BUILDING ASSET VALUATION IN A CIRCULAR ECOSYSTEM

A guide to circular trading and procurement

Submitted By

Name: Panjwani S. (*Siddharth*)

Student Number: 1324454

Email Address: siddharthpanjwani@outlook.com

TU/e Email Address: s.panjwani@student.tue.nl

Graduation Committee

Chair	prof. dr. ir. B. (Bauke) De Vries	b.d.vries@tue.nl
Supervisor	prof. dr. ir. P. (Pieter) Pauwels	p.pauwels@tue.nl
Supervisor	ir. H. (Hajo)Schilperoort	h.schoperoort@tue.nl

In partial fulfilment of the requirements of the degree Master of Science in Construction Management and Engineering at the Faculty of Built Environment, Eindhoven University of Technology for 40 ECTS defended publicly on 21 December 2022 in Vertigo 5.07.

The thesis has been carried out in accordance with the rules of the TU/e Code of Scientific Integrity. All information included within this document is public information.

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Preface

The "Building Asset Valuation in the Circular Ecosystem" thesis research is a small step toward information management in the building sector regarding circular procurement process. The objective is to help readers comprehend significance of building components in a building after its first life in the context of circularity.

The pandemic was a difficult period for everyone. The necessity of isolating oneself for a significant portion of the thesis work was problematic since it hindered the free exchange of information. Therefore, the importance of recognizing those who stood up and assisted on this journey is much greater than it would be under normal conditions.

The supervisors of the graduation project, Professors Pieter Pauwels and Hajo Schilperoort, provided continual support and constructive criticism that made this work possible. Their expertise and patience in assisting with the thesis are exemplary. Professor Bauke De Vries, chair of the graduating committee, listened to the research ideas during the proposal and research phases and directed the research activity in the correct path. At TU/e, the support of non-academic individuals has been enormous. Ms. Ingrid Dekkers, Ms. Josee Pulles, Ms. Marlies Strieder, Ms. Mirjam Hagoort, Ms. Martje van der Horst M.Sc., Ms. Virginie Kuppens, and Ms. Hedwich van Engelen were among the graduation group members who assisted with the organization and visual representation of the research project.

In addition, Mr. Bob van Bronkhorst, Mr. Pablo van Den Bosch, and the other three interviewees provided an opportunity for an insightful conversation that set the groundwork for this project. Ms. Aditi Mathur contributed to the transcriptions. Mr. Selahattin Dulger, Ms. Silvia Taurer and others helped in fixing faults of the survey conducted for the study. In addition, the survey respondents who donated their time to the study were a tremendous asset. Mr. Dulger further provided great insight into the workflow involved in creating and using point clouds. Mr. Soheil Derakhshan gave pertinent criticism on the organization and timetable of the thesis. In addition, this project would not have been possible without the contributions of the researchers whose research and theories made it possible.

In addition, all the friends and coworkers in India and the Netherlands, Team CASA and ESA, helped finance and sustain life at TU/e by offering opportunities to work on other projects. Also, all the doctors in the Netherlands and India assisted in addressing the health difficulties during the research project.

Last but not the least, my parents and brother made it possible for me to persevere with this endeavor and my education in the Netherlands.

The significance of your participation to this research effort cannot be overstated. Thank you!

Regards,
Siddharth Panjwani

Summary

Due to increasing demand and decreasing availability, the built environment and its raw material suppliers have become institutions and stakeholders respectively that must urgently align themselves with the regenerative cycles of the planet in which we live. The intelligent and environmentally responsible procurement of resources is a step in the right direction towards this vision. Hence. It becomes necessary to define a system that allows buildings' resources to be appraised and restored prior to their decommissioning and exhibit a cyclical pattern. The value of an asset, according to Damodaran (2015), is a prerequisite for making prudent property investment decisions. The asset's value determines the appropriate acquisition price. It is helpful when determining how to allocate capital and how much to pay in dividends. Moreover, Damodaran (2015) outlined three prerequisites for valuation: "a larger model is not always preferable because valuators experience input fatigue and produce irrelevant results," "valuation is not a simple science and is fraught with uncertainty," and "the stakeholder who employs the valuator should not introduce bias into the model." Taking these principles into account, the objective was to develop a procurement framework and its constituents that guide the value of building assets, such as systems, components, products, and materials, for their second use and, in turn, to create a circular ecosystem where asset value is retained whenever possible. This, in turn, can contribute to the development of measurable, transparent, and quantifiable criteria for second-use procurement.

To propose a circular procurement framework, it was crucial to understand the industry's perspective on circularity as a concept. This was accomplished by conducting interviews. Sustainability and circularity were frequently associated with or confused with one another. To dispel this misconception, the United Nations' adopted sustainability goals have been highlighted. Numerous concepts that appear to indicate circularity were examined. Additionally, circularity definitions were examined using criteria derived from prior research to better comprehend them. At its core, circularity is about minimizing waste and utilizing resources ethically while maintaining consumption within the constraints that sustain life on earth by closing loops. In addition, it was discovered that the circularity and circular actions of an organization can take on a variety of forms, depending on the system it is focusing on and the bias or purpose that organization brings to the table. This fluidity may have a reverberating effect on the elements of the circular system or the surrounding environment. Therefore, the circular procurement process (CPP), which encompasses multiple stakeholders and processes, is the circularity scope for this project. All of this boils down to the standard trade scenario in which a vendor sells a product to a customer via a broker-facilitated process. This serves as the foundation for this investigation.

Therefore, the first step was to examine the CE butterfly diagram in the context of CPP. Additionally, current circular procurement frameworks and common business models (CBMs) were investigated. On this basis, organizational and societal influences on stakeholders, namely a buyer and a seller, and some buyback principles were investigated. Using a survey and review of the relevant literature, the varied characteristics and preferences of stakeholders based on whether they are the seller, or the buyer have been investigated. This resulted in the establishment of CPP elements that can guide the decision-making process of the ecosystem. Based on the CPP elements and its emphasis on building and its constituents, the search for relevant circularity indicators were done. This search resulted in the categorization of CPP indicators according to their use by sellers, buyers, processes, and medium to make pertinent decisions in a circular ecosystem. The most important aspects of CPP valuation were discovered to be exit scenarios, quality, market demand, disassembly potential, and lifecycle sustainability analyses of diverse building assets (LCSA). Although LCSA examines the social, environmental, and economic effects of a system, only the economic and environmental effects were investigated. This resulted in the creation of the concept diagram for the framework. For a building asset to be circular, it is necessary to comprehend its value within a circular

framework that enables urban synergy, so that its value can be restored using various strategies while monitoring its impact on the environment, the business interests of building stakeholders, the economy, and society in the present and future. Based on this, an investigation was conducted into the current end-of-life procedures in the built environment, with a focus on demolition and deconstruction. Prior to demolition or deconstruction, the site is planned and inspected, and then building components are either discarded or sold. This resulted in the design of process diagrams of a near-reality CPP ecosystem that permits the adoption of both demolition and deconstruction methodologies to optimize a building asset's exploitation for its next life, with a primary emphasis on online resource trading.

A site and inventory inspection database, an exit scenario and resource recovery plan, a partial deconstruction plan, and an online marketplace for resource trading are the principal deliverables of the ecosystem. These are discussed in detail in Chapter 5. All four deliverables constitute of asset passports that have different purpose based on the task at hand. The site and inventory section addresses team composition, interactions between the site and inventory inspection team members and their work, the mobile application, the database, and the visual quality framework. Exit scenario and resource recovery necessitate planning and preparation for resource recovery, as well as analysis to create a strategy for resource recovery. It includes the use of BIM processes to generate a product passport based on information from the site and inventory database, as well as the formation of external databases to conduct analyses. These analyses are based on the needs of stakeholders and employ CPP indicators relevant to sellers. Mandatory evaluations include the potential for asset disassembly, a product exit scenario, an analysis of market demand, and a calculation of residual value. It is critical to calculate environmental and economic impacts using LCA and LCCA. It is necessary to utilize BIM 4D and 5D capabilities to create a WBS, CBS, and OBS while developing a partial deconstruction plan. For resource trading, the use of QR codes to handover product information during trade was recommended. An analysis of existing online marketplaces to create the ideal online marketplace for used goods was done. The proposed trading platform should consist of fourteen key factors proposed through this research. Also, the marketplace can utilize CPP indicators pertinent to online medium and buyers.

The research is investigative by design. During several levels of deconstruction, CPP employs the notions of circularity and sustainability. It is possible to perform additional research on LCA and LCCA to better include them into the framework. Also, it was found that CPP indicators and circularity indicators are distinct. Since the research spans the whole deconstruction phase of a building, including the resource trading process, it was challenging to validate the complete framework through a single case study. Thus, crucial aspects of the research have been designed and offered based on existing solutions. While this does not suggest any new methods for calculating the indicators in question, it does indicate that the framework can be implemented with the help of the available resources and data. All four deliverables have their own unique set of requirements for system design of possible applications that can ease the decision-making process for the stakeholders involved.

Abstract

Due to rising demand and shrinking supply, the built environment, and its raw material' suppliers must align with the world's regenerative cycles. The aim of this research is to create a circular procurement framework that determine the value of building asset at its end of life and preserve that value. It thus creates a transparent and measurable standard for circular procurement process, thereby reducing waste and optimizing resource use. In a CPP, a product goes through a process chain when exchanged between seller and buyer through an online marketplace. CPP considers exit scenarios, quality, market demand, disassembly potential, and LCSA of a building asset.

With an emphasis on demolition and deconstruction, the present end-of-life practices in the built environment were investigated. The ecosystem's major deliverables include a database of site and inventory inspections, an exit scenario and resource recovery plan, a partial deconstruction plan, and an online marketplace for resource trading. A vital part of making the proposed framework work is making sure that the asset information for each deliverable is included in the passport for that deliverable. The site and inventory section addresses team composition and relationship between the team members and delivers a site and inventory database, along with a visual quality assessment framework. Exit scenario and resource recovery requires planning and preparation for resource recovery, as well as assessment requirements to establish a resource recovery plan using indicators relevant for sellers. The utilization of BIM 4D and 5D capabilities to form a WBS, CBS together with an OBS is crucial for producing a partial deconstruction plan. For resource trading, QR codes are recommended to handover product information during trade. A review of existing online marketplaces was conducted to recommend the most appropriate platform for used goods. It encompasses fourteen key parameters, guided by CPP indicators pertinent to the online medium and buyer.

The framework proposed in this research aims to use existing tools and indicators to realize a CPP. It also incorporates essential requirements and BIM concepts that can form the basis for the system design of applications that can ease the decision-making process of the stakeholders in a CPP.

Keywords: *Circular Procurement, Deconstruction, Lifecycle Analysis, Quality, BIM, Online Trading*

List of Abbreviations

ABBREVIATION	FULL FORM
2D	Two- Dimensional
3D	Three- Dimensional
AC	Air Conditioners
AEC	Architecture, Engineering and Construction
BCAM	Building Circularity Assessment Model
BIM	Building Information Management
BIM 4D	Time based information takeoff using BIM tool
BIM 5D	Cost based information takeoff using BIM tool
BPMN	Business Process Model and Notation
BWPE	BIM-based Whole-life Performance Estimator
C2C Air	C2C Clean Air and Climate Protection
C2C Material Health	C2C Material Health Assessment Methodology
C2C Product Circularity	C2C Circular Product
CAD	Computer Aided Design
CBM	Circular Business Models
CBS	Cost Breakdown Structure
CDW	Circular and Demolition Waste
CE	Circular Economy
CEBI	Circular Economy Benefit Indicators
CEI	Circular Economy Index
CET	Circular Economy Toolkit
CEV	Circular Economic Value
CI	Circularity Index
CICS	Construction Information Classification System
CI/Sfb	Construction Index/ Samarbetskommitten for Byggnadsfragor
CP	Circular Pathfinder
CPP	Circular Procurement Process
COBie	Construction Operations Building Information Exchange
DBB	Design, Bid, Build
DB	Design Build
DP	Disassembly Potential
ECI	Environmental Cost Indicator
ECVR	Eco Cost Value Ratio
eDim	Ease of Disassembly Matrix
EDT	Effective Disassembly Time
EEI	LCA- Eco-efficiency index
EER	Economic-Environmental Remanufacturing
EIA	Energy Investment Allowance
EOLi	End of Life Indices
EOLix	End of Life Index
EPD	Environmental Product Declarations
GDP	Gross Development Product

GPP	Green Public Procurement
Graph-DB	Graph Databases
GRI	Global Resource Indicator
IFC	Industry Foundation Class
IoT	Internet of Things
IPD	Integrated Project Delivery
JSON	JavaScript Object X Notation
KPI	Key Performance Indicators
LASER	Light amplification by stimulated emission of radiation
LCA	Lifecycle Assessment
LCA - CPI	LCA- Circular Economy Performance Indicator
LCC	Lifecycle Cost
LCCA	Lifecycle Cost Assessment
LFI	Linear Flow Index for Product Families
LI	Longevity indicator
LOIN	Level of Information Need
MCI	Material Circularity Indicator
MDI	Material Durability Indicator
MEP	Mechanical, Electrical, Plumbing
MFA	Material Flow Analysis
MIA	MilieuInvesteringsaftrek
MIS	Multi-dimensional Indicator Set
MKI	Milieukostenindicator
MPG	MilieuPrestatie Gebouwen
MPV	Material Price Variance
MSCR	Material Supply Chain Risk
NIBE	Dutch Institute for Building Biology and Ecology
NL/SfB	Dutch Samarbetskommitten for Byggnadsfragor
NMD	Nationale Milieu Database
No-SQL	Not Just SQL
O&M	Operation and Management
OBS	Organization Breakdown Structure
PBL	Netherlands Environmental Assessment Agency
PCA	Property Condition Assessments
PCI	Product Circularity Indicator
PLCM	Product Level Circularity Metric
PRDI	Product Recycling Desirability Index
PRecI	Potential Recycle Index
PReuI	Potential Reuse Index
PR-MCDT	Product Recovery Multi-Criteria Decision Tool
QA	Quality Assessment
QC	Circularity of Material Quality
RCC	Reinforced Cement Concrete
ReF	Remanufacturing Framework
ReM	Remanufacturing Metrics
REPRO	Remanufacturing Product Profiles

REV	Retained Environment Value
RP	Reusability Potential
RPI	Reuse Potential Indicator
RVI	Residual Value Indicator
SCI	System Circularity Indicator
SDGs	Sustainable Development Goals
SQL	Structured Query Language
TLCM	Total Lifecycle Cost Model
UN	United Nations
WBIT	Web- based Inventory Management Tool
WBS	Work breakdown structure
WEEE	Waste Electrical and Electronic Equipment Regulation

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the **utilization of renewable or directly reused or upcycled resources**. The **recovery** of usable resources from reused or recycled materials is another component. In addition, it is quite typical to **extend the service life** of a product by repairing, updating, and reselling it. **Sharing** resources and utilizing items as a service are further ways in which businesses can create a CPP ecosystem.

Furthermore, based on literature research on the organizational and business aspects, some conditions are necessary for CPP to happen. There should be national or regional policies surrounding CPPs, or the top-level managers of an **organization should be interested in participating** in one. Contractual agreements should reflect CPP's policy objectives. In addition, before an organization participates in a CPP, **significant knowledge retention and exchange regarding CPP** and **training of relevant CPP actors** should occur. Also, in addition to focusing on the lifetime of a product, its environmental, economic, and societal impact, its quality, and monetary value, a competitive dialogue mechanism should exist to mitigate the risks associated with circular procurement. When the circular procurement process is broken down into a transaction process amongst the different stakeholders, there is a better understanding of how the framework could be approached and which indicators could be used to facilitate decision-making. Once the conditions have been established, it is easier to comprehend the resource flow in a CPP.

In the best case, a CPP is nothing more than a procurement process that involves buyers, sellers, a product, and a process that they go through to complete a transaction over a certain medium. A buyer can be a new buyer, an established supplier with no ownership or sharer, or sharer. Also, many people in the construction industry, like clients, architects, wholesalers, and real estate developers, can influence buyers during the transaction process. A seller may be the owner of the facility or the owner of the product. It is important to keep in mind that a seller can be affected by other people in the industry, like local suppliers, installation companies, and demolition and recycling groups.

For a successful CPP transaction the following considerations are crucial. First, a successful transaction can occur in a variety of ways depending on the business strategies of the involved parties and there must be presence for circularity clauses in **contractual agreements between stakeholders**. Second, sellers must be mindful of the time and **additional costs that may arise when selling their products**, and they must implement lucrative business strategies that support their long-term organizational goals. Third, to launch a circular purchase, the **buyers must be socially conscious and have an authoritative position** and relevant contacts within the firm. The final essential component is the **product itself**. There are many elements that characterize a product. But a product 's CPP's success is determined by **product's quality, durability, ease of assembly and disassembly, environmental impact, and market demand and its exit scenarios apart from its economic value.** Hence, it is crucial to comprehend how these features and relevant concepts can be utilized to complete a CPP. There have been many indicators for circularity based on the context. Based on investigating 78 proposed indicators (Appendix D / Chapter 11)that entail building and its constituents as scope, 50 indicators were deemed relevant for the CPP elements that are under categories of buyer, seller, medium and a process. Furthermore, it was found that the exit scenario of a product, lifecycle (environment and cost) assessment, market demand and supply of the product, quality and residual value of the product are essential elements for CPP and concepts like disassembly potential, material passports, bill of materials and more along with them can constitute circular procurement ecosystem.

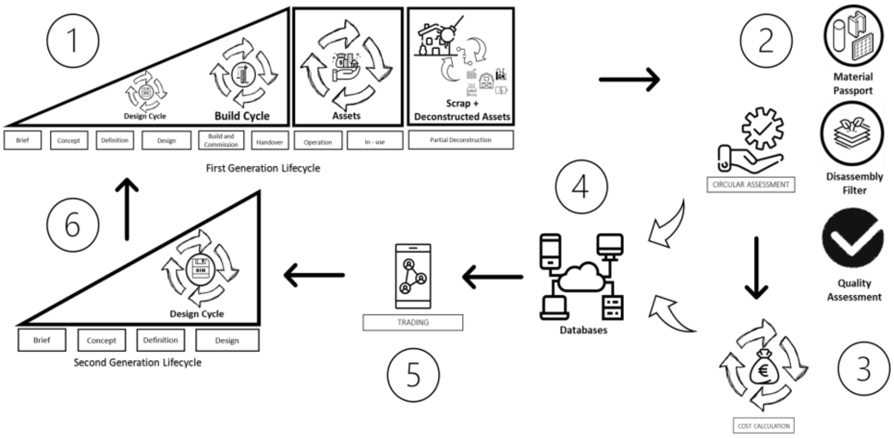

FIGURE 33 CONCEPT DIAGRAM FOR CIRCULAR ECOSYSTEM

Figure 33 showcases the conceptual diagram for the CPP in a circular ecosystem that encompasses these recurring themes. There are six important milestones that a material or a product must go through to close the loop in a circular ecosystem. The building product and its constituents at the end of its first-generation use should be removed from the building and broken down (if necessary) in a way that are relevant for disassembling easily and smartly. Also, it is important to have all relevant product and material information such as its quality, its impact on environment and technical information along with some relevant circular assessments. The information is stored in databases to be used while trading. Once determined the aspects of disassembly and quality verified, it is important to regulate the price of the second-hand product through some cost calculations. This is further provided in a trading platform where the items, recovered in value, are traded for their second life and the cycle continues. This trading can take forms based on CBMs as established in section 3.4.4 such as circular inputs, resource recovery, sharing platforms, product life extension and product as a service.

In the next chapter, deconstruction and demolition is investigated in more detail to understand how and when the milestones mentioned in the concept diagram (Figure 33) can be retrieved and how they might vary based on the processes involved within the scope of this project.

4. Chapter 4: Building Asset Lifecycle

4.1 Introduction

An asset is an item, thing, or entity that has potential or actual value to an organization, according to ISO (2018). In addition to tangible assets such as machines, property, raw materials, and inventory, an organization's assets can also include intangibles such as royalties, patents, and other intellectual property. A building is an asset for the owner or real estate developer in this regard. With the advent of circularity, the perception of a building as an asset is shifting, resulting in the emergence of new business models and practices.

4.2 Building Lifecycle in a Linear Ecosystem

Buildings and infrastructure projects alike use a lot of energy and materials, and the construction industry has always been one of the biggest consumers in these categories. This endeavour necessitates time, money, and engineering expertise. Such a product requires decades to demolish. But a building is not a static thing that never needs repairs. It is a product that requires an endless supply. Despite a limited but usually long lifespan, its value fluctuates despite being an asset for numerous stakeholders. According to Amadi-Echendu (2004), the lifecycle analysis of an engineering asset such as a building can demonstrate its fluctuating value over time.

