for reducing the waste. So, lean BIM can also play a major role. Thus, quantifying the salvaged by object based programming or other means in addition, deliver to target audience Lean-BIM measures the efficiency.

DfD is another smart initiative where duo plays a key role and project based on DfD could be a scale to measure financial feasibility. There are quite less projects which are designed for deconstruction. It has potential to be a parameter for economical deconstruction of a building.

Thus, by analysing strengths, weaknesses, present opportunities, and external threats of projects with respect to available BIM and other waste minimising resources, economic efficiency of building deconstruction could be measure.

Another question searched about market potential of combination while practising the deconstruction in architecture and construction industry for long run.

Evaluation of the market potential for lean-BIM approached dismantling projects with respect to materials and stakeholder.

With the help of this research, Lean-BIM exhibited the market potential at certain extent. For deconstruction economy, salvaged elements are fuel. The more material produces the higher resale price would be achievable. First, proper intact dismantling of building is prior concern for professionals which starts from the planning of dismantling to deliver the recovered materials to the destination. The role of interactive Lean-BIM would assess the building deconstruct-ability and then selection of components and respective technology for removal. The less damages will occur the more utilisable the material would be. Accuracy and reduction in variability of the process increase the probability of good quality materials. Good quality material could be decided by the framework which suits for the material to check precise economical feasibilities. Those are reusability, recyclability and handling the equipment/tools for extraction of the materials from existing building. At the primary stage BIM with lean evaluate the reuse ability of a material by life cycle assessment, size, and specifications. If that is not reusable, then check for recycle ability or required treatment to make it recyclable. Technology selection, verify and validate, simplification of process with BIM interaction and interoperability are other features which help to evaluate the potential for secondary market.

Primary stakeholders in deconstruction are Government authorities/body, Non-profit organization, community, and the consumer. Policies and laws are deciding factors in terms of construction waste generation by failed deconstruction, unused material and waste disposal for landfilling. For this government plays an important role to promote sustainable use and then extraction of secondary materials are obligatory. They put penalties for improper treatment of construction waste which generates from mishandling of materials dismantling. Government also provides subsidies to promote such activities. Which shows future potential of deconstructed materials. They also facilitate the new market help to provide new infrastructure for that. Likewise, a non-profit organization helps to promote that too as “Rekindle” of New Zealand and “Delta Institute” of USA did in this sector. These organization based on non-profit so, it helps to minimize the initial cost of deconstruction. As deconstruction has more eco-friendly and social values, community also come forward to involve in such project which again help to reduce the initial cost of materials and provide a new market for resale to end users. Moreover, e-communicating features of several BIM tools locate the right place for the secondary materials. Similarly, web shopping works as exhibition centre for the materials.

On the contrary, lack of awareness regarding Lean-BIM, traditional methods are in practice which are more manual and mostly success with wooden structure and limited to certain materials like bricks and rest turn into demolition waste. Lean-BIM also has their own challenge while operating such as need knowledge, advancement of BIM etc. Lean-BIM failed to many projects because retrieving BIM model is not possible. Cybersecurity is one of concerns which limit its application. In addition, stakeholders such as government also makes laws to control profit, health and safety which hinders sometimes to optimal use. Lean-BIM are not a huge share of implementation of dismantling cost so, it does not put strong impact.

However, deconstruction is in rising phase, so at current situation is in favour of that. Advancement of technology promotes more positive points rather negative. In such perspective, Lean-BIM opened a new dimension an ‘automation’ in deconstruction.

5.2 Conclusion and Recommendation

The lean techniques are well suited for the production sector and deconstruction comes under that construction sector where material produce from an existing building. In addition, the BIM is an inevitable tool for building industry. Thus, combination of Lean and BIM for such subject is vital for disassembly of buildings. This research focused on Several lean principles which can apply while using BIM for deconstruction projects. The function of BIM is examined with respect to each lean principle and found there are several permutation and combination which can be implied during execution of deconstruction. Though, in this paper the interactions between Lean and BIM seem simple and limited but it can affect other principles which fall under deep technicality. However, these combinations may guide professionals for the extended adaptabilities. Lean is working as a platform where all BIM functionalities are connected to reduce the waste and enhance the quality recovery from dismantling of the physical structures. Although, in terms of cost benefit it (combination) is not much effective though its role turns impactful if it is applied in a design phase of a building development. DfD is an audacious initiative that has a huge potential for the secondary market.

Cost and estimation for this subject depend on various factors such as recyclability, reusability of rescued elements. In addition, BIM limitation, challenges while operating BIM and dismantling equipment, geographical location and market also affect the financial part of deconstruction industry. Waste reduction, effective management and quality deliverability are the recognisable features which can be achieve with design for deconstruction in the context of deconstruction. Since, cost wise it is not attractive yet though study showed the deconstruction has enough potential to improve as the new market and techniques will be developed. So, role of different audience such as Government, community and Non-profit Organization are also highly considerable.

In this research paper lean-BIM matrix focused only on institutional and residential type of building. There are still lots of opportunities to work on different type and scale of buildings. Economical aspects could be quantifying in the future works and validation of methods for the salvaged material is also opened for future tasks in this sector. More perspectives like technical disassembly sequences development and legal are open for implementation of lean techniques and BIM in deconstruction.

Another research area could be software application for design details in deconstruction (DfD), specific tool utilization in different stages where deconstruction could be incorporated in design stage to reduce demolition waste after completion of a building life.

Declaration of Authorship

I hereby declare that the attached Master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Berlin, 30-07-2021

Location, Date

Signature of the student

Hochschule für Technik und Wirtschaft Berlin
University of Applied Sciences

English translation for information purposes only.

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APPENDIX A

1.Figures

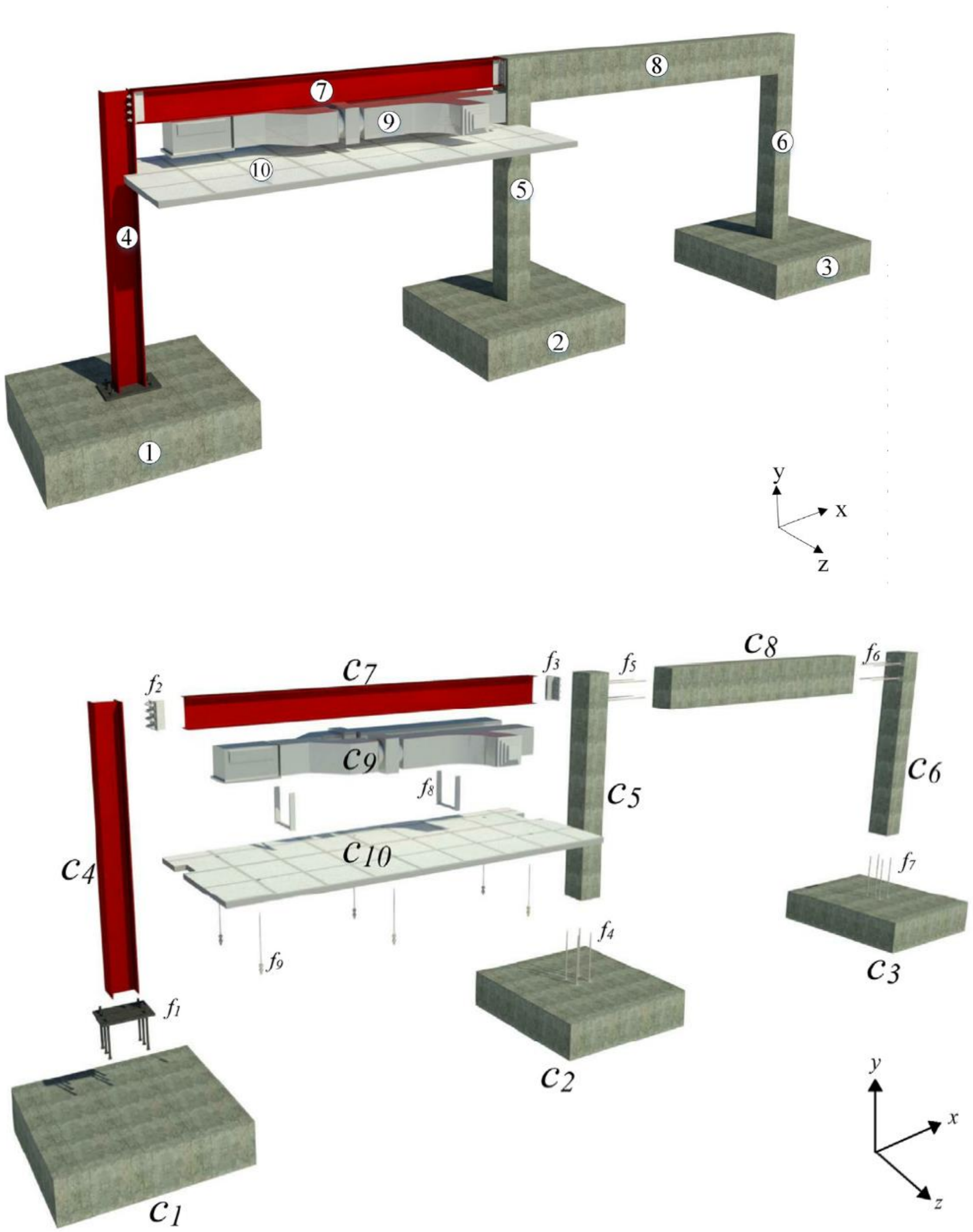

Figure: 6D BIM building assembly prototype for deconstruction study purpose

2. Tables

Materials	Quantity	Recycle	Reuse	Disposal
Furniture(chairs)	414		yes	
Furniture (Tables)	207		yes	
Carpet	2499 m2		yes	yes
Bricks	1017.891 m3	yes		
Concrete (column)	42.42 m3	yes		
Concrete (wall, floor)	690.41 m3	yes		
Gypsum board	36.14 m3	yes		
General doors	69	yes		
Fire doors	8			yes
Glass	1.17 m3	yes		
Rebar	30.06 ton	yes		
Asbestos	0.83 m3			yes

Table: Example of Salvage Generated from deconstruction of Building 2, UTS (Australia)- case study

3. Interview Questions & Answers

These questions and answers are encrypted as per objectives of the study. It is interpreted and written in formal version though that was a telephonic conversation and those were a little informal explanation of answers.