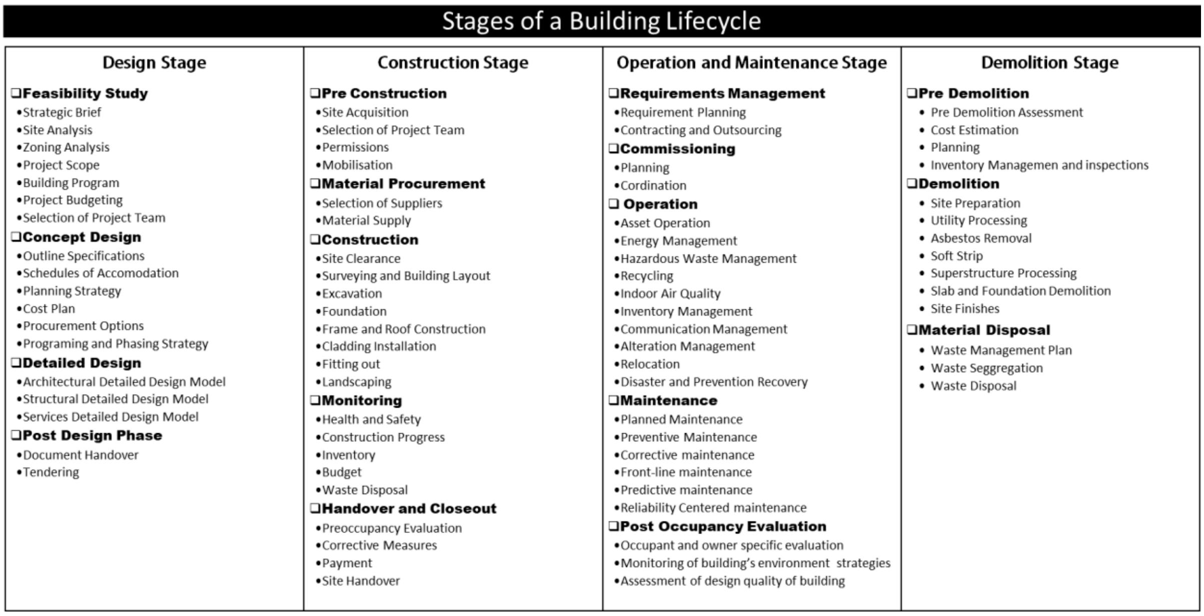

FIGURE 34 STAGES, PHASES AND PROCESSES INVOLVED IN A BUILDING LIFECYCLE

Many scholars have classified the building lifecycle in categories that fulfil their own research purpose. According to Ngwepe & Aigbavboa (2015), there are six life cycle stages of building, namely, raw material extraction; manufacturing; construction; operation and maintenance; demolition; and disposal, reuse, or recycling. This division was done to highlight the environmental impact of each stage. According to Kwok et al. (2016), the lifecycle of a building is divided in five stages, material extraction and manufacturing, construction, building life, operation and maintenance and end of life to structure a comprehensive carbon-emission framework for a building. Traditionally, a building is stated to have four life cycle stages shown in the figure below namely design, construction, operation and maintenance and demolition stage as shown in Figure 34 and explained in Appendix F (Chapter 13).

Based on the Figure 34 and the other categorizations done by Kwok et al (2016) and Ngwepe & Aigbavboa (2015) , a key element that is found is that a building lifecycle comprises of the various phases and processes which are divided into stages based on the system and the surroundings set by the concerned stakeholder(s). These lifecycle stages comprise of a combination of complex parallel and concurrent processes that involve many stakeholders. As highlighted in the study by Ustinovičius et al (2015), the stakeholders and their contributions in these stages are nuanced and complex, involving not only the construction and manufacturing industries, but also the information industry, human resource industry, and others. This makes it considerably more difficult to comprehend the total impact of a building on the available resources and on the stakeholders involved. Thus, it is essential to define a proper system boundary when developing a framework for CPP, as it is necessary to have a system that is easily comprehensible and monitorable and fits the research's scope.

4.3 From Demolition to Deconstruction

4.3.1 Building Element as an Asset

In accordance with Section 4.2, to comprehend building value and achieve the goal of this study, we must define an easy-to-use system. Because this study focuses on building elements and their applications in a circular ecosystem, the system boundaries become clearer when we consider a building as a reserve of components with their own production lifecycles.

A building component is created by extracting, manufacturing, utilizing, maintaining, building, and reusing raw materials (if possible). This method is more straightforward and makes understanding stages of building components independent of the building. By analyzing building components as assets rather than the entire building, the complexity of the construction industry's transition to a circular economy can be reduced. Building parts may have more than one lifetime and can be used as assets by one or more organizations over time, unlike buildings, which only last for a certain amount of time as they progress through their various stages.

However, because the construction industry is plagued by stagnant data collection and standards sources, the framework proposed in this project employs a hybrid approach. Based on the data available, it tends to regard these elements as a single entity or a collection of entities. This method is like the hybrid method proposed by Kwok et al (2016), to calculate carbon emissions over the entire lifecycle of a building, which combined top-down and process methods.

As a result, building components can be considered building assets. Because the research is focusing on the procurement of building materials and products after their first life, it is critical to define a circular building asset. Kirchherr et al. (2017) define circular building assets as:

> "For a **building asset** to be circular, it is important to understand its value in a circular framework that enables urban synergy such as its **value can be restored** using different strategies while monitoring its **impact** on the **environment**, building stakeholder's **business interest**, **economy**, and the society at **present** and in the **future**."

4.3.2 Decomposition of Building Elements

When buildings are seen as a complex collection of assets coexisting in a dynamic manner, it is difficult to explore and assess these assets, as indicated previously. To reach from the building level to the material level and assess them for CPP, it is necessary to breakdown a building according to specific system classification and boundary conditions. Building decomposition and abstraction is used to tackle the problem as shown in Figure 35.

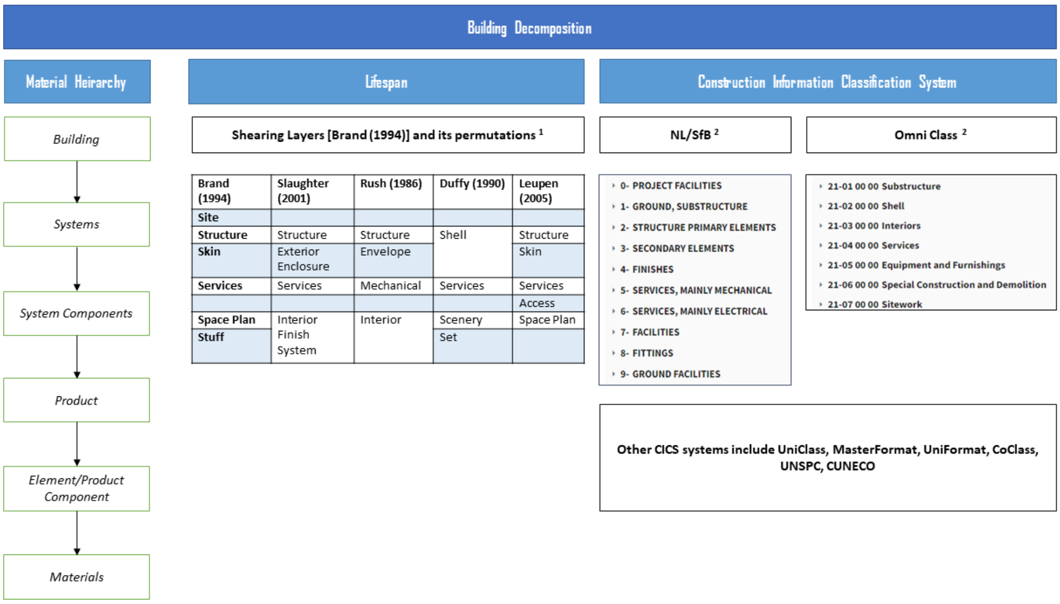

FIGURE 35 MATERIAL HIERARCHY, SYSTEM DECOMPOSITION, ABSTRACTION (J. VERBERNE, 2016), 1: (SCHMIDT III ET AL., 2011B), 2:(MADASTER, 2020)

Lifespan

Shearing Layer is a term coined by Frank Duffy that Brand (1994) has used to define an abstract decomposition system that constitutes support and infill and is based on the principle that each system constitutes a different lifespan. Regardless of the 'system' level that is followed, it is essential to recognize that their lifespans vary, which is a crucial factor to consider in terms of cycle length. It can be the time that building assets meet technical requirements *(technical lifespan),* the time that building assets function properly *(functional lifespan)*, the time that building assets are profitable to maintain *(economic lifespan)*, or the time that a building asset looks good *(aesthetic lifespan).*

Duffy, (1990) stated four shearing layers of a building at 'system' level. The first layer is a *shell* which is the traditional structure of the building with a lifespan of around 30 to 50 years. Then there are *services* such as cabling, plumbing, air conditioning that need replacing every 15 years. The third one is *scenery* which comprises of layout of partitions and dropped ceiling that last 5 years. Then there is the layout of furniture that might change every few months, weeks, or even more frequently. This was termed as *set* and represents the last layer of the building and the easiest to remove at time of deconstruction.

Brand (1994) expanded upon this idea and proposed six layers of division at a 'system' level as shown in Figure 36. There is *site,* which is the geographical setting, urban location, and legally defined lot and is stated to have an unlimited lifespan. Then comes *structure* which consists of foundation and load-bearing elements and can last from 30 to 300 years. In addition to that there is *skin* which is all exterior surfaces with a lifespan of 30 years approximately. Like Duffy, (1990) , Brand (1994) also included the layer termed as *services*. This layer consists of installations, communication wiring, electrical wiring, plumbing, sprinkler, and HVAC. Based on the constituents these last from 7 to 15 years. Apart from that there is *space plan* which is the interior layout such as walls, ceilings, floors, and doors which have a life ranging from 3 to 30 years and there is *stuff* like furniture, chairs, desks, phones, pictures, lamps which may or may not last more than a year. According to Schmidt III et al. (2011), Shearing Layer have other iterations proposed such as in the research works by Slaughter (2001), Rush & American Institute of Architects (1986), and Leupen et al (2005).

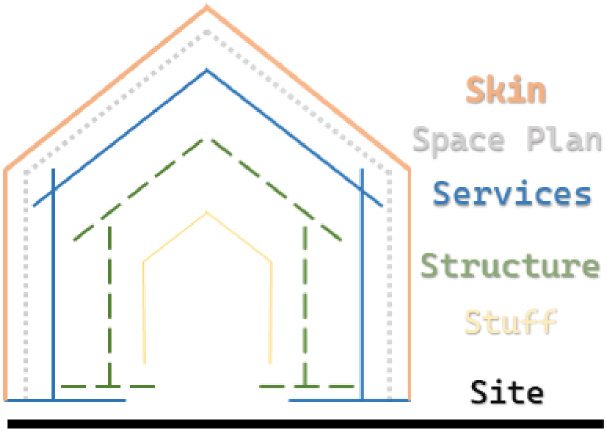

FIGURE 36 SHEARING LAYER

Construction Information Classification System

According to NATSPEC (2022), the conditions for classification can be of two forms.

- Classifications in a "hierarchical/enumerative" scheme are arranged in a hierarchy, with smaller categories nesting beneath larger ones. This system is the result of a division based on specific characteristics. As division continues, hierarchical classification "lists" or enumerates complex subjects.
- In "faceted" classification, each item is understood from multiple conceptual perspectives. These perspectives are referred to as Tables. The subjects within each table/aspect of a facetted system are also organized hierarchically.

It is crucial to keep in mind that the selection of a classification system is not based on the complexities of abstraction, but on the classification's intended purpose. Also, a good classification system should have consistent terminology and use controlled language. The notation used at the last step of the classification system should be a short, clear subject identifier that makes it easy to move navigate through the classification system.

There are many classification systems. For instance, NL/Sfb in the Netherlands; OmniClass, UniFormat and Masterformat in USA; UniClass in UK; Cuneco Classification System in Denmark; Talo in Finland; CoClass in Sweden; NATSPEC in Australia and many more. In this research, the focus would be on NL/Sfb and OmniClass only.

NL/Sfb:

It is the most widely used faceted classification system for building components in the Netherlands. It is the Dutch version of the building classification system CI/SfB. CI stands for Construction Index. It is in accordance with the ISO 12006-2 standard (NATSPEC, 2022). SfB stands for Samarbetskommitten for Byggnadsfragor, the initials of a Swedish committee which was assigned to formulate a construction classification arrangement for three key construction industry books: a price book, a specification book, and a product book (Leen Kang et al., 2000). In BIM and CAD systems, these open standard layers and objects are used to code, and NL/SfB is used to organize information from suppliers. The classification comprises of five tables as shown in Table 17. The most used table is Table 1 for functional building elements and hence it is also called Elementenmethode in Netherlands.

TABLE 17 NL/SFB

TABLE NAME	DESCRIPTION
Spatial Facilities (Table 0)	It helps in classifying spaces in and around buildings.
Functional Building Elements (Table 1)	It classifies functional building parts
Construction Methods (Table 2)	It classifies construction methods
Construction Materials (Table 3)	It classifies materials
Activities, Characteristics and Properties (Table 4)	It classifies activities and requirements.

The notation uses combinations of numbers and letters, and this combination structure varies at every table.

OmniClass

It is a faceted classification used to structure data and to classify from multiple points of view. According to Afsari & Eastman (2016), it encompasses key elements of EPIC, ISO 12006-2, ISO 12006-3, MasterFormat and UniFormat for building lifecycle and project management for the construction industry. National Building Information Standard (NBIMS) developed by buildingSMART (Keady, 2013) is based on OmniClass. It also aligns well with the classification system used in Construction Operations Building Information Exchange (COBie). Thus, making it compatible with BIM. It uses 15 different ISO tables, each of which represents a different facet of construction information. Each table can be used independently to classify a particular type of information, or it can be combined with in other tables to classify an entity that is not included as shown in Table 18. OmniClass notation consists of numerical codes, generally of six digits. These can be extended by adding more digits after a decimal point. The notation is hierarchical (NATSPEC, 2022).

TABLE 18 OMNI CLASS TABLES (CONSTRUCTION SPECIFICATIONS INSTITUTE, 2020)

TABLE NAME	DESCRIPTION
Construction Entities by Function (Table 11)	*"These are significant, definable units of the built environment comprised of elements and interrelated spaces and characterized by function."*
Construction Entities by Form (Table 12)	*"These are significant, definable units of the built environment comprised of elements and interrelated spaces and characterized by form."*
Spaces by Function (Table 13)	*"These are basic units of the built environment delineated by physical or abstract boundaries and characterized by function."*
Spaces by Form (Table 14)	*"These are basic units of the built environment delineated by physical or abstract boundaries and characterized by physical form."*
Elements (includes Designed Elements) (Table 21)	*An Element is a major component, assembly, or "construction entity part which, on its own or in combination with other parts, fulfils a predominating function of the construction entity. A Designed Element is an "Element for which the work result(s) have been defined" (ISO 12006-2).*
Work Results (Table 22)	*"Work Results are construction results achieved in the production stage or phase or by subsequent alteration, maintenance, or demolition processes and identified by one or more of the following: the skill or trade involved; the construction resources used; the part of the construction entity which results; the temporary work or other preparatory or completion of work which is the result."*
Products (Table 23)	*"Products are components or assemblies of components for permanent incorporation into construction entities."*
Phases (Table 31)	*"A portion of work that arises from sequencing work in accordance with a predetermined portion of a Stage"*
Services (Table 32)	*"These are activities, processes and procedures relating to the design, construction, maintenance, renovation, demolition, commissioning, decommissioning, and all other functions occurring in relation to the life cycle of a construction entity."*

Disciplines (Table 33)	*"These are practice areas and specialties of the actors (participants) that carry out the processes and procedures that occur during the life cycle of a construction entity."*
Organization Roles (Table 34)	*"Organizational Roles are the functional positions occupied by the participants, both individuals and groups, that carry out the processes and procedures which occur during the life cycle of a construction entity."*
Tools (Table 35)	*"Tools are the resources used to develop the design and construction of a project that do not become a permanent part of the facility"*
Information (Table 36)	*"Information is data referenced and utilized during the process of creating and sustaining the built environment"*
Materials (Table 41)	*"Materials are substances used in construction or to manufacture products and other items used in construction."*
Properties (Table 49)	*"Properties are measurable or definable characteristics of construction entities."*

Material Hierarchy

'Building' Level represents the compositions of systems which represents the functional separations of building constituents. The 'systems' consist of 'system components' which together make up the systems such as finishing systems, enclosure systems, services, and others. These components comprise of various building 'products' that can be structural, architectural, or MEP product. An example would be a wall frame, door, or a window as shown in Figure 37. These products are further divided into 'product components or elements' such as a top plate, lintel, jamb stud, still trimmer, head trimmer in case of a kind of wall frame. These elements are composed of materials such as wood, steel, and other materials.

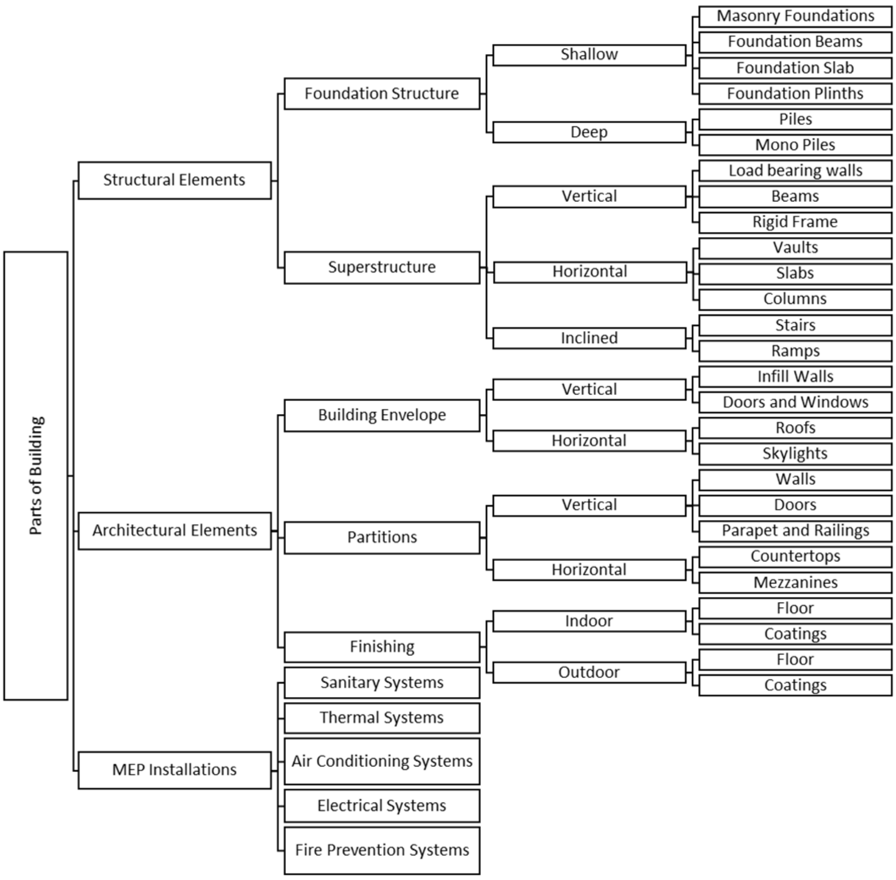

FIGURE 37 DECOMPOSITION BASED ON MATERIAL HIERARCHY

4.3.3 Demolition Practices in the Construction Industry

If we are to transit to a circular ecosystem where procurement of second-hand material is the norm, apart from assessing building's transformation capacity and decomposition in theory as stated in section 4.3.2, it is also essential to understand how buildings are decomposed in a real world system. The first step towards that is to comprehend the potential exit scenarios of a building.

According to Bertino et al. (2021), the building's end of life can be divided into four categories – maintenance, refurbishment, demolition, and deconstruction.

- Maintenance, which is constant over time, is quick and easy and cheap in most cases and entails repairing, renovating, and replacing parts of building without altering the overall volume or changing the utility of the building.
- Refurbishment is usually expensive and is done for heritage buildings. It usually restores a structure to a former better condition and can be retrofitted to a completely different utility.
- The most common end of life scenario is demolition as shown in Figure 38. It is very cheap and quick and easy to undergo as compared to the other scenarios.
- In a linear ecosystem, the deconstruction becomes part of demolition and is usually characterized with downcycling.

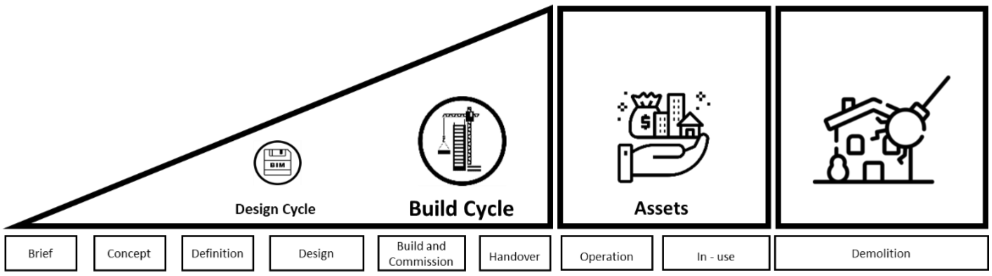

FIGURE 38 BUILDING LIFECYCLE IN A LINEAR ECOSYSTEM

In the building lifecycle, demolition is the most dangerous stage if not safely planned. It takes enough time to plan the work, conduct necessary audits, and adhere to national standards with effective information management. As stated in Appendix F (Chapter 13), the demolition phase is comprised of three phases: pre-demolition, demolition, and material disposal. Typically, this is the phase of a building's lifecycle that is the shortest. However, this does not imply that the processes involved in this stage are simple, as they require speed. On-site demolition takes less time than construction. In addition, site cleanup must be expedited due to the necessity of restoring access to infrastructure facilities and utilities, which may disrupt daily operations.