1) Do you use BIM and Lean techniques (reducing waste generation and improve work quality during the process) for the deconstruction of your projects? is it helpful to fix the work quality of the organization?

SS Response: Yes, I use it for better accuracy and minimizing waste. It helps in order to intact the extracted materials which maintain the qualities.

2) Is currently, the deconstruction methods and processes are flexible/smooth?

SS Response: Not exactly, as projects are complex and unique so, there is not any standard process or tool developed for, specifically deconstruction. BIM is developed a lot now a days but still there is not any precise tool for dismantling. We usually plan these BIM features or Lean principles if there are any possibilities to imply that. However, when these techniques fit to dismantling work then it gives some positive edge like smooth workflow and flexibilities in conceptualisation and alternatives.

3) Which BIM tools are you using for dismantling/deconstruction?

SS Response: Usually, I use Revit and it is helpful for analysis, communication, 3D visualization and collaboration with my team.

4) Which BIM tools are you using for dismantling/deconstruction cost?

SS Response: For costing, my teams use…. same Revit.

5) Which information do you need before applying Lean/BIM for the deconstruction?

SS Response: A Planning is most important before taking any steps related to that. So, detailed design of the building is highly required including materials and services related information. In short point cloud model of the existing building. Images and videos of the site/building then check availability of tools for formulation of dismantling steps. Storage facility for salvaged elements is another requirement. To figure out scope of the salvaged after extraction whether utilization in other project or reuse in the reconstruction of same building.

6) What are your expectations from BIM and Lean in the near future?

SS Response: First of all, awareness regarding utilization of BIM and Lean techniques for the purpose of building deconstruction should be more focused. At certain point I am not expecting from Lean principles as these principles are useful and playing well to standardise the deconstruction processes, but BIM needs more development in the field of deconstruction and demolition. BIM tools need to have a user interface that is friendly for non tech savvy workers. Too much sophistication prevents it from being used widely. Organizations responsible for implementation of Lean principles need to conduct more workshops to increase awareness among industry professionals.

7) Which BIM tools, do you think will be helpful but not evolved yet for deconstruction purposes?

SS Response: Augmented reality tool are helpful but not designed for deconstruction simulation. Plugins for Revit related to deconstruction processes and BIM lens.

8) In terms of cost-benefit and market, how far did we achieve and to what extent we can move forward?

SS Response: Well, it depends on various factor so, it is quite tough to say related to market value of salvaged elements. Though, in terms of cost it is not as beneficial as it is socially and environmentally. To make it cost effective, we need to work more during conceptual formulation of a building and in the same time development of BIM for dismantling is highly required.

APPENDIX B

Deconstruction questionnaire 2021

Please provide the following information by clicking the appropriate option

*Required

1. What is your professional discipline? *

- Demolition Engineer
- Construction manager
- Civil Engineer
- Architect
- Project manager
- BIM manager/coordinators
- Other:

2. What is your role in your organization?

- Top-level management
- Middle-level management
- Low-level management

3. What is your highest academic qualification?

- Graduate-level Degree
- Post Graduate level Degree
- Other, please specify

4. How long have you been working in the construction industry?

- Under 5 years
- 5 < 10 years
- 10 < 15years
- 15 < 20years
- 20 years and above

Mark your level of awareness/understanding (Q5-16)

5. BIM in Deconstruction/demolition practices in the construction industry.

1 2 3 4 5

6. Lean in Deconstruction/demolition practices in the construction industry.

1 2 3 4 5

7. Top Management support to support BIM for deconstruction practices in the project life cycle management

1 2 3 4 5

8. Top Management follows Lean techniques for deconstruction practices in the building dismantling processes.

1 2 3 4 5

9. Software interoperability of BIM design tools

1 2 3 4 5

10. Availability of BIM for deconstruction experts and client advisors

1 2 3 4 5

11. Cost of software and equipment to support BIM for deconstruction practice

1 2 3 4 5

12. Lean approach with BIM lead time to allow deconstruction analytics during design

1 2 3 4 5

13. Client understanding of BIM and lean approach for deconstruction benefits

1 2 3 4 5

14. Collaboration among project design and deconstruction teams

1 2 3 4 5

15. Comprehensive professional guidelines for deconstruction operations integrated from planning and design stages (DfD)

1 2 3 4 5

16. Cost effectiveness of Deconstruction in current practices

1 2 3 4 5

APPENDIX C

1. Contact Details for Lean-BIM Questionnaire

Unfortunately, author did not get those professionals who has experience in deconstruction related projects. Some industry experts did not respond the phone call and email. There are some contact and name along with email attachments below which did not get respond.

1) SN Contractors, Building Demolition and Dismantling

13/2 Hindon Vihar Ghaziabad Uttar Pradesh (INDIA).

EMAIL ADDRESS:

info@sncontractor.in

PHONE NO: +91 9971416003

2) TRITHERM TEHNO SOLUTIONS
No. 4/13, First Floor, Church Road

C.Pallavaram, Chennai – 43.

Mobile No: +91 9884846446, 9841140786, 7358333397

Telephone No: 044 – 24891086

Email Id: arul786@yahoo.co.in, ttsarul@gmail.com

Website: www.trithermtechnologies.co.in

3) Purkupiha Group, Vantaa Recycling Station

Degermosantie, 01760 Vantaa

tel. +358 10 524 4094, email: vaaka.vantaa@purkupiha.fi

2. Attached Emails

There are attached emails whom author tried to approach for interview or to find expert's suggestions on given subject.

Query regarding Building Deconstruction

From Raj Bir Kumar
To abbruch@btb-bautransporte.de
Cc info@btb-bautransporte.de
Date 23.07.2021 16:47

Message 7 of 46

Dear BTB Team,

I am writing this mail regarding awareness and usefulness of deconstruction for better habitat and society. I am an admirer of your work and working on these issues. I tried to contact you by phone which I failed to connect.

I would be very grateful if you give the short answer of my some curiosities. These are:

1) Do you use BIM and Lean techniques (reducing waste generation and improve work quality during the process) for the deconstruction of your projects? is it helpful to fix the work quality of the organization?