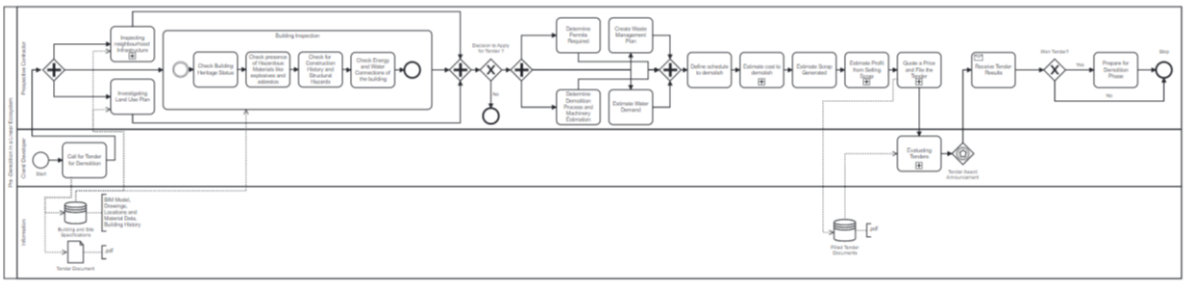

FIGURE 39 PRE-DEMOLITION PHASE IN LINEAR ECOSYSTEM

Pre-Demolition phase as shown in Figure 39 and in section 14.1 (Appendix) starts with a call for tender for demolition after a developer acquires a space or it has already been signed between an owner and contractor who have done business before. In any case a pre-inspection is usually done of the neighbor infrastructure and the land use plan of the area. Apart from that building inspection is also done. The intensity of it varies based on whether it falls into the first or the second case as stated above. For sake of convenience, we focus on a case before agreement has been reached between owner and a potential contractor.

For building inspection, the building heritage status is checked, the tender document is used to understand the time and like state of build and a visual inspection usually ensures the presence of hazardous material like asbestos or explosives that can cause a catastrophe during demolition process. Also, construction history and possible structural and demolition hazards are investigated apart from checking energy and water connections of the building. Risk assessment is a major step while focusing on tendering process for demolition. The information gained from that usually make the potential demolition contractor decide whether to apply for a tender or not and for decommissioning process. There are other factors that are considered while making the decision to apply for a tender to demolish like brand identity of the estate developer and reputation of owner, the need for contractor to land a contract and more.

Once a decision is made to go further, an investigation is usually done for the permits and the costs it would entail, a possible demolition process (explosions and crushers are usual way to go) and estimate of water needed to cope up with the dust and the machinery required for the process. Furthermore, a waste management plan with inclusion of ownership and trade of scrap (based on tender regulations) is estimated. Then a schedule along with cost of demolition is worked out along with the profit from scrap trade after identifying potential buyers. The scrap trade is done by either the demolition company or the owner based on tender rules. All this information is analyzed to quote a price. Safety and evacuation process is sometimes asked when involved with demolition of projects that deal with complicated terrain, neighborhood, or presence of hazardous materials. Based on the tenders received, an evaluation is made, and the tender is awarded to one of the contractors. The winner then prepares for further negotiation and demolition phase if everything is worked out and contract is signed.

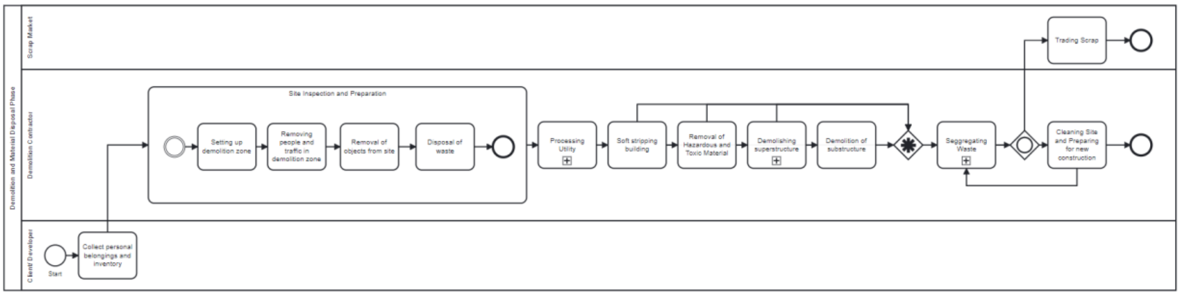

FIGURE 40 DEMOLITION AND MATERIAL DISPOSAL IN LINEAR ECOSYSTEM

During the demolition phase as shown in Figure 40 and in section 14.2 (Appendix), the owner is asked to collect personal belongings and inventory. Then a detailed site inspection is done to set up a demolition zone. People and traffic are restricted around and prohibited in the demolition zone. Objects are removed around the demolition site and the waste if any is disposed and scrap if any generated is recorded and sold. Afterwards, the water and energy lines are rerouted, and the soft strip of building (removal of accessories like door frames, windows, counters, furnishings to get the skeleton i.e., structure of the building) is done. This is followed or done parallel to removal of hazardous and toxic material.

This process is then proceeded by demolition of superstructure and substructure using various methods as planned before while taking proper care of the short term and long-term safety of the neighborhood. These processes happen in parallel and successive manner. The waste generated is segregated and sold for scrap or disposed of in a landfill or incinerated based on the waste disposal policies and permits of the municipality of the neighborhood.

According to Abdullah et al (2002), the demolition process usually can be categorized into three independent categories as shown in Table 19.

TABLE 19 CATEGORIES OF DEMOLITION

DEMOLITION TYPE	DESCRIPTION	TOOLS
Progressive Demolition	Controlled removal of sections of the structure while retaining stability of other structure. Good for Restricted Spaces.	Hand Tools such as impact hammer, diamond disc cutter, wire clipper. Machine tools such as Excavator attached with boom and hydraulic attachments, such as pulverizes, crushers, and shears. Balling using an iron ball and lifting mechanism
Deliberate Collapse	Removal of structural members to cause complete and safe collapse of all or part of a structure. Good for detached, isolated, level sites, where the whole structure is to be demolished with a big demolition zone.	Explosives, Rope Pulling
Linear Deconstruction	Dismantling of structure from top to bottom with reuse in mind. Used as part of renovation or modification work and to prepare the way for deliberate collapse. This process can maximize the use of resalable materials such as metal and concrete debris (to low value product) and subsequently reduce waste disposal costs.	Can be done by hand, machines, bursting, or hot cutting. Hydraulic excavators attached with pulverizers, concrete crushing, and screening machines, contractors' separate demolition debris.

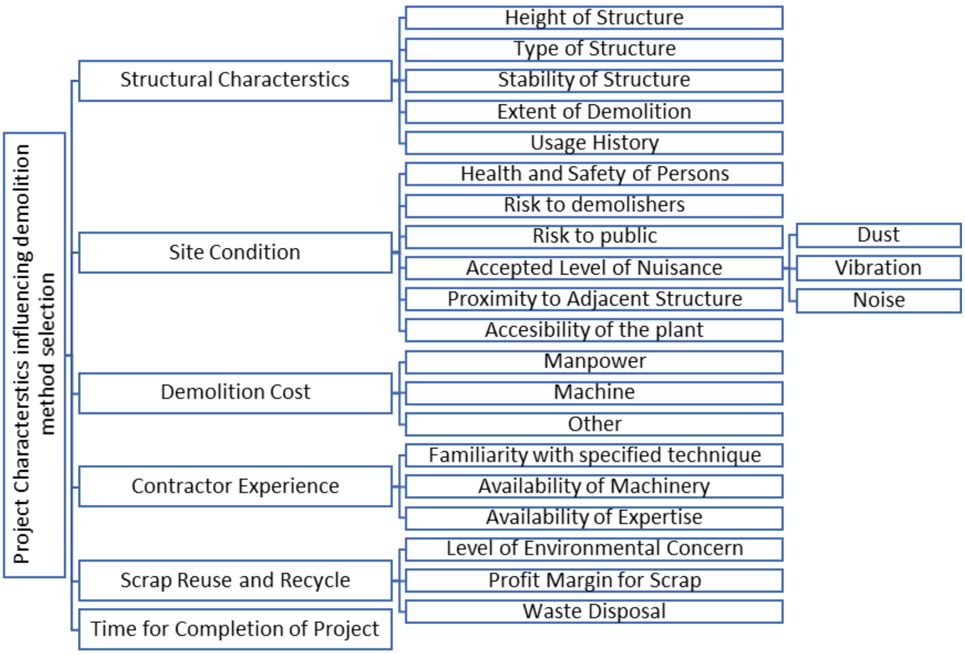

FIGURE 41 PROJECT CHARACTERISTICS THAT INFLUENCE DEMOLITION PROCEDURE SELECTION (ABDULLAH ET AL., 2002)

In a real-world scenario it is usually a combination of the processes as described above which are influenced by factors as shown in Figure 41. These characteristics have a significant impact on the type of demolition process used. In the case of a prestressed RCC structure, it is critical to select the appropriate cutters so that when the beams are removed with excavators, the structure does not collapse over the underlying area. When demolishing a concrete structure, it is critical to control dust, and the need for water is even greater. The identification and placement of explosives determine whether a deliberate collapse process is successful. Furthermore, the time between each detonated explosion can cause shockwaves and vibrations that can affect not only the substructure but also the surrounding neighborhood. The ability to generate profit by reselling scrap onsite as soon as a building component, such as a large shed, is improperly deconstructed can be drastically reduced, causing the contractor to suffer losses. The time it takes to manage and dispose of waste has an impact on the cost of maintaining the demolition zone. As a result, it is reasonable to conclude that the factors in Figure 41 have a significant impact on the demolition process and should be considered during the pre-demolition and tendering stages.

4.3.4 Deconstruction in a Circular Ecosystem

Introduction

As established already and further corroborated by Bertino et al. (2021), the built environment can be considered a key sector for the transition from linear to circular economy, contributing to resource efficiency, improvement in energy use during the lifecycle of buildings and better-quality sustainable materials, resource restoration and upscale utilization, and improved design. Section 4.3.3 established the current common end of life process of demolition and waste segregation. It also established a presence of linear deconstruction. To go circular, it is important to restore resources and upscale them to retain or increase its value. The most important aspect of this is to understand deconstruction in a circular ecosystem. It is also understood as 'construction in reverse', which is an ideal case for a building that is designed to be dismantled in parts while retaining the value of deconstructed assets, as established by Kanters (2018) and seen in Figure 45.

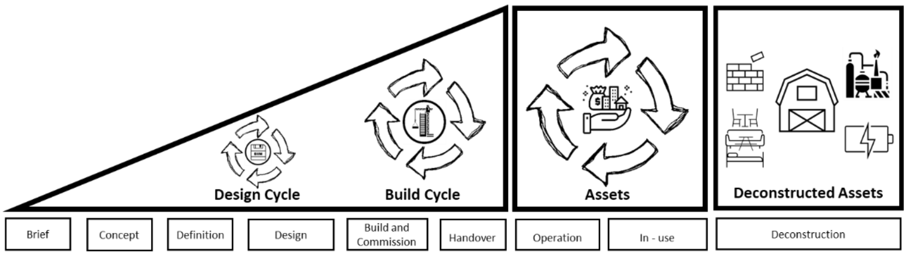

FIGURE 42 BUILDING LIFECYCLE IN A CIRCULAR ECOSYSTEM

Although deconstruction is not a mainstream constant, historical evidence suggests that it has been practiced since decades. Bertino et al. (2021) provide a good example for deconstruction's presence in the construction history. It is the Arch of Constantine in Rome, Italy whose parts date older than the arch's established construction period as shown in Figure 43. This showcases the reuse of parts of older buildings in newly constructed buildings.

FIGURE 43 THE RELIEFS OF THE ARCH OF CONSTANTINE, REUSED FROM BUILDINGS OF PREVIOUS EMPERORS (IMAGE BY DOMINIQUE DEVROYE FROM PIXABAY) (BERTINO ET AL., 2021)

In this decade as well, there have been buildings that have been deconstructed sustainably. For example, Circl Pavillion in Amsterdam, has interior space designed from material taken from other buildings. For instance, the movable walls are made from recycled aluminium and expanded metal, wall insulation is made from recycled jeans, window frames, hardwood flooring and internal wall partitions is taken from other demolition sites. Also, the wooden structures are connected using hollows and bolts and can be disassembled easily.

Deconstruction Prerequisites

Bertino et al. (2021) states that recent technological breakthroughs in BIM and photogrammetry along with industrial acceptance of concepts such as **digital twins, web-based inventory management tool (WBIT)**, **material passports** and **design for disassembly,** it is now feasible to reuse a building fully. The digital twins, WBIT, and material passports help in determining the extent to which a building can be deconstructed. And if the building is designed to be dismantled for reuse and recycle of its assets, then deconstruction can be possible. If these pre-existing conditions are satisfied, then a **deconstruction plan** can already be formulated for a building alongside its construction plan. A material passport with list of building elements, their complete description, and their possible end of life scenarios (as stated in section 3.5) for restoration of their value to enable re-entry in a dynamic material market. These **end-of-life scenarios** can be categorized into four umbrella categories as shown in Figure 44.

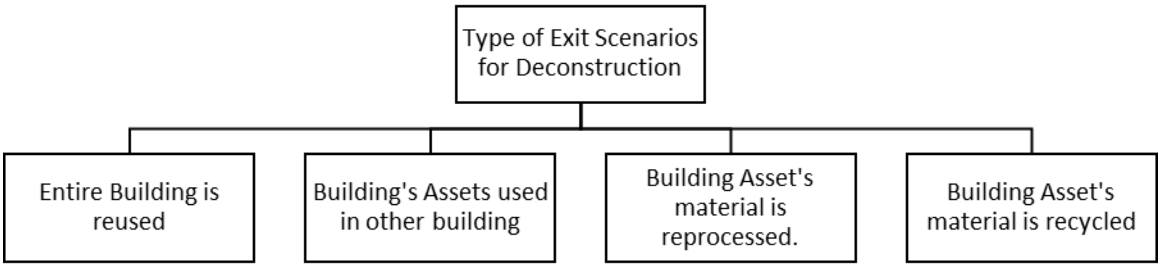

FIGURE 44 CATEGORIES OF EXIT SCENARIOS FOR DECONSTRUCTION (BERTINO ET AL., 2021)

The first type is where the building is moved to a new place with no waste generation. So, the building is deconstructed (with removing the foundation and/ or dividing building into sub- assemblies), transported, stored, and constructed. It is an expensive and rare process compared to the other two types. The second type is where components of the building are reused in other buildings with some, or no energy spent on reprocessing and refurbishment. It involves deconstructing components of building in sequence, transporting them to various locations based on the prospective users or storing them till they are not traded and then used for construction of other buildings. The third type is material reprocessing. The difference is that the energy used for refurbishment and reprocessing is usually high and the ideal condition is to upgrade the material. The only process that is new is repurposing as it requires external parties to restore or upscale the building asset. The fourth type is where the building asset is broken down into its raw materials and that raw material is used for another product. Based on the R framework (Figure 12), the first type is more favorable as compared to the fourth type. The combination of the latter three types is the focus of this research. However, it does not mean parts of the process established cannot be used for the first type of deconstruction.

Another important aspect is the **resource recovery plan**. It is essential for contractors to plan resource recovery strategies based on the available market options. According to (NAHB Research Center Inc. & Upper Marlboro MD, 2001), material recovered during structural or non-structural deconstruction will enter the **reuse market** via one of the following three methods: retail sales, on-site sales, or direct reuse.

- Outside of recycling, the most cost-effective solution is the on-site selling of recovered materials. Contractors provide resource-deconstruction agents with the cost and schedule associated with the removal of building materials. This minimizes contractors' resource recovery costs without adding labor or liability expenses. However, time constraints provide a substantial obstacle for on-site sales.
- Reclaimed materials, which can be directly reused, could assist a renovation contractor in meeting specific historic requirements that may be impossible to achieve with modern materials. For a new contractor, direct reuse aids in cost reduction. However, storage issues can prevent the reuse of resources from one project to another as the time between deconstruction and shipment for further use can impact the budget for deconstruction.
- The recovered materials are charged to subcontractors by deconstruction contractors who subcontract dismantling services. Subcontractors negotiate product prices with merchants in-person or online. These retailers can be for-profit or non-profit retailers, resulting in shared or transferred costs respectively.

According to Bertino et al. (2021), deconstruction also differs if the components involved are structural or non-structural. The difference is stated in Table 20.

TABLE 20 DECONSTRUCTION OF STRUCTURAL AND NON-STRUCTURAL COMPONENTS

CHARACTERSTICS	STRUCTURAL DECONSTRUCTION	NON-STRUCTURAL DECONSTRUCTION
Definition	(NAHB Research Center Inc. & Upper Marlboro MD, 2001) states that structural deconstruction is *"Dismantling of the structural building components that are an integral part of the building and contribute to its stability, such as beams and pillars for rigid frames and walls made by bricks for load-bearing systems."*	(NAHB Research Center Inc. & Upper Marlboro MD, 2001) states that non-structural deconstruction involves *"Recovery of non-structural components whose removal is not dependent on the structural integrity of the building and that are usually easy to dismount, such as doors, windows, and finishing materials."*
Machinery	Heavy	Simple Tools
Time Frame	Weeks	Days
Labour	Highly Skilled, Labour Intensive	Moderately Skilled, Limited Labour
Ease to accomplish	It is not always possible, depending on the construction technique used to build the building. It may change based on connection between the elements can be reversed or not	The building components can be removed without destructive approaches and additional structural support, such as bracing is usually not needed during the deconstruction operation.
Safety Conditions	High	Moderate

Salvaged Material	Framing Sheathing Roof systems Brick/Masonry Wood timbers/beams Wood rafters Floor joist system	Finish flooring Appliances/mechanical Cabinetry Windows/doors Trim Fixtures/hardware Fireplace mantels
Restriction on trading due to hazardous material	High	Moderate

As shown from Table 20, there is more complexity involved when deconstructing structural components as compared to non-structural components. Hence in a disassembly sequence, deconstructing the non-structural elements should happen first. Dismounting all the components such as appliances, windows, doors, and other finishing materials, which if removed do not cause the building to collapse. After the non-structural deconstruction, the structural deconstruction is done. It is usually realized from top to bottom, starting from the removal of the roof to get to the foundations to avoid the collapse of the building.

Another aspect is **the quality of material**. This is discussed in Section 3.5.Also, it should also be essential to understand the **environmental impact of reutilization** of the product The positive impact for salvaging second-hand product in terms of the energy saved by avoiding the energy saved during production of a virgin product creates a positive impact due to deconstruction.

The **presence of hazardous materials** in a product can have severe impacts on the environment, requiring restrictions on the resale of such products as stated by (NAHB Research Center Inc. & Upper Marlboro MD, 2001) . Many older structures are coated with lead and asbestos. Lead paint is commonly found on windows, doors, and trim. Lead-based paint removal may be necessary for architectural antiques and other significant non-structural items. During structural deconstruction, asbestos-containing materials may be detected when removing framing or sheathing. Asbestos can affect non-structural deconstruction because it can be found in fixtures like boilers and ovens. Hence, it is essential to incorporate inspection for hazardous material while doing site inspection.

Furthermore, it is essential to **check for necessary permits and regulations** for reuse to formulate resource recovery strategies as local code restrictions may not permit certain deconstruction methods over others.

Time constraint is a big issue while deconstructing a building. Hence, apart from **disassembly sequence**, the **ease to disassemble** a system or a product and its components also hold an important place. Ease to disassemble a system or a product is influenced by factors such as **time to disassemble** a system which in turn is dependent on the **transformation capacity of a building** or its disassembly potential. Another important aspect for deconstruction, according to Bertino et al. (2021), is the **access to deconstruction information** such as technical drawings and pictures, presence of as-built BIM model, database for identification of components, instructions to recycle and reuse. These elements have already been discussed in section 3.5. One of the key factors that influences all these is the type of connections. The connection type also influences the exit scenario of a building assembly and quality of building asset. For example, load bearing brick walls are usually connected using binder such as mortar, lime or cement and it is difficult to remove bricks and reuse them. Hence, they usually result in being downcycled and used to make roads. Even if the binder is removed chemically the bricks are usually not used as load bearing material and the process is time consuming. Hence, such factors must be taken care of. On the other hand, if the brick wall uses clay or concrete interlocking blocks with minimum mortar in a stretcher bond, then the assembly and disassembly is easier and cheaper. Other examples for better disassembly due to type of connections are wooden frames connected using nailing and interlocking, modular pre-stressed concrete blocks, steel frames connected using bolting, onsite RCC components segregated via localized and smart crushing.