2) Is currently, the deconstruction methods and processes are flexible/smooth?

3) Which BIM tools you are using for dismantling/deconstruction?

4) Which informations do you need before applying BIM for the deconstruction?

5) What are your expectation from BIM and Lean in the near future?

6) Which BIM tools, do you think will be helpful but not evolved yet for deconstruction purposes?

7) In terms of cost-benefit and market, how far did we achieve and to what extent we can move forward?

I believe the above-mentioned queries will encourage me to work as an architect in the near future. I really will be thankful to you for your time, knowledge and expertise related to these amazing practical subjects.

Best regards

--
Raj Bir Kumar (Matrikelnummer: 572549)
Hochschule für Technik und Wirtschaft (HTW) Berlin
Treskowallee 8
10318 Berlin
Raj.Kumar@Student.HTW-Berlin.de | www.htw-berlin.de

Regarding query, circular economy, IARFE Day 30-04-2021

From Raj Bir Kumar
To office@rigv.fi
Date 30.04.2021 16:09

Message 23 of 46

Dear Dr. Krish SANKARAN,

I RajBir Kumar student of M.Engg(construction & Real Estate Management), attended your seminar on the circular economy, IARFE Day. It was very impressive and insightful. I am curious about 'how IoT and Lean techniques are useful for waste management?'

Furthermore, I would like to work with you as I will be graduated this July 2021. I would be happy to join you on this sustainable journey.

Best Regards,

--
Raj Bir Kumar (Matrikelnummer: 572549)
Hochschule für Technik und Wirtschaft (HTW) Berlin
Treskowallee 8
10318 Berlin
Raj.Kumar@Student.HTW-Berlin.de | www.htw-berlin.de

Query regarding Building Deconstruction for Master Thesis 2021 - Google Chrome
mail.metropolia.fi/owa/projection.aspx

Query regarding Building Deconstruction for Master Thesis 2021

Raj Kumar
Fri 7/23, 5:47 PM
vaaka.vantaa@purkupiha.fi

Sent Items

Dear Purkupiha group Team,

I am writing this mail regarding awareness and usefulness of deconstruction for better habitat and society. My Master Thesis topic is Application Lean Techniques and BIM in Building deconstruction.

I would be very grateful if you give the short answer of my some curiosities. These are:

1) Do you use BIM and Lean techniques (reducing waste generation and improve work quality during the process) for the deconstruction of your projects? is it helpful to fix the work quality of the organization?

2) Is currently, the deconstruction methods and processes are flexible/smooth?

3) Which BIM tools you are using for dismantling/deconstruction?

4) Which informations do you need before applying BIM for the deconstruction?

5) What are your expectation from BIM and Lean in the near future?

6) Which BIM tools, do you think will be helpful but not evolved yet for deconstruction purposes?

7) In terms of cost-benefit and market, how far did we achieve and to what extent we can move forward?

I believe the above-mentioned queries will encourage me to work as an architect in the near future. I really will be thankful to you for your time, knowledge and expertise related to these amazing practical subjects.

Best regards

--
Raj Bir Kumar

Gmail

Rajbir <masterrajbir@gmail.com>

Query regarding Deconstruction of Houses

1 message

Rajbir <masterrajbir@gmail.com> Fri, Jul 16, 2021 at 11:13 PM
To: ussupportcenter@habitat.org

Dear Habitat for Humanity International,

I am writing this mail regarding awareness and usefulness of deconstruction for better habitat and society. I am an admirer of your work and working on these issues.

I would be very grateful if you give the short answer of my some curiosities. These are:

1) Do you use BIM and Lean techniques (reducing waste generation and improve work quality during the process) for the deconstruction of your projects? is it helpful to fix the work quality of the organization?

2) Is currently, the deconstruction methods and processes are flexible/smooth?

3) Which BIM tools you are using for dismantling/deconstruction?

4) Which informations do you need before applying BIM for the deconstruction?

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I believe the above-mentioned queries will encourage me to work as an architect in the near future. I really will be thankful to you for your time, knowledge and expertise related to these amazing practical subjects.

Best regards,
Raj Bir Kumar
Berlin, Germany

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