Based on the aspects and information discussed in the previous sections and chapters, the deconstruction process can be divided into two stages. The first phase is Pre-Deconstruction phase (Figure 45), which comprises of processes to create a deconstruction plan and estimate the cost and time to deconstruct along with the de-constructability of the building. This phase also comprises of inventory inspection (Figure 46). The second phase is Deconstruction and Resource Recovery phase (Figure 47). This phase comprises of actual deconstruction and segregation of resources and their subsequent trading (after recovery if needed).

Pre-Deconstruction Phase

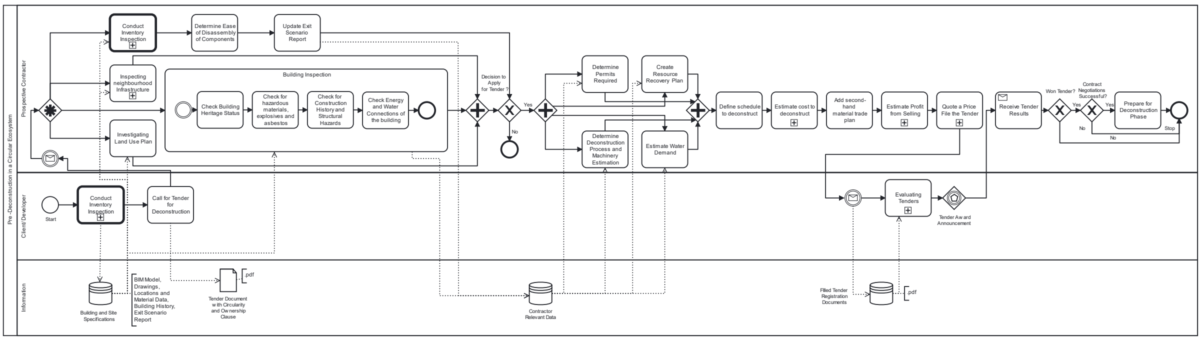

FIGURE 45 PRE-DECONSTRUCTION PHASE IN A CIRCULAR ECOSYSTEM

In the pre-deconstruction phase (Figure 45 and section 14.3), the client should order an inventory inspection before issuing tender for deconstruction. During the inventory inspection the building and site specifications should be provided. Such information entails some or all the building data, such as BIM model, 2D drawing, material location and technical information, building construction history and the exit scenario report for building assets. While issuing tender, it is important to include clauses for circularity expectations and ownership of deconstructed assets.

Then a prospective contractor can conduct their own building site inspection alongside inspection of neighborhood buildings and investigating the land use-plan. The building site inspection comprises of checking the building's heritage status, presence of hazardous and explosive materials, understanding construction history and structure hazards and end with investigating the energy and water connections of the building and presence of underground infrastructure that needs to be rerouted. This part is like the pre-demolition inspection as stated in Figure 39. The part where it differs is the decision to do their own inventory inspection based on the reports provided by their prospective client. Based on their own inspection, the prospective contractor can determine the ease of disassembly of components and update the exit scenario report.

Based on the inspection, the contractor can decide whether to apply for the project or not. If the answer is yes, then like pre-demolition phase, the contractor can determine what sort of permits are required for the process, determine the deconstruction process, and estimate the type of machinery, quantity of water and type of labor needed to execute the tasks. They are also required to create a resource recovery plan based on the ownership clause of the tender and circularity requirements of the client. Based on this, the prospective contractor can estimate the schedule and cost of deconstruction and profits from trading of building assets that they can get. This information is sufficient to quote a price and file for the tender. If the tender is rewarded, then contractor and client can negotiate and prepare for deconstruction phase.

As stated before, the difference between pre-demolition phase and pre-deconstruction phase is inventory inspection. The client as shown in Figure 46 (section 14.4) here can be both the owner/ real estate developer associated with the building or the prospective contractor based on who requires the services of inventory inspection team which comprise of surveyors, designers, and analysts.

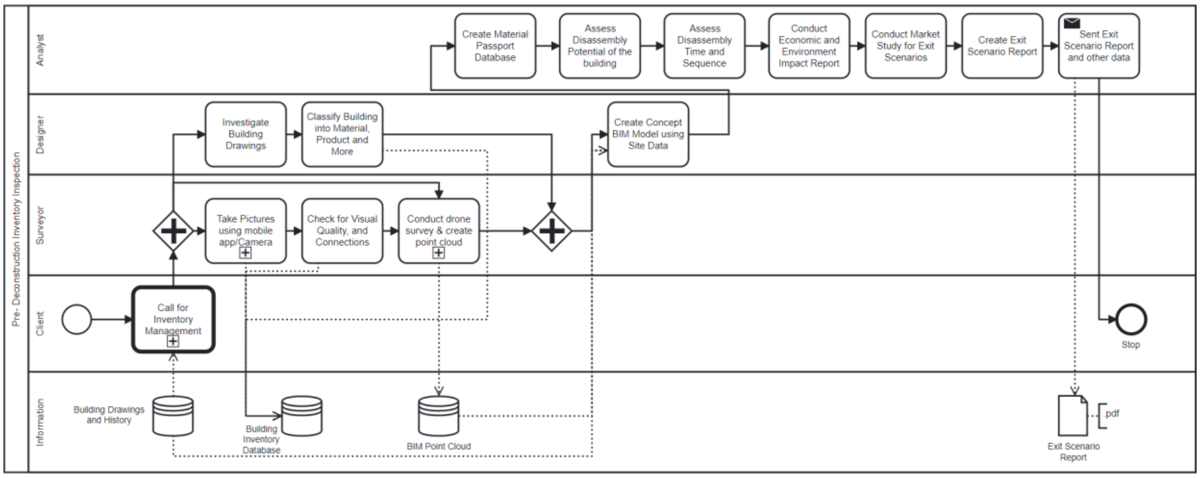

FIGURE 46 PRE-DECONSTRUCTION INVENTORY INSPECTION

Once the client calls for inventory management, the team of surveyors go for site visits and capture as much information about building components as possible using phone application, and/or drone survey. They also check for visual quality parameters and connections in the building systems. The information collected is given to the designers. They investigate the building drawings and other pertinent information such as point clouds and put them to make a BIM model or feed them in a data processing platform. The team of analysts uses the BIM model and/or the data processing application to constitute a material passport database. They also assess the disassembly potential of the building along with the time and sequence for disassembly. Furthermore, if required they can use the material passports to create an economic and environment impact report and investigate the market for restoration to create an exit scenario report. Once all the information is collected, processed, and analyzed, this is sent to the client for further use.

Deconstruction and Resource Recovery Phase

Once the tender is awarded and contract negotiations are completed the deconstruction and recovery phase start, as shown in Figure 47 and section 14.5. A detailed deconstruction plan is made, and the client is asked to collect personal belongings. This is followed by site inspection and preparation. This is like demolition phase as shown in Figure 40. This step constitutes of setting up a deconstruction zone, creating an onsite storage space, removing people and traffic in the zone, removing objects from sites based on contractual agreement if any. The step ends with preparing setup for quality inspection before the deconstruction work starts to examine the quality of assets before and after deconstruction to avoid disagreements with client if the asset is damaged.

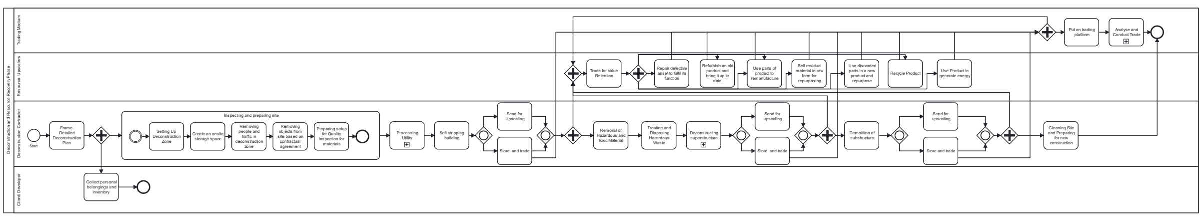

FIGURE 47 DECONSTRUCTION AND RESOURCE RECOVERY PHASE

Once finished, the utilities are processed to cut energy and water connections. The building is cleared of the non-structural elements and the material is either sent for upscaling or stored for trading. This step is followed by removal, treatment, and disposal of hazardous waste materials and then the superstructure and sub-structure is deconstructed based on the deconstruction plan. This does not mean that the inspection is done only after non-structural deconstruction. It is placed in this manner due to the higher impact of the presence of hazardous material on structural deconstruction. All these steps are followed by a quality inspection after deconstruction and then either storing the assets for trading or sending them for upscaling. The resource upscalers then upscale the building assets and then send them back to contractors or trade them based on the agreement with the contractors. At the end all the material is put on an online platform where it is analyzed and traded if entry requirements are met.

4.4 Conclusion

Circularity alters our perception of buildings as assets that have value for the owners, resulting in new economic models and behaviors. Building lifecycle stages are based on the system and environment specified by the concerned stakeholder (s). These lifecycle stages include complicated parallel and concurrent activities. The stakeholders and their contributions at various stages of a building lifecycle can be nuanced and may involve processes like the manufacturing and installation of products and systems, their maintenance of systems and managing related information, among others. This makes it harder to understand a building's impact on a region's resource capacity. Because this study is about building elements and how they are used in a circular ecosystem, the boundaries of the system become clearer when we think of a building as a store of systems and components that have their own production cycles. These can be regarded building assets in a CPP, where their value must be understood in a circular framework that facilitates urban synergy and where they can be restored in many ways while monitoring their impact on the environment, building stakeholders' economic interests, region's economy, and society of the present and the future.

When buildings are considered as a complex collection of dynamic assets, it is tough to explore and appraise them. To assess building materials for CPP, a building must be broken down by system categorization and boundary conditions. To address the issue, building decomposition and abstraction are utilized. Some key decomposition systems are done based on material, lifespan and CICS systems such as NL/SfB, Omni Class, UniClass, MasterFormat and more.

Furthermore, while establishing a framework for CPP, it is important to define a good system boundary so that it is clearly comprehensible, monitorable, and meets the research scope. Since CPP entails the end-of-life phases, for the sake of simplicity the end-of-life stage of a building is considered a system for the research project. According to Bertino et al. (2021), the building’s end of life can be divided into four categories that are maintenance, refurbishment, demolition, and deconstruction. The most common end of life scenario is demolition. It is very cheap and quick and easy to undergo as compared to the other scenarios. However, to transit to a circular ecosystem, it is essential to create a process where each building asset is either reused, restored to a same or higher value product, or sent for energy recovery rather than being downcycled as shown in demolition process. The key aspect of a circular deconstruction is the disassembly potential of a building asset, its quality at the end of life and the related costs and energy impacts and other necessary metadata relevant for circular deconstruction process.

Given the recent technological advances such as BIM and concepts like digital twins and design for disassembly have made it possible for a building to be reused completely. However, a full deconstruction is not entirely possible. This is in line with the current demolition practices highlighted in section 4.3.3 where linear deconstruction is practiced. To transit to a circular deconstruction as highlighted in section 4.3.4, it is necessary to have an adjustment to a more realistic approach. Hence the proposed framework takes elements of sections 4.3.3 and 4.3.4, and focuses on partial deconstruction. In this real-life framework through proper planning and inspection a building can have most of its assets ready for their second life and some can be repurposed and upscaled and the least amount can be downcycled and in worst case scenario disposed for landfill. Hence, this framework is designed in such a way that circular deconstruction (with higher preference) is paired with other demolition strategies.

The first phase is Pre-partial Deconstruction phase (Figure 48 and section 14.6), which comprises of processes to create a deconstruction plan and estimate the cost and time to deconstruct along with the de-constructability of the building. This phase also comprises of inventory inspection (Figure 49 and section 14.7). In the pre-partial deconstruction phase (Figure 48), the client should order an inventory inspection before issuing call for a tender for deconstruction. During the inventory inspection the building and site specifications should be provided. Such information entails some or all the building data, such as BIM model, 2D drawing, material location and technical information, building construction history and the exit scenario report for building assets. This information is broken down in the next chapter. While issuing tender, it is important to include clauses for circularity expectations and ownership of deconstructed assets. Then a prospective contractor can conduct their own building site inspection alongside inspection of neighborhood buildings and investigating the land use-plan. The building site inspection comprises of checking the building's heritage status, presence of hazardous and explosive materials, understanding construction history and structure hazards and end with investigating the energy and water connections of the building and presence of underground infrastructure that needs to be rerouted. The part (quite like traditional inspection and demolition audits) differs only in sense of the decision of the contractor to do their own inventory inspection based on the reports provided by their prospective client. Based on their own inspection, the prospective contractor can determine the ease of disassembly of components and update the exit scenario report much like the ideal deconstruction process. The difference is that some components can be disassembled, and others must be removed using traditional demolition strategies. This makes the assessment of disassembly potential important.

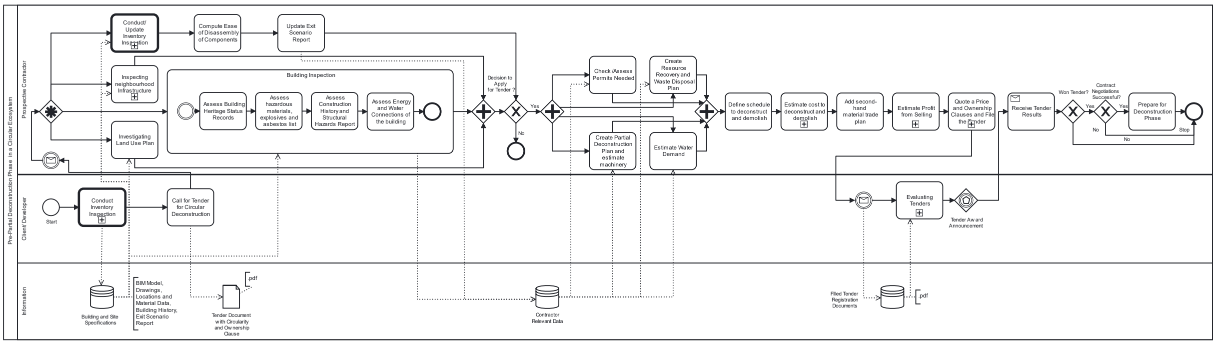

FIGURE 48 PRE-PARTIAL DECONSTRUCTION PHASE IN A CIRCULAR ECOSYSTEM

Based on the inspection, the contractor can decide whether to apply for the project or not. If the answer is yes, then like pre-demolition and pre-deconstruction phase in the previous methodologies, the contractor can determine what sort of permits are required for the process, determine the partial deconstruction process, and estimate the type of machinery, quantity of water and type of labor needed to execute the tasks. They are also required to create a resource recovery and waste disposal plan based on the ownership clause of the tender and circularity requirements of the client. Based on this, the prospective contractor can estimate the schedule and cost of deconstruction and demolish. A cost benefit plan can estimate profits from trading of building assets that they can get to reuse, restore, recover, and dispose. This information is sufficient to quote a price and file for the tender. If the tender is rewarded, then contractor and client can negotiate and prepare for the partial deconstruction phase.

This proposed framework's inventory inspection is like the inventory inspection in the deconstruction framework stated in sub section 4.3.4. In the partial deconstruction ecosystem, the client (as shown in Figure 49) can be both the owner/ real estate developer associated with the building or the prospective contractor based on who requires the services of inventory inspection team which comprise of surveyors, designers, and analysts. The team of analysts can also have the repurposing and recovery agents available in the market to help framing the exit scenario report. When a client requests inventory management, surveyors go to the location and gather as much information as they can using a phone app and/or a drone survey. They look at visual quality as well as system connections. Designers make use of the information gathered. They create a BIM model or feed a data processing platform using architectural drawings and other information, such as point clouds. To create a material passport database, analysts use BIM and/or a data processing program. They investigate the building's disassembly options (Appendix E/ Chapter 12), time, and sequence (section 3.5). They could use the material passports to create an economic and environmental impact analysis as well as an exit scenario report. The data is given to the client after it has been collected, processed, and evaluated. The only difference is the computation of percentage of system that can be disassembled and demolished at a system or a building level.

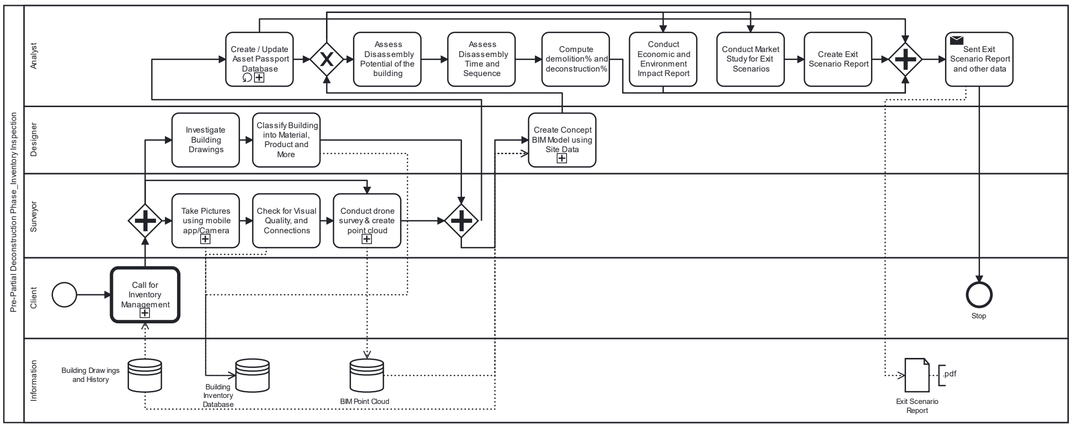

FIGURE 49 PRE-PARTIAL DECONSTRUCTION PHASE - INVENTORY INSPECTION

Figure 50 (and section 14.8) shows the second phase i.e., partial deconstruction, and optimal resource utilization phase. This happens after the tender is awarded and contract discussions are concluded. This is like deconstruction phase apart from waste disposal and downscaling of some building components.

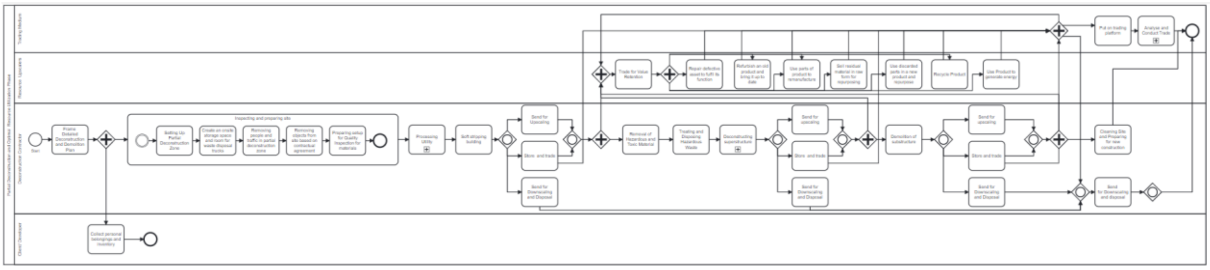

FIGURE 50 PARTIAL DECONSTRUCTION AND OPTIMAL RESOURCE UTILIZATION PHASE

Before dismantling and demolishing, the client must retrieve personal items. Then comes site inspection and preparation. This process involves setting up a partial deconstruction zone, arranging onsite storage and room for waste disposal vehicles, and other deconstruction phase activities based on contractual agreement. The process ends with quality inspections before deconstruction and demolition to minimize contract disputes if assets are destroyed. Utility companies disconnect power and water after inspections. Soft stripping removes explosive and hazardous chemicals. Plan calls for partially disassembling and demolishing the superstructure and substructure. Assets are stored for trading or disposal after partial deconstruction and quality evaluation. Resource upscalers and downscalers return or trade building assets based on the contract. If the admittance requirements are met, all content is traded an online platform or offline sit

5. Chapter 5: CPP Ecosystem Breakdown

5.1 Introduction

According to Icibaci (2019), trading used goods deconstructed from a building can produce a circular ecosystem in the construction industry. In section 4.4, a methodological framework containing various processes is described. This partial deconstruction framework consists of two phases in which relevant stakeholders are involved. To make the proposed methodology viable, each stakeholder group must complete specific processes and deliverables. In this chapter, the most important elements that can be utilized to implement this framework are given.

5.2 Asset Information Querying and Processing in CPP

5.2.1 Level of Information Need (LOIN) for CPP

Sacks et al (2018) states that the building data generated over the lifecycle of a building is enormous and complex and involve stakeholders with distinct disciplines and goals such as real estate developers, owners, financial institutions, regulatory bodies, all areas of architecture, engineering, and construction (AEC), manufacturers, facility managers and planners, asset managers; sustainability designers; and demolition and disassembly parties within the building lifecycle agreeing to different contractual models like Design-Bid-Build (DBB), Design-Build (DB), integrated project delivery (IPD) and their variations. Since this study focuses on the end-of-life scenario of building components and their subsequent use, it becomes difficult to analyses all the data that may have been collected over the entire building cycle. A smarter way is to breakdown the processes involved in CPP and investigate the data that is needed for the processes to be completed and who requires that data and who can deliver that information.

A similar strategy is proposed in in ISO 19650 Part 1 called ‘level of information need (LOIN)’ for BIM models. The LOIN states that the information relevant to a purpose must be added only. This follows the lean approach to reduce information waste. It is important to start with the end in mind and be purpose specific to define Level of Information Need. According to CERN - European Committee for Standardization (2019) On European level, the pr EN 17412 is published for LOIN.

FIGURE 51 ELEMENTS OF LEVEL OF INFORMATION NEED (LOI) CERN - EUROPEAN COMMITTEE FOR STANDARDIZATION (2019)

While investigating the asset information requirements for the CPP and specifying LOI, the following aspects should be taken care of:

- **Identify the purpose of the information:** To complete a task, it is critical to identify the required information. This in turn is the purpose of that information. The partial deconstruction stage consists of three phases: pre-partial deconstruction, partial deconstruction, and resource utilization. It is important to break down the processes in each stage in the context of delivery milestones to understand their significance and identify the purpose of related information.
- **Setting delivery milestones:** It is vital to consider and predict the level of information and actual use of it at specific processes across distinct milestones throughout the partial deconstruction stage.
- **Specifying actors or parties involved:** Throughout the stage, there are not only actors but also various parties participating as specified in Section 3.4.5. Therefore, it should be precise who will oversee producing the information and who will receive and process it.
- **Determine the kind of information and method to be delivered:** Multiple types of information must be considered in a CPP ecosystem during the partial deconstruction stages, including geometric information such as detail, dimensionality, location, appearance, and parametric behaviour, alphanumeric information such as identification and information content, and documentation such as reports, specifications, manuals, photographs, sketches, signed documents, physical information, and handovers.

In summary, to specify the LOI and how information is going to be delivered, the purpose for the use of the information to be delivered as stated before along with the information delivery milestones for the delivery of the information must be stated. Furthermore, the actors who are going to request and deliver the information and objects in one or more breakdown structures of delivery must be included.

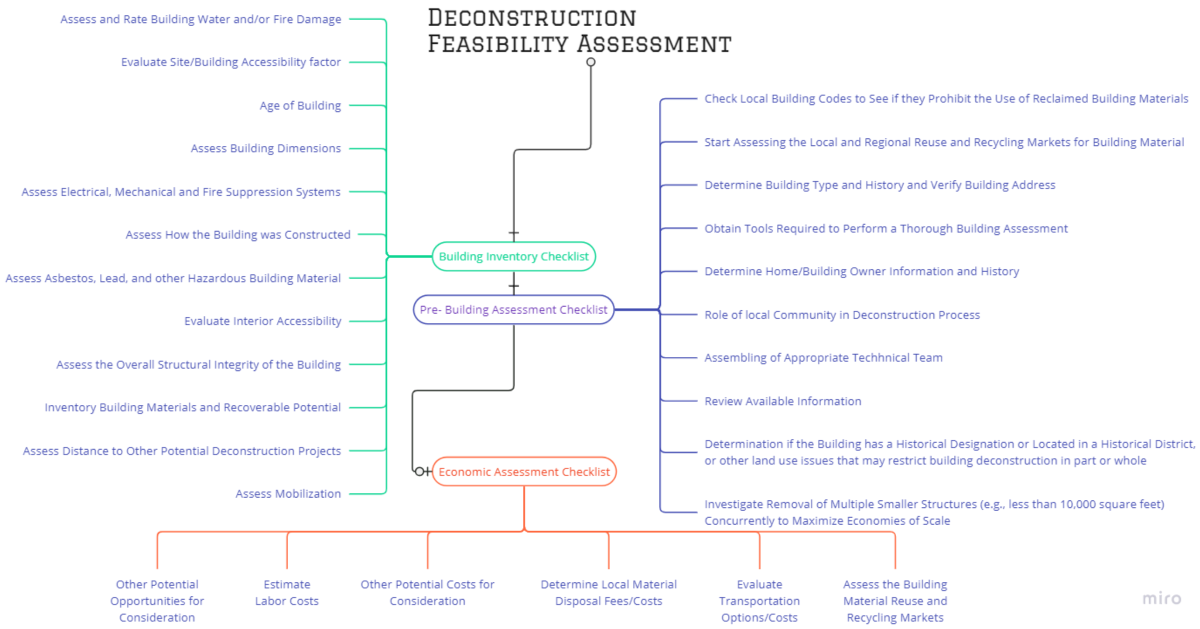

FIGURE 52 DECONSTRUCTION FEASIBILITY ASSESSMENT (ENVIRONMENTAL PROTECTION AGENCY, 2012)

For deconstruction to happen and CPP to finish, it is necessary to assess if it is feasible to deconstruct or not and what is needed to enable CPP after deconstruction, this is the main purpose for all the information that is needed during the end of life of a building or its assets. A deconstruction checklist proposed for different phases of deconstruction has been proposed by Environmental Protection Agency (2012) as shown in Figure 52. There have been many other frameworks proposed that can assess feasibility of deconstruction. However, this proposal is close to the methodological framework proposed in Chapter 4. Based on this checklist, a client or a real estate developer can issue tenders to assess feasibility of deconstruction, frame tenders for hiring contractors, site inspectors, resource analysts and resource traders. Furthermore, it also gives a chance to involve the local community in the deconstruction process and provide an economic assessment.

5.2.2 Asset Information Requirements based on End Deliverables in CPP

Section 4.4 outlined the processes for partial deconstruction stage, from calling for deconstruction bids to online resale of restored and reused items. Each task in the process requires specific indicators and elements (discussed in Section 3.5) for the task to be completed. The input for these elements, indicators, and to-be-completed tasks is the required information for the CPP. The input based on the different tasks of the deconstruction process can be categorized based on the principal deliverables which they serve. Since the CPP ecosystem proposed in the previous chapter comprises of many processes and information types, it is essential to identify the key milestones in the partial deconstruction stage to simplify the process. There are four key deliverables that can be identified- Site and Inventory Inspection Database, Exit Scenario and Resource Recovery Plan, Partial Deconstruction Plan, and Resource Trade Plan. Hence, the information needed for delivering these milestones is necessary for CPP to happen. Hence, the various processes necessary for these deliverables are categorized in Figure 53. The checklist proposed in Figure 52 , can be divided among these four key deliverables to determine the information needed for the CPP to happen.

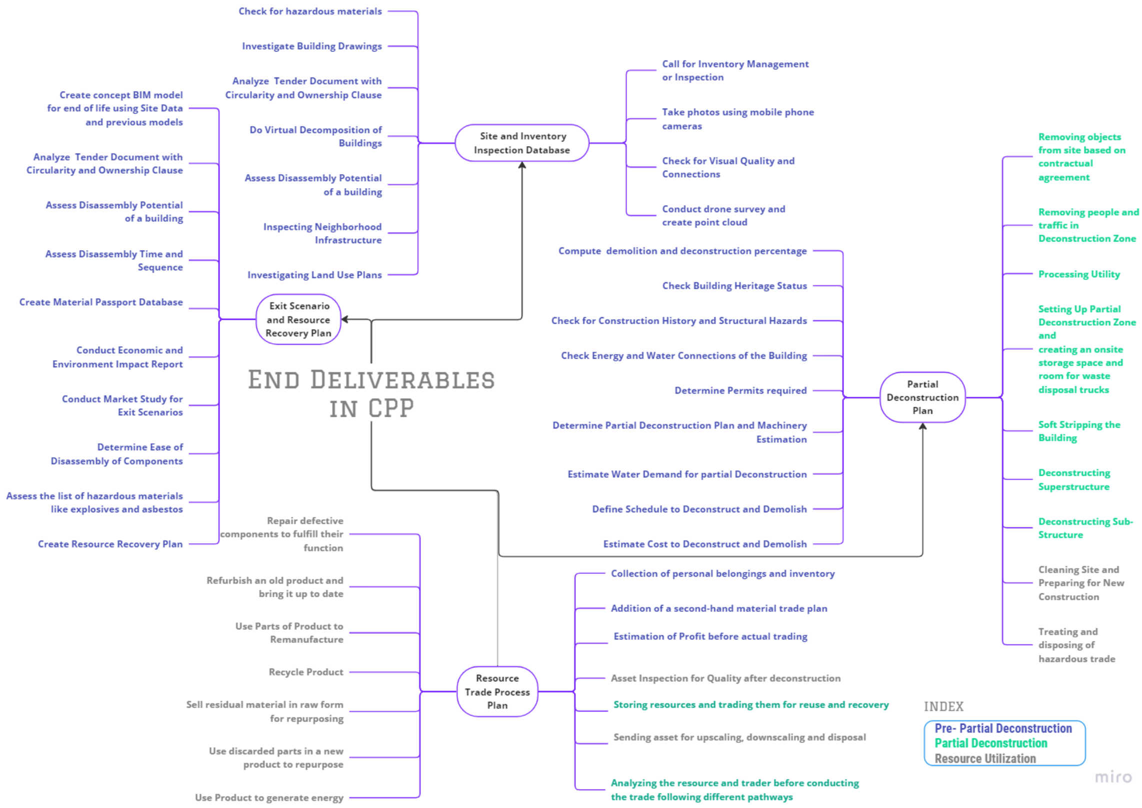

FIGURE 53 PROPOSED FRAMEWORK'S PROCESS DISTRIBUTION BASED ON PURPOSE

Based on the checklist as well the deliverables, the client or real estate developer must issue tenders for three deliverables and come into agreement with three different teams for partial deconstruction to happen before resource trading can happen in a CPP based on the owner of the asset. These three teams are site and inventory inspection team, resource recovery team and the deconstruction team.

5.3 Site and Inventory Inspection Database

The processes involved in preparation of site and inventory inspection database happen during pre-partial deconstruction phase. The client calls for tender to create a database to be used ahead in the deconstruction process. This client can be the owner of the property, the real estate developer on behalf of the owner or the contractor responsible for deconstruction based on the agreements between the parties involved. In the process, the client's team composes guidelines and specifications for inventory inspection and formulates a tender to look for the site inspection team. An ideal site inspection team comprises of at least three roles based on the functions needed to be performed as shown in Figure 54.

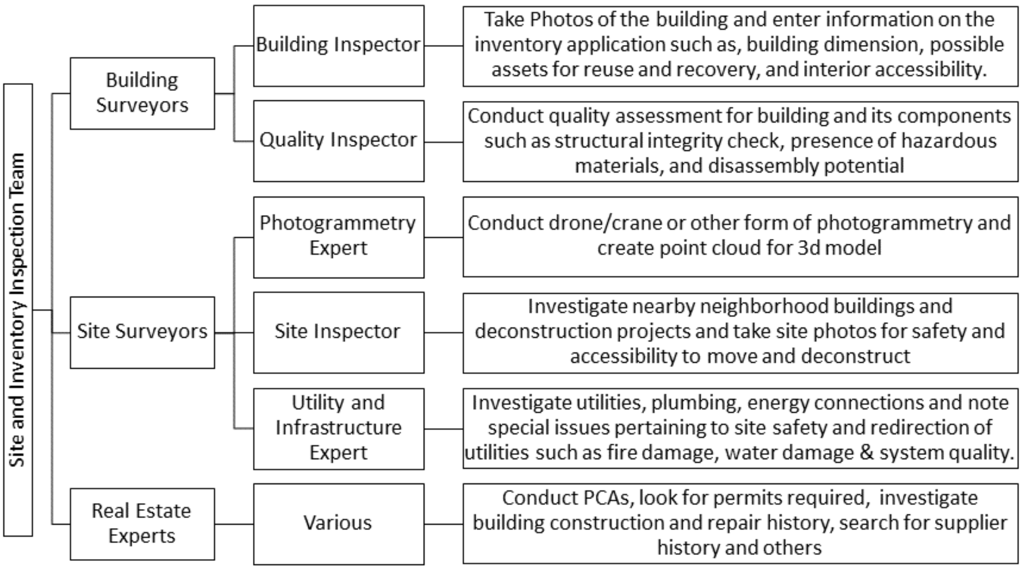

FIGURE 54 SITE AND INVENTORY INSPECTION TEAM COMPOSITION BASED ON FUNCTION

After the constitution of the team based on the complexities involved with deconstruction of a project and the tender guidelines and goals of the client with the project, the building surveyors can go to the building site if there is desire for deconstruction to list the building assets, take their photographs and assess the quality of the building asset. This survey for quality and quantity inspection of building assets also depends on the pre-existing knowledge of the real estate experts hired who investigate the land use plan of the site, investigate needed permits for deconstruction, and the building history in their property condition assessments (PCA). Furthermore, the site surveyors inspect the site; the neighborhood buildings; and utility and infrastructure plans; for safety guidelines to be added to the deconstruction tender. The team, when contractually obliged, can also investigate the potential for local community's involvement as it facilitates a positive social impact as evident in study by Denhart (2009) . The client's desire to deconstruct can be based on the result of PCAs conducted by the real estate expert. Furthermore, a study by the resource analysis and recovery teams of building's disassembly and reuse potential, if they are hired already, can make the client's decision to deconstruct more concrete. It should be noted that the resource and recovery team may also need already existing building drawings, BIM models or some non-graphical information, to constitute the disassembly potential of a building to facilitate generation of a profitable deconstruction plan.

The relationship of the elements necessary to achieve site and inventory database is shown in Figure 55.

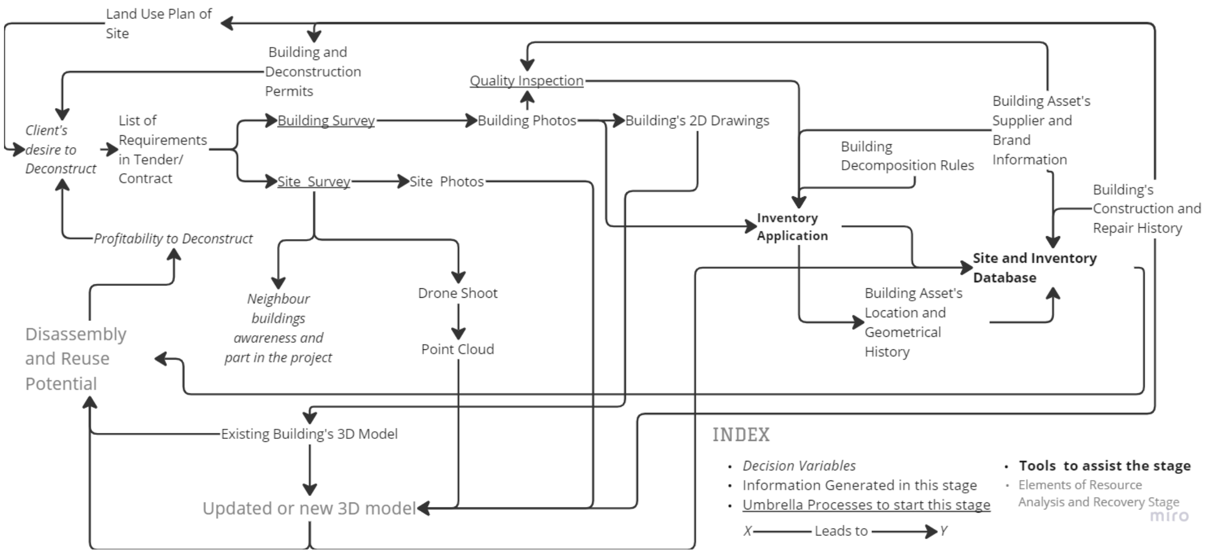

FIGURE 55 POSSIBLE RELATIONSHIPS BETWEEN ELEMENTS OF SITE AND INVENTORY INSPECTION

This can lead to various processes that can be born out of the relationships and the availability of the elements. One type of process that can be born out and presented in the methodological framework is when a client and his team wish to deconstruct (Figure 56) based on PCAs conducted. Then a contract with the inspection team is signed, and under favorable circumstances and some pre-requisite knowledge, building surveyors can go to the site and take photos. They can then add relevant visual information such as location, geometry, quality, and other remarks through a user interface which can be a phone or a computer application. This information is sent to the site and inventory inspection database that can be accessed by other groups and teams to add further information to it. The other information that can be added to the database via the application can be building assets' supplier and brand information, notes on visual quality inspection, relevant photos at site that may showcase some relevant connections, presence of hazardous materials or unique elements on the site. The site and inventory database can contain building construction and repair history pertaining to sections of buildings or building assets.

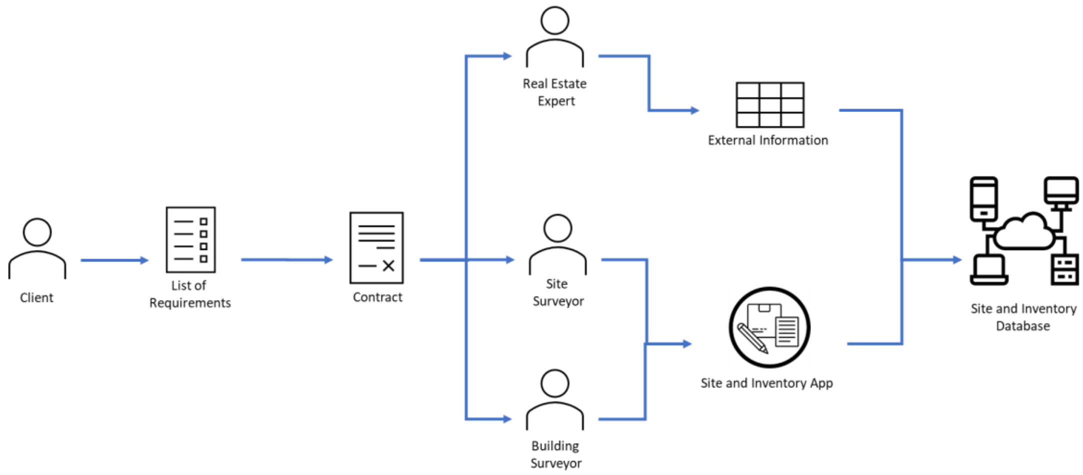

FIGURE 56 OUTLINE OF A PROCESS FOR SITE INVENTORY AND INSPECTION

The process outline in Figure 56, matches with the research and design project of Breteler (2022). It describes the traditional site and inventory inspection process used in Bnext.nl[34], a company that specializes in deconstruction. It involves the client's team (commercial team) laying down guidelines

[34] https://bnext.nl/

for the deconstruction which if accepted makes the calculator examine the building for reusable materials which if found leads to a site visit by surveyor (account manager) to identify them and upload pictures to a computer and create project documents with relevant reusable products' pictures and additional information. This leads to then drafting of a tender along with a plan of action for company directors to approve and assign project leader and dismantling team after decision on a budget.

Breteler (2022) proposed an inventory application that can be used by a surveyor to take photos and input information on site which is connected to a database that the information analyst can utilize for the further plan of action as shown in Figure 57. This switch from manual inventory inspection to an app-based inspection saved 150 minutes when additional inventory inspection is applied. As shown in Figure 57, there is a login page which lets the surveyor logs in to the existing project or start a new project or logout of the application. Then there is an information page for the project, if a new project is started, then it asks for a project number, project name, client name, address, place, expected deconstruction date, description of the project and add photos taken at site. It further leads to an add product screen, which displays the project number and requires information such as Product Name and ID, NL/SfB Code (section 4.3.2), location, material description, function, quantity, length, breadth, height, volume, diameter, surface area, brand of product, price, expected lifetime, quality, product description, created and edited on and by, types and amounts of connections, instruction for disassembly, and product photos. Furthermore, if the surveyor logs in and enters an existing project, then a page for project overview is displayed, where project information can be modified and once edited can return to project overview screen. This project overview screen leads to product overview screen where all the added products can be seen. Once a product is selected, it leads to an edit product screen, where the information pertaining to selected product can be edited or new information can be added.

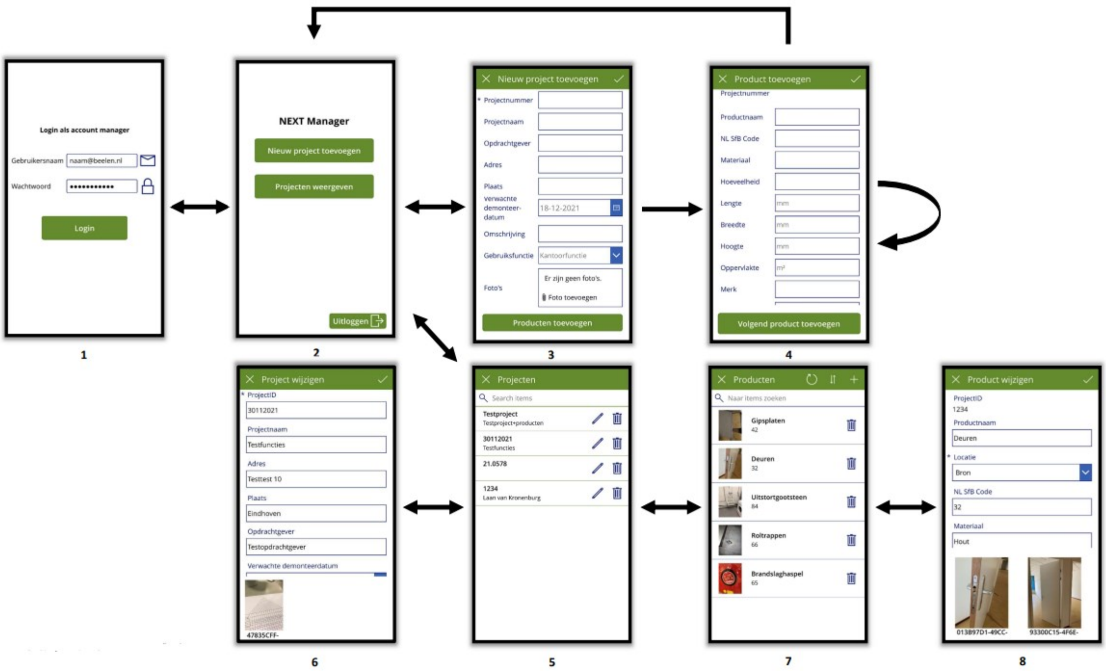

FIGURE 57 EXAMPLE OF AN SITE AND INVENTORY MOBILE APPLICATION (BRETELER, 2022)

While entering building asset data into the site and inventory mobile application, it is necessary to have a check for factors that can be verified visually or through further analysis of building drawings and supplier information obtained for disassembly potential of building elements. There are many potential routes it can take based on various studies. Some of the studies mentioned in this project are done by Breteler (2022), Arko van Ekeren (2018) and van Vliet (2018). A simple connection type identification as done by Breteler (2022), who investigates the type of connections and checks for the pre-defined list, based on CB'23 passport, as shown in Figure 58 below, along with a text for dismantling instruction. Other disassembly factors along with their categories can also be added based on proposed categories by Arko van Ekeren (2018) and van Vliet (2018) as explained in sections 12.1 and 12.2 respectively.

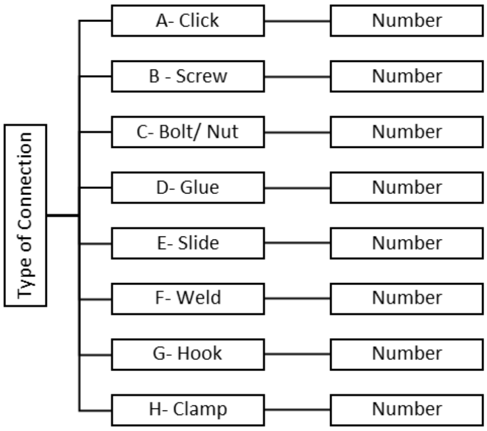

FIGURE 58 REQUIREMENT FOR DISASSEMBLY POTENTIAL ASSESSMENT DURING SITE INSPECTION BY (BRETELER, 2022)

Furthermore, it is also essential to define some visual quality assurance criteria to assess the salvage value of the building asset. According to Kim et al (2019), quality assessment (QA) of buildings and civil structures is an essential process in a construction project. Hence, there have been various methods that can be employed to assess the quality of building components. A example for quality assesment criteria during inspection can be seen in Figure 59 on Page 87.

According to Kim et al (2019), quality assessment (QA) of buildings and civil structures is an essential process in a construction project. Hence, there have been various methods that can be employed to assess the quality of building components. One example is NEN 2767-1. It gives a way for determining the technical state of building components objectively and precisely uses three aspects of a specific type of defect: quality indexation **level** from 1 to 6 which is the level of necessity, **the scope of the problem** which states the reach of the problem, and the need of inspection is stated by the **intensity** as shown in Table 21 on Page 87.

The standard defect lists are an integral component of this methodology. These defect lists (deficiency dataset) are organized according to a predetermined structure framework and offer an overview of the potential flaws in a building component, their severity, and, if relevant, their intensity. Based on the problems that have arisen, maintenance/upscaling costs and other liabilities can be estimated. Based on this condition measurement, it is simple to establish the order of importance for the required deconstruction.

An example of quality assessment based on the NEN 2767 is a mobile inspection tool to assess the building quality before renovation developed under P2ENDURE by Gralka & van Delft (2017). As stated previously, the NEN 2767 can be applied to all building components including MEP/HVAC systems. However, the P2Endure inspection tool was designed exclusively for visual condition evaluation. Therefore, only visual checks are performed for MEP systems, such as ensuring that there are no apparent pipe leaks, damage, or corrosion. It was proposed that an expert inspect the performance of the MEP/HVAC systems in considerable detail, if needed. As stated by Gralka & van Delft (2017), the site and building surveyor can access the application through a mobile application, desktop application or a web browser and create a quantity takeoff. The general page of the condition assessment tool contains component ID and other information such as construction history, inspection dates and building location, and stakeholder information as shown in Figure 60.

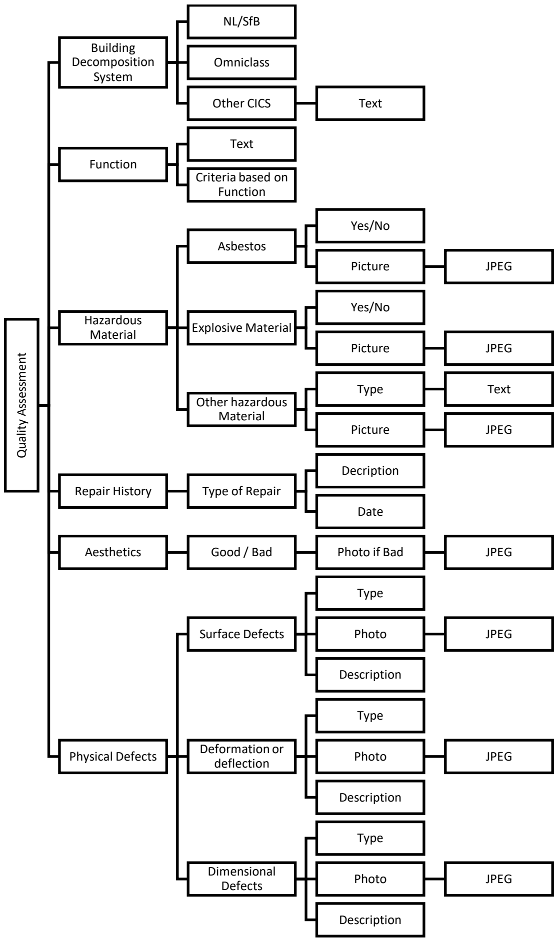

FIGURE 59 EXAMPLE OF A VISUAL QUALITY ASSESSMENT CRITERIA

TABLE 21 BUILDING ASSET CONDITION SCORE IN ACCORDANCE WITH NEN 2767 (A. P. M. (TON) VERBERNE, 2022)

PROBLEM	INTENSITY	SCOPE OF PROBLEM				
		<2% incidental	2% -10% local	10%-30% regularly	30%-70% considerable	>70% general
Minor	Baseline	1	1	1	1	2
	Serious	1	1	1	2	3
	Major	1	1	2	3	4
Serious	Baseline	1	1	1	2	3
	Serious	1	1	2	3	4
	Major	1	2	3	4	5
Major	Baseline	1	1	2	3	4
	Serious	1	2	3	4	5
	Major	2	3	4	5	6

Score Level
-1: Very good (New construction)
-2: Good (Comparably to new construction with a little age in the components)
-3: Reasonable (No new construction but some maintenance required)
-4: Mediocre (Clear need for maintenance and repairs)
-5: Bad (Mayor need for maintenance and repairs)
-6: Very bad (No maintenance possible, replacement required)
There are a few other levels as well.
-8: Need another look
-9: Not to inspect

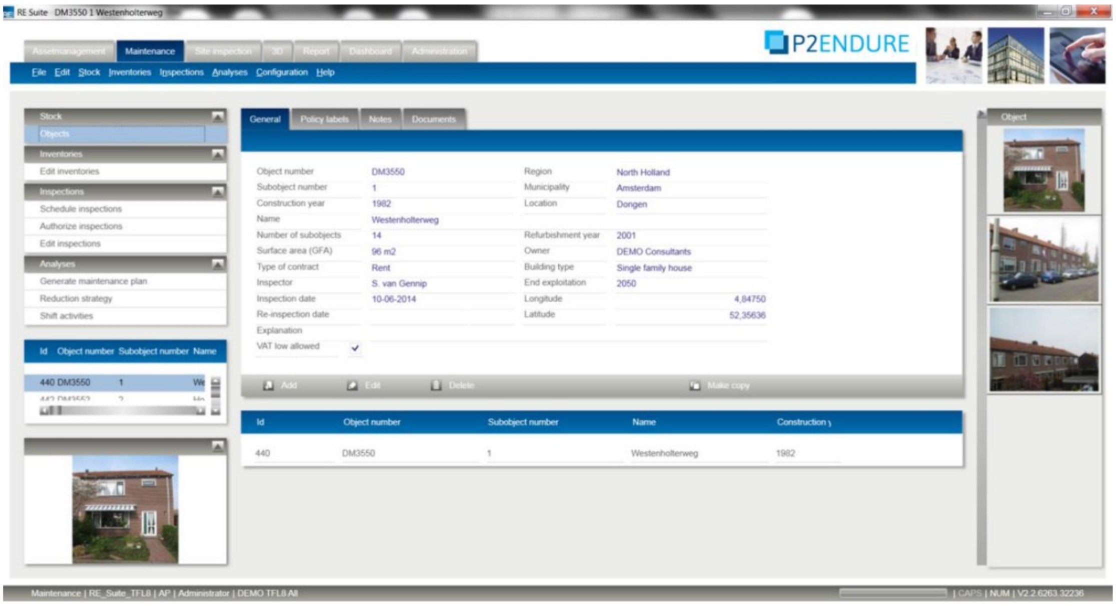

FIGURE 60 P2 ENDURE SITE INSPECTION TOOL SHOWCASING GENERAL PRODUCT INFORMATION UNDER MAINTENANCE (GRALKA & VAN DELFT,2017)

A list of defects can be seen in Figure 61, which showcases the type of defect with unique ID that can be scored based on the NEN2767 tool as shown in Table 21.

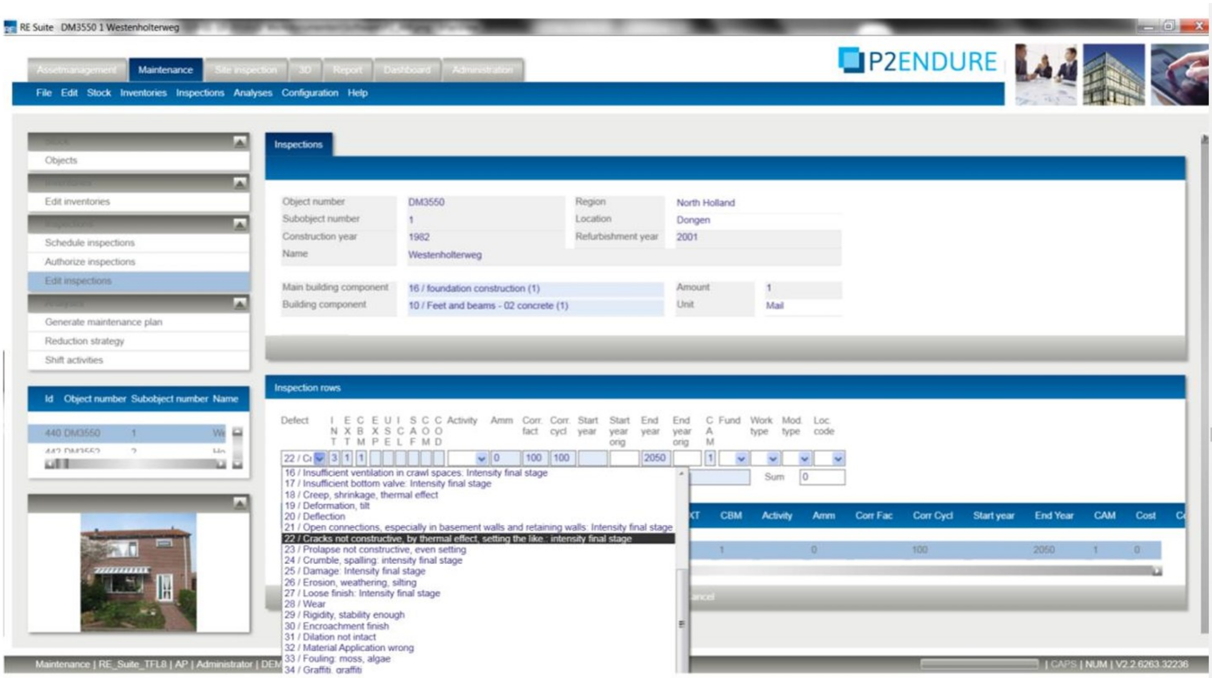

FIGURE 61 P2 ENDURE SITE INSPECTION TOOL SHOWCASING GENERAL PRODUCT INFORMATION UNDER MAINTENANCE (GRALKA & VAN DELFT,2017)

Furthermore, the tool allows the use of a BIM model to take specific quantity takeoff from the model. All the required and available information is synchronized with a mobile/ tablet device that helps in keeping the data up to date. The tool has a list of other aspects apart from technical quality assessment factors for overall asset assessment based on financial and economic policies of the stakeholder. Hence, it is important to note that the information required for the next three CPP deliverables, can be also added to the information required to be obtained for site and inventory database and create a unified application platform.

For a simplified version of the process as shown in Figure 62 and section 14.9, the level of information need is as stated below, under the conditions that the team has all the members as shown in Figure 54.

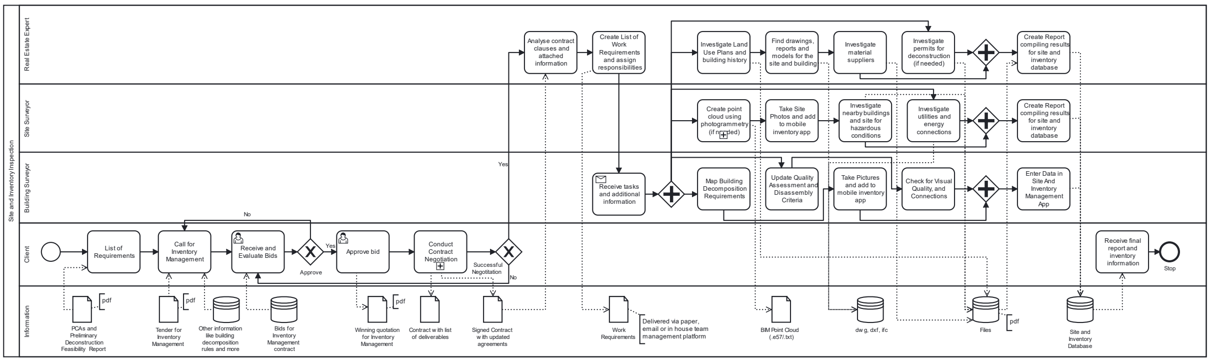

FIGURE 62 SITE AND INVENTORY INSPECTION INFORMATION EXCHANGE

Purpose of Information- To fill a site and inventory database for the project

Information Delivery, Milestones and Stakeholders Involved

- PCAs for Contract Guidelines and Deconstruction Feasibility before the hiring of site and inventory inspection team from real estate team to client signifying the profit from deconstruction
- List of Requirements by clients to the tender management team to formulate the contract for hiring of the inspection team.
- Tender with ownership requirements along with summary of PCAs: These can include circularity clauses and goals for prospective inspection team; quality compliance and assessment expectations; desired completion period for inspection; budget constraints; information management standards and processes; building's construction history and the intent of the client behind deconstruction; and desired building decomposition standards to sync information received in the database for further analysis with other traditional information usually presented in a tender. This information does not need to be exact but clear enough for quotes from prospective real estate and deconstruction companies.
- Quotations for tender from prospective teams with their team composition, a methodology for inspecting that meets the standards of the client, the required time and the price quotation and the type and quality of information delivered in the Site and Inventory Database along with a confidentiality agreement on future ownership of data if needed along with a proposition of possible recovery items that can be generated if building history is provided.
- Contract with detailed list of deliverables before negotiations between client and the selected team and after negotiations with involvement of the legal counsels from both stakeholders.
- Building surveyors during site inspection deliver visual information such as photos of building assets they consider relevant for deconstruction along with location, geometry, quality, and other remarks as shown in Figure 57. This information can be added to their own database which further analyzed can be delivered to client as processed into a report along with raw data from the database or can be collected directly in client database if the application used for inventory is provided by the client. The type of information and possible formats are in the Table 22.

TABLE 22 INFORMATION FROM THE INVENTORY MOBILE APPLICATION

S.NO	TYPE OF INFORMATION	POSSIBLE UNITS
1	Project Name	String
2	Project ID	Integer

3	Client Name	String
4	Address	String/ Geocoded Latitude and Longitude
5	Postal Code	String
6	Location	String
7	Expected Deconstruction Date	Date (dd/mm/yyyy)
8	Project Function	ENUM
9	Site Photos	JPEG
10	Asset Name	Text
11	Product ID	Integer
12	Product NL/SfB (Decomposition) Code[35]	Integer
13	Product Type	List
14	Product location(s)	ENUM
15	Product material description	String
16	Product function	String
17	Product quantity	Integer
18	Product geometric information such as length, breadth, height, volume, diameter, surface area	Float
19	Product photos	JPEG
20	Product Quality Defects	Multiselect
21	Product Defect Intensity	Multiselect
22	Product Defect Intensity Score	Multiselect, Range {1:6}
23	Product expected lifetime (optional)	Integer
24	Name of people involved with inspection of the asset and further edits	Integer
25	Time of inspection and edits	DATETIME (dd/mm/yy_hh:mm)
26	Types and amounts of connections (preferred)	ENUM, Integer
27	Other disassembly potential factors (Optional)	Enum
28	Instruction for disassembly (Optional)	Boolean (Yes/No), String (if yes)
29	Presence of hazardous and explosive materials (preferred)	Boolean, String (Yes/No)
30	Product brand (preferred)	String
31	Current price of same or similar product (optional)	Integer and Enum (Price and Choice between same and similar product)

- Site photos from the site surveyor can be added to the mobile app, whereas a report indicating hazardous substances, energy and water utilities and neighborhood buildings that may be hampered during deconstruction activities can be directly added to site and inventory database as deemed useful. Furthermore, if included in the contract, a point cloud to recreate BIM model can be made through appropriate photogrammetry techniques based on the complexity, time and budget percentage of the project assigned to reality capture.
- Real estate Experts can provide PCAs at the beginning of the process to client and a PCA summary for tenders can be shared with the possible inspection team if they are with the client from the beginning of the process before the rest of the site and inventory inspection team is formed. They are also responsible for translating the contract into a list of requirements that are sent to various other team members based on their function either as a hard copy, or an email or on the team management platform such as Relatics[36], Slack[37] and others.

[35] Based on client's contract agreement for data handling
[36] Relatics enables model-based system engineering for construction projects
[37] Slack is a platform for team coordination that is both web-based as well as desktop application.

- During the inspection process, the real estate experts should provide with building drawings, construction and repair history, information of material suppliers apart from researching for permits needed for deconstruction and reuse of materials in accordance with local municipal regulations as separate file and a report compiling all the information necessary for entering the next stage as stated in accordance with updated contractual agreement between client and the team.

5.4 Exit Scenario and Resource Recovery Plan

5.4.1 Introduction

The purpose of the information from the site and inventory database is to evaluate the building for its deconstruction potential, provide different pathways for building assets to be sold at their highest value, and identify difficulties to upscale them. This section deals with information needed to create a resource recovery strategy for the contractors to follow during the partial deconstruction of the building. The CPP deliverable based on this information is to provide outline for resource recovery along with exit scenarios of the building assets.

Based on Figure 48 and Figure 49, the exit scenario and resource recovery plan start with creation of a BIM model using site and inventory database (if stated in the contract) and use it to create an asset passport. With the information present in the passport, different analyses are done, and a resource recovery plan is generated. The different analyses can be market study for product demand, lifecycle study for impact of the building asset and the deconstruction feasibility of building and asset along with usage of exit scenarios for the building assets. This part ends when the resource usage strategy is delivered to the contractor for deconstruction.

However, in real life, the steps involved to reach the final deliverables is influenced by the order of hiring and the composition of team while hiring. The team if hired before the site and inventory inspection team, may result in the deconstruction feasibility being determined based on old drawings and information researched. If they are hired alongside the site and inventory inspection team, they work hand in hand with them while sharing and storing information. If they are hired after them, then the work of information analysis to create a recovery report will be delayed. Furthermore, the amount of analysis that needs to be done will be based on the level of information that the inspection team procures. Also, it is important to note that, like the inspection work, the exit scenario and resource recovery occurs during pre-partial deconstruction phase. Hence to save time and money, it is wise if it happens along with the site and inventory inspection team as there is an opportunity to actively collaborate. Any issue of interpretation of results obtained while site inspection goes on can be resolved during the process of analysis and changes made will be easier and better planned based on the list of requirements from the client for the respective teams. This is also beneficial to avoid loss of information during handover if the tasks of one team precedes other.

As stated for the site and inventory database, the client can be the owner or the real estate developer or the contractor hired for deconstruction. Even if the team is hired by the deconstruction contractor rather than the client, this does not change the dynamics between the two teams, but the influence of contractor’s methodology would be more than the owner/real estate developer. It just implies that all the processes that are highlighted in Figure 46 will be done after the contractor is hired by the client for deconstruction.

The process of exit scenario and resource recovery is influenced by a lot of elements on which the deconstruction feasibility report and an exit scenario report can be based. There are indicators for sellers to judge which product can be and should be sold based on a) the needs of buyers as stated in section 3.4.5.2; b) the requirements for seller, as mentioned in section 3.4.5.3 and the respective CPP indicators, as mentioned in section 3.5; and c) the process of resource recovery as proposed in section 4.4 and the deconstruction checklist in Figure 52. Apart from that, the environmental, social, and economic impact of the deconstruction procedures should be predicted based on the contractual agreements and the level of information obtained in the site and inventory database, to give a broader overview of decision variables for a deconstruction contractor and the resource trader to make the appropriate decision in the later part of the deconstruction phase.

The process of resource recovery comprises of three different stages: *Planning; Preparation; and Analysis & Delivery.* The planning part answers the question what information we have before the start of the work by resource recovery team; the preparation part deals with making guidelines and deliverables for creating a database and filling it with good quality data and identifying limitations that will constraint some analysis and third part deals with analyzing the data for assessing deconstruction feasibility, measuring the environmental and economic impact of deconstruction and identifying different resource trading opportunities.

5.4.2 Planning for Resource Recovery

When a client hires the resource recovery team alongside site and inventory inspection team, there is a list of requirements that are included in the tender for resource recovery team in terms of deliverables. After filing a quotation along with a general plan, the tender is awarded to the most desirable party. After contract negotiations are done and all parties agree and break down the list of deliverables, it is the team manager who creates a work break down schedule and assigns the work to the relevant team members.

There are five tasks that need to be performed in the planning for resource recovery.

1. The first task is managing information exchange protocols between site and inventory inspection team and resource recovery team. There is a high probability if the teams are hired together, that some members of the inventory inspection team will also be playing a key part in the resource recovery team. They could either be actively involved or join as advisors in the planning committee of the resource recovery team.
2. The second task is analyzing the contract document and converting client requirements into deliverables to understand the scope of the project and define a schedule. The review of available information that has been delivered by the site and inventory inspection team must be done. After the review is concluded, it is recommended to see the gap in terms of available information and desired goals. This leads to adjusting deliverables based on the quality of information that can be obtained.
3. The third task in planning is to agree on the kind of analysis that needs to be done and then list the requirements that are needed for making that analysis happen. There are many different types of analysis that might be needed – Circularity Score, Disassembly of Building, System, Component or Element as required, Exit Scenario of the building asset, Lifecycle assessment for assessing environmental Impact of the product so far, and the impact due to the operations that must be performed, the quality assessment of the asset by calculating its residual value, and lifecycle cost assessment for the asset based on different exit strategies. This is further discussed in section 5.4.4.
4. The fourth task is to understand the current market demand for similar products. This task must be conducted to choose the most viable option for exit scenario analysis.
5. The fifth task after the decision on the type of analysis that should be done is to list down the rules that need to be followed alongside list of CPP indicators and the information needed.

5.4.3 Preparation for the resource recovery and analysis

Once a plan is laid for the resource recovery and analysis the next step is to use the available information and tools to create the asset passport database that can be used for further analysis. The scope of analysis defines the type and quality of data that is attached to an asset passport. Furthermore, the use of BIM tools also influences the transition of information from site and inventory database to an asset passport database. It has already been stated that the teams should work together in close collaboration to achieve results faster. Along with that, the use of BIM tools assure that the information drop is fluid and minimum for all the users involved. This decision is corroborated by the Figure 63. Hence, it is recommended to adapt the selective use of BIM and concurrent work between the site and inventory inspection team and the resource analysis and recovery team, based on the project's financial and knowledge constraints, to implement the partial deconstruction ecosystem proposed in section 4.4.

In context of this research, BIM stands for Building information Management. It is defined by Pauwels & Petrova (2020) as “the information management process, which mainly focuses on enabling and facilitating the integrated project flow and delivery by collaborative use of semantically rich building information in all stages of the project and building life cycle. The BIM process is unique as it is based on digital, shared, integrated and interoperable building information models”. Hence the Building Information Management process can be well-defined as a facility that enables information management throughout the building lifecycle, while a Building Information Management Model is the (set of) semantically rich shared 3D digital building model(s) that act as the pillar of the Building Information Management process. In conclusion, when the term “BIM” is used, it means Building Information Management and focuses on how information is managed and exchanged over time.

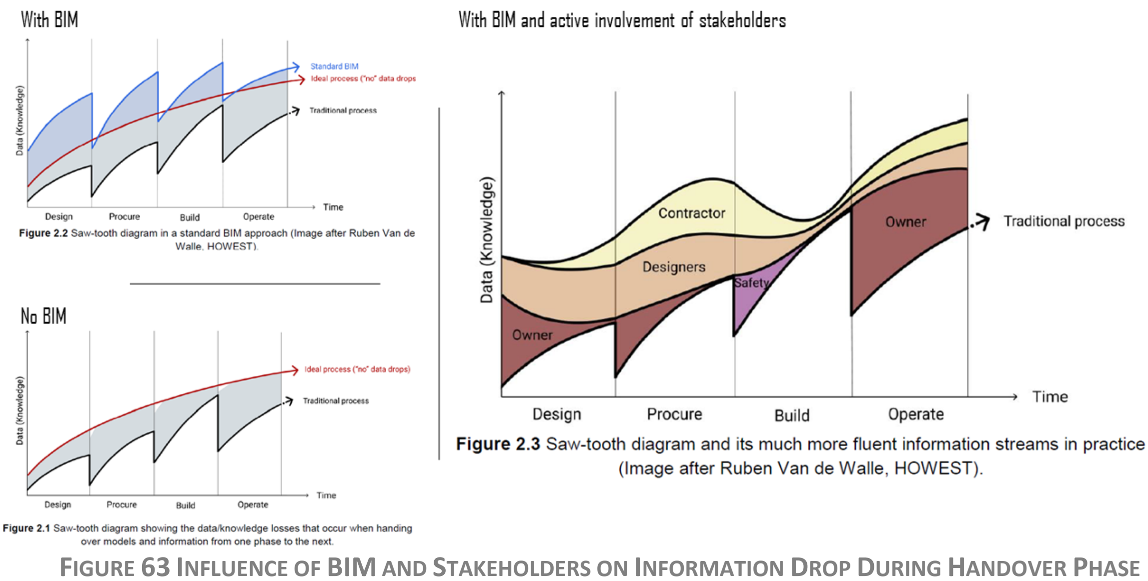

FIGURE 63 INFLUENCE OF BIM AND STAKEHOLDERS ON INFORMATION DROP DURING HANDOVER PHASE (PAUWELS & PETROVA, 2020)

The first stage of this is transfer of information from site and inventory inspection database to the application generating asset passport databases. The assets can be building, a system, a product, or a material. The concept of asset passport database is nothing new. It is evident that the necessity for product and material-related information is a crucial part of understanding procurement in a circular ecosystem. Therefore, product manufacturers and suppliers are stewards of the goods they lease or sell to consumers. This enables explicit accountability at the end of the use period of the product and the generated waste. In economic terms, this would imply a decrease in product losses between phases. This concept is known as "extended producer responsibility" (EPR).

Several researchers, depending on the conditions stated in their own investigations, have established unique passports for assets. This is comparable to the demand for asset information throughout the project delivery phase, when varied levels of information needed are provided based on stakeholder requirements or the construction process. The concept is that every asset has its own unique combination of environmental, social, financial, and technical requirements that fit together like pieces of a jigsaw puzzle to enable various procedures and accomplish various goals. van den Bergh (2020) states that a material-specific version of EPR is a "material passport" that keeps track of where materials are and where they are going, or an "obligatory take-back system" that forces producers to get rid of old consumer goods. Hence, a product-specific version is product passport. And since established in this study, a building asset with a list of information pertaining to that is a building asset passport.

The first step is to create a framework for asset passports based on the type of building asset such as building, system, component, product, or material. To do that' it is essential to establish specific codes for different building assets based on the building decomposition structure such as NL/SfB or others. This is essential for mapping and querying asset specific information.

Since the site and inventory database has information stored in terms of products, the asset passport considered in this stage is the product passport. Hence, the next step is to use the information collected by site and inventory inspection team and creating a product passport on which the future analysis is based on. There are three pathways that the process can follow to constitute an elementary product passport and further adding new properties to it as shown in Figure 64.

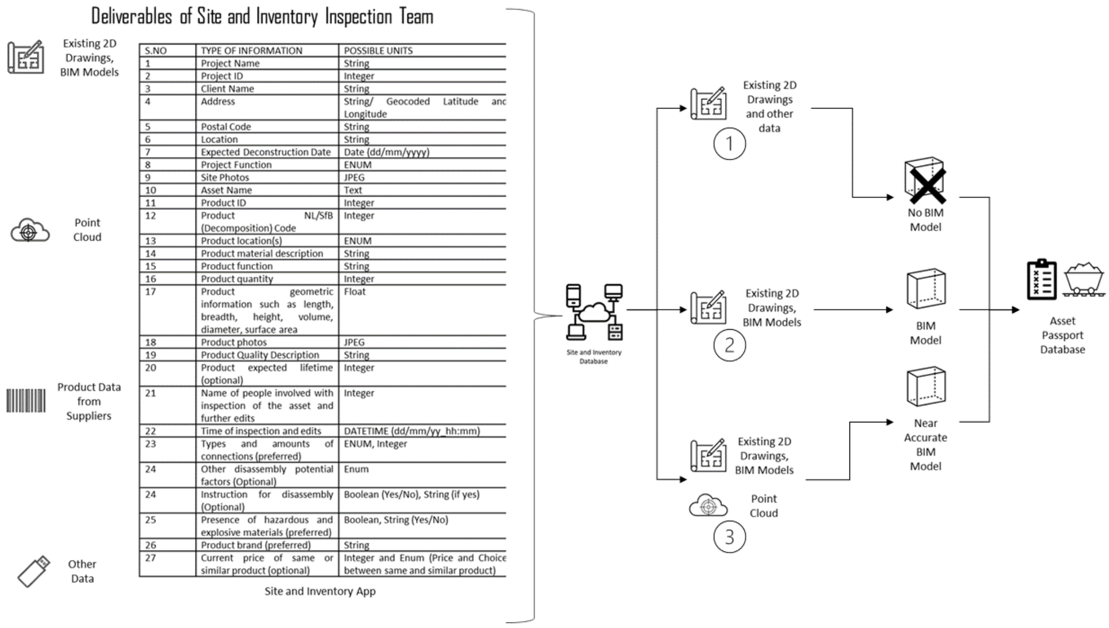

FIGURE 64 PATHWAYS FROM SITE AND INVENTORY DATABASE TO ASSET PASSPORT DATABASE

Path 1 - Site and Inventory Database to Product Passport

The first path is where a BIM model is not used and existing 2D drawings and data are used to constitute a passport for further analysis. This can be seen as the most adaptable pathway in the regions where BIM practices are not commonplace because creating a BIM model require an expert, and it adds to the project's cost and time while implementing BIM for the first time. It is possible but it would still require some time if done using manual method and estimation. An alternative is using an application that directly generates product passports without using a BIM model as such tools are commonplace in operation and maintenance industry.

However, despite using such tools, if proper planning is not done, this can also result in analysis confined to product level as usually such tools are made to generate a data table (usually in excel format) and other assets such as entire systems and material will not be assessed due to lack of scale change while conducting information takeoff. Furthermore, if strict compliance code for information collection is not enforced, then the quality of information processed from the data entered in such an application will be poor and the results generated further won't have an impact on partial deconstruction strategy resulting in a higher demolition percentage.

The paths below employ the use of a BIM model so there is more flexibility in terms of information takeoff for an asset passport for a specific asset. The only difference in the latter is the use of BIM model from various 2D drawings and old models is updated by use of point cloud from reality capture using photogrammetry and laser capture.

Path 2 – Using existing building drawings for creation of a BIM model for generating relevant asset passports

The second path is where a BIM model is made using existing 2D drawings and old BIM models to create a model that is not real. However, it can be noted that this BIM model can still be used if proper complementary tools such as site and inventory application also add the information where changes in the building have occurred in normal text.

To generate an asset passport from a BIM model, there is a need to have the right parameters against the building asset in the model, which can be left blank and be filled later during modelling or after information takeoff. Hence there are two ways where such properties can be created while dealing with the BIM model. The first way is based on assigning new parameters to a model while creating it in the modelling software. Such feature is available in common modelling software. For example, property set for objects can be created in Revit as done by de Barros Lima (2020) as shown in Figure 65.

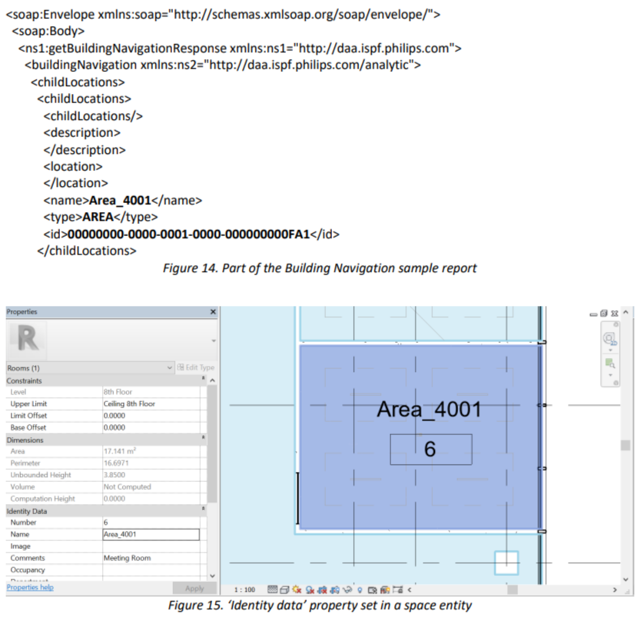

FIGURE 65 DEFINING PROPERTY SET IN THE MODELLING SOFTWARE (DE BARROS LIMA, 2020)

Information here can directly be analyzed through use of Add ins such as Grasshopper for Rhino or Dynamo for Revit which can use the information directly from the model and conduct the analysis. The second way is that after a model is created and a property can be added in the IFC file using IFC Open Shell [38]which uses C++ or Python to edit IFC files and create user specific properties. The properties are defined in a document such as .csv and is imported and added to the IFC object using the IFC open shell viewer. Figure 66 showcases a hypothetical and generic example for this case and it is not investigated in this study in detail.

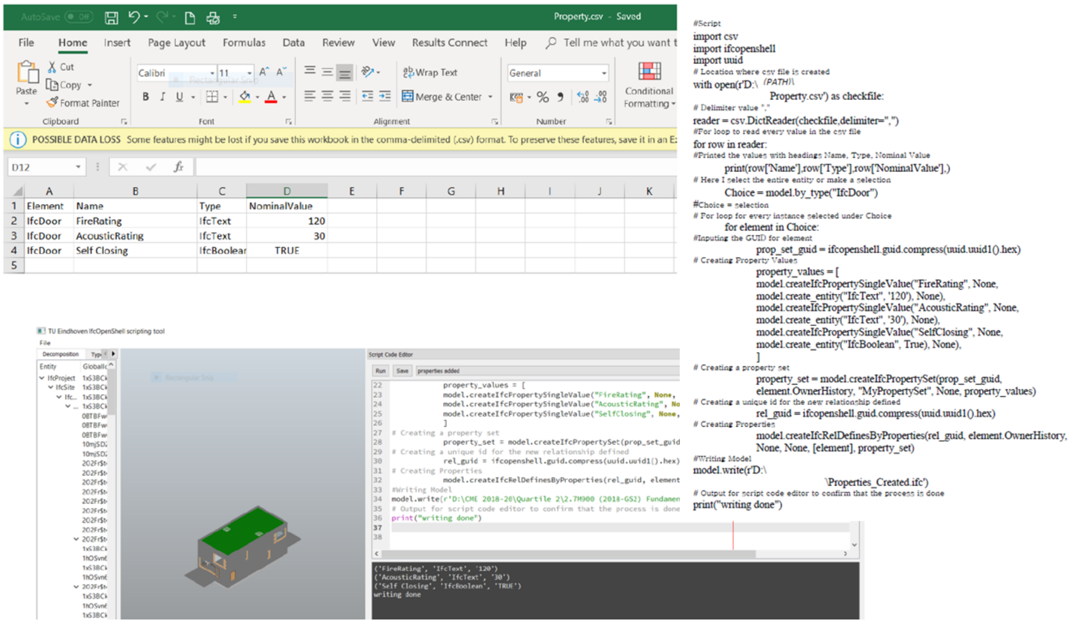

FIGURE 66 ASSET PASSPORT PROPERTY ADDED USING IFC OPEN SHELL

Then the IFC files are open in a BIM viewer such as Solibri or Navisworks for information takeoff as shown in Figure 67. IFC viewer function is also available in applications as P2Endure, MADASTER circularity database where the information can be directly used and analyzed.

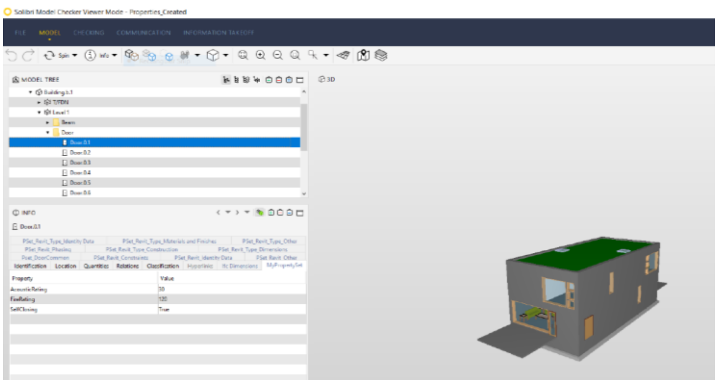
FIGURE 67 NEW PROPERTIES FOR ASSET PASSPORT VIEWED IN SOLIBRI

[38] IfcOpenShell is an open source (LGPL-3.0-or-later) software library for working with the Industry Foundation Classes (IFC) file format. Extensive geometric support is implemented for the IFC releases IFC2x3 TC1 and IFC4 Add2 TC1. Support for parsing is provided for IFC4x1, IFC4x2, and the IFC4x3 release candidates. Extending with support for arbitrary IFC schemas is possible at compile-time when using C++ and at run-time when using Python.

Properties can also be defined and added after the information take off is done by querying inside a database. Non-Relational Databases such as Graph DB, and NoSQL fit better for such a task as compared to relational databases such as SQL.

Path 3 – Using point cloud to create a near real BIM model for generating relevant asset passports

The third path is the use of photogrammetry and laser-based reality capturing to constitute a point cloud and adjust the old BIM model to make it realistic. Then the process to create an asset passport from the real BIM model is followed.

In the early days of usage of point cloud in BIM, the adaption of that technology by the industry is limited. There was a reason behind that as stated by Volk et al (2014). The study states that due to time-consuming data capture, processing, and modeling, BIM models are infrequently used in existing buildings. Moreover, a high degree of information is frequently required for maintenance or deconstruction, which may not be compatible with the time and money invested. But reality capturing has progressed much further since then. The use of BIM model generation using point cloud and 2D design drawings for deconstruction has improved as stated in studies of Ge et al (2017), Volk et al., (2018) and van den Berg et al (2021) due to the technical advancement and reduced cost. There are many industrial solutions in the context of Scan to BIM such as Edgewise[39] to create as-built pipes, structural elements, ducts, walls, conduit, and cable trays from point clouds, Airgo virtual site [40]for site scanning, pixl4D[41] for drone-based inspection and model creation and Mobile Mapping Workflow Solution[42] that creates a plan using point cloud solution automatically.

Honic et al (2020) proposes a methodology for generating semi-automated material passport by capturing existing building using relevant scanners and then generating a BIM model from that. Then adding specific information to generate a material passport for further use. This material passport generation was based on BIMaterial for the assessment of the material composition, recycling potential and more was conducted for the preliminary and conceptual design stage, where the Material Passport served as an optimization tool. However, there were some limitations. Honic et al (2020) demonstrated that occlusion and noise hinder computer-vision approaches for semi-automated as-built BIM generation. Trees in the scans created holes in the point cloud. Point clouds give a tremendous amount of data, necessitating data compression and loss. The material passport was constructed using the manually created BIM model.

Hence, the process of capturing building information using photogrammetry tools to create point clouds should be done in an efficient way. Once the BIM model is created using existing drawings, point cloud made from photos can be used to compare the two to detect changes in the building. This gives an understanding of the changes in the building over the years. This can be done using existing solutions which allows monitoring and assuring quality of captured data and can be used directly with BIM model viewers such as Navisworks, Solibri and others for issue management to change the model specifications and conduct another site assessment at that point. One such solution is Verity[43] by Clear Edge 3D. For comparison and detecting change, it should be noted that careful decision on tolerance must be accounted for while creating point cloud. Then using LASER-based scanners, those specific areas can be measured accurately, or normal measurement techniques can be used to translate those changes in the BIM model. If a project involves deconstruction of an important building such as a nuclear plant, a historical monument and more, thermal, and magnetic scanners to see the systems

[39] EdgeWise - https://www.clearedge3d.com/edgewise/
[40] Site Scanning - https://www.airsquire.ai/airgo
[41] Drone Scanning - https://www.pix4d.com/industry/inspection
[42] Mobile Mapping Wall Generator - https://www.clearedge3d.com/mobile-mapping/
[43] Verity - https://www.clearedge3d.com/verity/

inside thick walls and their visual quality and position can be recorded. Since surveys are done in turns, then generation of BIM model, reality capture and adjustment of BIM model can be done in batches as is usually done in the design and construction phase.

5.4.4 Data analysis and Information delivery

Once the workflow for generating asset passports is ready with or without the use of BIM model, the next part is analyzing the data generated for the deconstruction site for further analysis.

The first important aspect is the **type of analysis**. There are a lot of analyses that can be conducted for deciding on the way the deconstruction and resource recovery strategy is formed. There can be a lot of analyses on which this can be based. As stated in the ecosystem BPMN diagrams as shown in Figure 45 and Figure 46, they are deconstruction feasibility, market demand, environmental impact due to upscaling or retaining, economic impact after deconstruction and by resource trading on the asset value and the effect of quality on the value of asset. There can be various other investigations involved in this phase. For the sake of simplicity, the discussion is about the essential elements as stated in section 3.5.

The second important element is **order of the analysis**. All these analyses can be conducted separately, and the results are combined in a score by assigning weights based on the priority of the analysis as done by the analyst. For example, the deconstruction feasibility can be of more importance than the environmental impact. Another example is that the quality analysis can have more impact than market demand while deciding the strategy for deconstruction.

The third important element is the **relationship between different analyses** as this means that one analysis results can define the extent of the other analyses. An example in this case is that the market demand of the assets can imply that the search for specific assets and their quality and deconstruction set has more priority than others whose demand is less. Another case would be if the contract agreement asks for 80% assets to be deconstructed and only 20% are allowed to be demolished, then the top priority is to identify materials with the easiest and most economic disassembly and then it does not matter if the environmental impacts are necessary.

By stating these examples, it can be stated that before defining doing the analysis, it is important to understand how this analysis can be positioned to achieve what has been stated in the contracts or what holds priority for the specific stakeholders involved in the project. Hence, one way to sort this out is to list the requirements and priorities set by different stakeholders based on their interest. This can be sorted by doing **stakeholder analysis**.

The first step is to identify and brainstorm the stakeholder groups in the process. In this part of the process, it is the client's team who hired the team who can be the owner or the contractor responsible for deconstruction. The second stakeholder group is the potential buyer of the resources. The third stakeholder is the government organizations that you need to satisfy for deconstruction and resource trading to happen. The fourth stakeholder is the people living in the neighborhood. The fifth stakeholder is the site and inventory inspection team. The sixth stakeholder is the resource recovery team.

The second step is to identify the decision makers among all these identified stakeholder groups. These are usually the people you need to satisfy to go on with your analysis. A few examples are the owner or the client's representative, the head of municipal government who will sign the required permits, the committee head of the local neighborhood and the person who is coordinating the site and inventory inspection team's work with the resource recovery team.

The third step is to create a power interest grid and put these stakeholder groups in that process. This power interest grid showcases what sort of actions should be taken while analyzing the right pathway for the resource analysis. An example of filled power interest grid is shown in Table 23.

TABLE 23 AN INSTANCE FOR POWER/ INSTANCE GRID FOR RESOURCE RECOVERY TEAM (GROUPED WITH MORE POWER RANKED FIRST)

MORE POWER, LESS INTEREST	MORE POWER, MORE INTEREST
(To be monitored while deciding on the sequence and priority in analysis)	*(To be engaged and consulted with in the decision-making process)*
Municipal Government (1)	Client (1), Resource Recovery Team (2), Site, and Inventory Inspection Team (1/2)
LESS POWER, LESS INTEREST	LESS POWER, MORE INTEREST
(To be monitored while deciding on the sequence and priority in analysis)	*(To be kept informed while making decision on the sequence and priority in analysis)*
Buyer (1), Resource Upscalers (1), Resource Downscalers (2)	Neighborhood Committee (1)

The fourth step after the power instance grid is made, is to find the requirements of the most powerful and most interested groups and then regulations and limitations that can be imposed by the other three groups. Once that is listed this analysis can be ranked based on the ranks of the stakeholders with more power and more interest and any requirements of the group with low interest and high power need to be satisfied. The other two groups with less power can be monitored and their informed. Once a decision is made on the rank and priority of analysis, the weights for the final decision for each can be assigned on the results of these different analysis based on rank.

Once the order and the relationship of analysis is established, the analysis can start based on the purpose they deliver. It is also important to analyze in small batches of information. The batches can be based on the completion of BIM model detailing or the information in site and inventory database. Based on the proposed ecosystem in section 4.4, there can be many examples how the different examinations are sequenced. An example for the sequence of resource analysis consisting of all the essential elements till the exit scenario of the asset is shown in Figure 68.

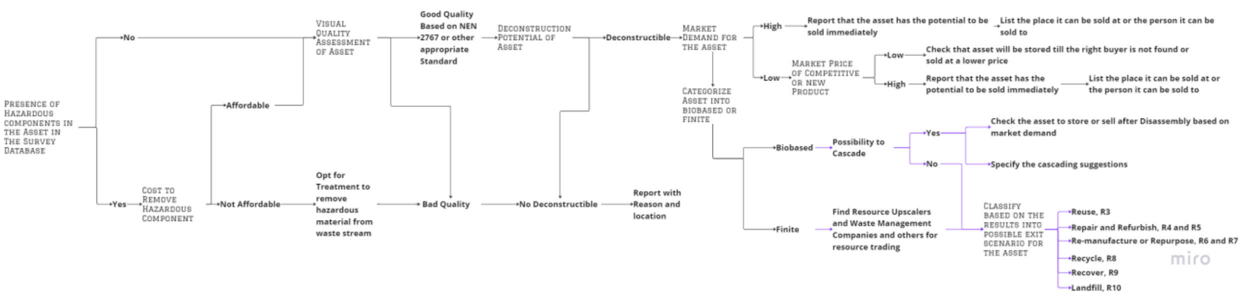

FIGURE 68 SEQUENCE FOR RESOURCE RECOVERY ANALYSIS

The analysis starts with checking for hazardous substances. If they are present, then an estimation into their amount and if the asset can be rid of it should be investigated. If the treatment is possible and affordable, then they can be upscaled, otherwise they are of bad quality and must qualify for treatment before waste disposal and fall into demolition category. If the analysis shows no presence of hazardous materials, they can go further for visual quality analysis along with the assets that can get rid of hazardous materials. Once the visual quality is analyzed and it is stated that they are of good quality, then they go for analysis for disassembly potential using scores presented in section 3.5 that help in not only disassembly potential, but also disassembly time and sequence if they are also mentioned as requirements for exit scenario and resource recovery team to handle. If a BIM model is present and used in the workflow, then disassembly scores can be calculated easily. Studies like Akinade et al (2015); Ge et al (2017); and Sanchez et al (2019) provide good examples for using BIM for deconstruction assessment. The bad quality assets fall under demolition category. The assets with disassembly potential are checked for market demand and fall under either in sell or store category.

The market demand estimation has been discussed in brief in section 3.5. and should focus on the marginal value that a product offers to the potential buyer and the marginal cost per product for the seller. If the former is more than the later than the CPP can happen. In a CPP, this also involves market demand of the new virgin product that has similar marginal value. Hence, it is essential to understand the market demand of virgin as well as second-hand product along with marginal cost to produce a product for CPP to happen. The demand and supply curve gives the market equilibrium for the product and leads to decision whether a trade would happen for the product in a CPP. The first order of business to calculate a market demand is to look at the projects nearby where similar products might be needed. The second is to check the suppliers that are in the market and see if they are willing to trade or what prices the virgin product has as compared to the assets in question. Furthermore, role of local community also plays an important role while announcing deconstruction and sale and hence if they are involved early, more understanding of what to sell and what to store can be identified quickly. The final and most important aspect is the regulation of selling reclaimed materials. It is possible that it is prohibited in the region where deconstruction is happening to sell the building assets. This is where online platforms come into picture. And if the online platforms are to be reviewed then there is a necessity to focus on their pre-requisites. So proper note of those should be taken and relevant information must be stored for the asset. Also, proper note of the interface should be taken and the form the information must be delivered in. For example, Breteler (2022) proposed a matching application (Figure 69) for buyers to search for similar products that they need on the online circular hub. This is specific for inhouse trading and uses a BIM model from Revit for a new project and matches with similar products using a mapping algorithm that use geometric information to carry on the research algorithms. Another example is searching on construction marketplaces as those listed in section 1.1 while investigating prices of competitive products.

Once the market demand is calculated, the assets with passable disassembly score are further classified into biobased or finite resources based on the presence of bio-degradable material in them. The biodegradable asset that can be further cascaded is marked for their next cycle. The asset which is not easily cascaded fall in with the finite assets that can be marked into categories based on the R framework. The sequence to check for exit scenarios should be based in a way that check for reuse should be done first followed by repair, refurbish, remanufacture, repurpose, recycle, and end with recover. Indicators such as *Circular Pathfinder, End of Life Index, End of Life Indices, Potential Recycle Index, Potential Reuse Index, Product Recovery Multi-Criteria Decision Tool, Reuse Potential Indicator, Remanufacturability Matrix, Economic-Environmental Remanufacturing and Reusability Potential* stated in section 3.5 can be used to help identify the exit scenario of the asset. Based on the input information required and available information, the correct indicators to assist in determining the exit scenario can be used. Furthermore, the availability of the type of upscalers and waste management companies can be used to determine the exact possibilities to retain or upscale asset value.

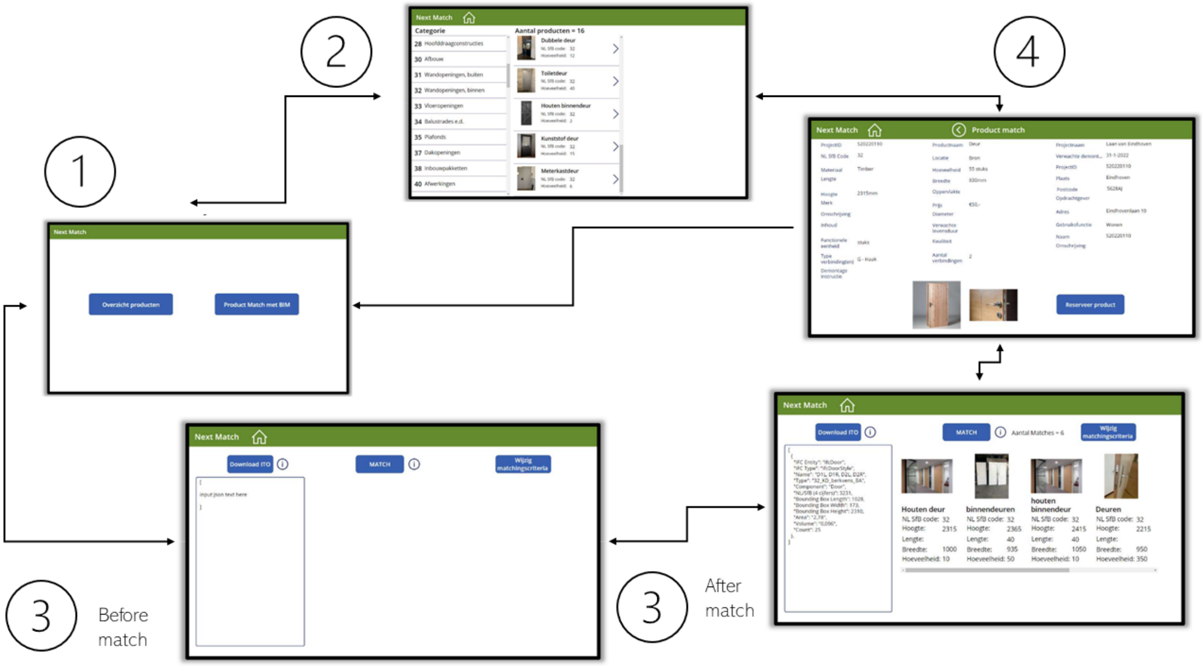

FIGURE 69 EXAMPLE OF MARKET SEARCH FOR SIMILAR PRODUCTS BRETELER (2022)

Further analysis based on economic feasibility and environmental impact is done based on the asset's exit scenario. Also, the quality inspection can further expand into calculating residual value of asset based on different parameters. All the essential indicators that can help in analysis have been stated in Figure 29. Once the sequence of analysis is specified, the methodology and standards are specified for each analysis to avoid any issues and discrepancy.

TABLE 24 TYPES OF ANALYSIS AND ESSENTIAL INDICATORS FOR EACH EXIT SCENARIO

S.NO	EXIT SCENARIO	ANALYSIS	INDICATORS	RELEVANT CASE STUDIES
1	Reuse	Residual Value	Residual Value Indicator, BIM-based Whole Performance Estimator	(Akanbi et al., 2018; Jiang, 2020; A. P. M. (Ton) Verberne, 2022; Xu et al., 2018)
		Durability	Material Durability Indicator	(Mesa et al., 2020)
		Environmental Impact on Reuse	LCA- operational and embodied energy	(Gemert, 2019; Ramon et al., 2022)
		Environmental Impact of Manufacturing Virgin Product	De milieukosten indicator, Embodied Energy	(Ecochain, 2021; Gemert, 2019; Stichting Nationale Milieudatabase, 2020; S. Su et al., 2020)
2	Repair or refurbish	Cost to repair or refurbish	LCCA of similar product	(Dawood, 2016; Gurum, 2018; Marzouk et al., 2018; Nour et al., 2012; van Oeveren, 2020)
		Environmental Impact due upscaling	LCA – Operational Energy	(Ramon et al., 2022)
		Environmental Impact of Manufacturing Virgin Product	De milieukosten indicator, Embodied Energy	(Gemert, 2019; S. Su et al., 2020)
3	Remanufacture or repurpose	Disassembly Potential of Constituents	Disassembly Potential, Ease of Disassembly Matrix	(Arko van Ekeren, 2018; Durmisevic, 2006; van Vliet, 2018; Vanegas et al., 2017; Zhai, 2020)

		Cost to remanufacture or repurpose	LCCA of similar product	(Dawood, 2016; Gurum, 2018; Marzouk et al., 2018; Nour et al., 2012; van Oeveren, 2020)
		Environmental Impact due upscaling	LCA – Operational Energy	(Ramon et al., 2022)
		Environmental Impact of Manufacturing Virgin Product	De milieukosten indicator, Embodied Energy	(Ecochain, 2021; Gemert, 2019; Stichting Nationale Milieudatabase, 2020; S. Su et al., 2020)
4	Recycle	Environmental Impact due to upscaling	LCA – Operational Energy	(Ramon et al., 2022)
		Environmental Impact of Manufacturing Virgin Product	De milieukosten indicator, Embodied Energy	(Ecochain, 2021; Gemert, 2019; Stichting Nationale Milieudatabase, 2020; S. Su et al., 2020)
		Costs in Recycling	End of Life Indices, Potential Recycle Index	(Akbarnezhad & Nadoushani, 2014)
5	Recover	Calorific Value of a Product	-	(Rogoff & Screve, 2019)

The fourth important element is the **external databases** that supplement the lack of information in the resource analysis. Based on the planning and the decided strategies on the required analysis, the information from external databases is required. This is largely influenced by data ownership and the cost to obtain data relevant for the analysis must also be considered. For example, LCA database, LCCA database, quality specification database, and supplier information database need to be constituted once the plan and strategy is done before moving on to the actual analysis.

Once the analysis is finished, the reports can be generated, and data can be handed over to the client based on the handover guidelines agreed upon before the start of actual deconstruction project. The key component for the information is the technical information of the inventory alongside disassembly potential, quality, market demand analysis. The environment and economic analysis report is essential but can be done by the deconstruction contractor based on the given information.

5.5 Partial Deconstruction Plan

It is the responsibility of the contractor and the associated deconstruction team who proposed the winning quotation for the partial deconstruction tender issued by the owner of the building to formulate this deconstruction plan before start of the actual partial deconstruction and update it when necessary, during the process to incorporate changes that are usual in the deconstruction business by means of the Change Control process in WBS. The plan should include a detailed work breakdown structure (WBS), along with an organizational breakdown structure (OBS) and cost breakdown structure (CBS) along with other necessary reports substantiating the decisions for the proposed WBS, OBS and CBS. Once a structure is agreed upon, a cost and schedule plan can be formed.

The partial deconstruction may resemble the conventional demolition procedure. However, it requires the expertise of both traditional demolition specialists and deconstruction specialists. It is necessary to constitute the percent of structure that can be upscaled and the rest goes for demolition. This is necessary to identify the sequence and plan for deconstruction and demolition when performed together as discussed in section 4.3 and section 4.4. The processes essential for inclusion in the partial deconstruction plan happen in pre-partial deconstruction which influence the plan along with the exit scenario and resource recovery plan and processes in the partial deconstruction phase act as main elements in the WBS and complementary breakdowns as shown in Figure 68.

Once the resource recovery and analysis strategies are established and the tender call by client is done, the first order of business is to analyses the exit scenario and resource recovery plan and update it based on the site inspection conducted by the contractor. This usually concludes with use of the updated plan to outline a strategy that the contractor would use to carry out the tasks. Based on the outline, a preliminary cost and schedule plan is proposed along with the quotation to the owner or real estate developer. If it matches the client requirements, the contractor enters contractual negotiations and lay down project requirements as shown in Figure 50. It is recommended to include the resource trading strategies within the scope of ownership of assets agreed upon by the building owner and transferred to the contractor are also included in the requirements.

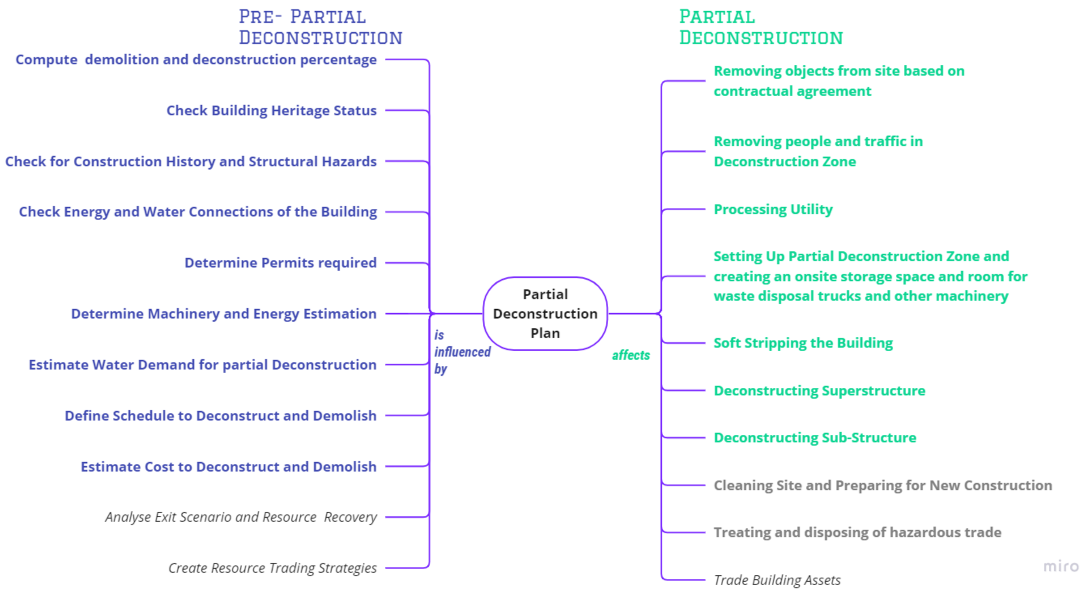

FIGURE 70 PROCESSES ON FOCUS IN PARTIAL DECONSTRUCTION PLAN

Once all the information is collected and broken down, the next step is to identify key members involved in the deconstruction process. The next step is to create a WBS. In the built environment, either a deliverable based WBS is used, or a phase based WBS as shown in Figure 71. The WBS usually has at least three levels. The first level is the major deliverable or phase for a deliverable based or phase based WBS respectively, the major components or deliverables are placed on the second level in that order and the work packages are usually on the third level. These work packages are manageable segments of work to facilitate planning and control of the scope, schedule, and cost. Based on the resource trading agreement, the WBS should also include the activity of trading building assets.

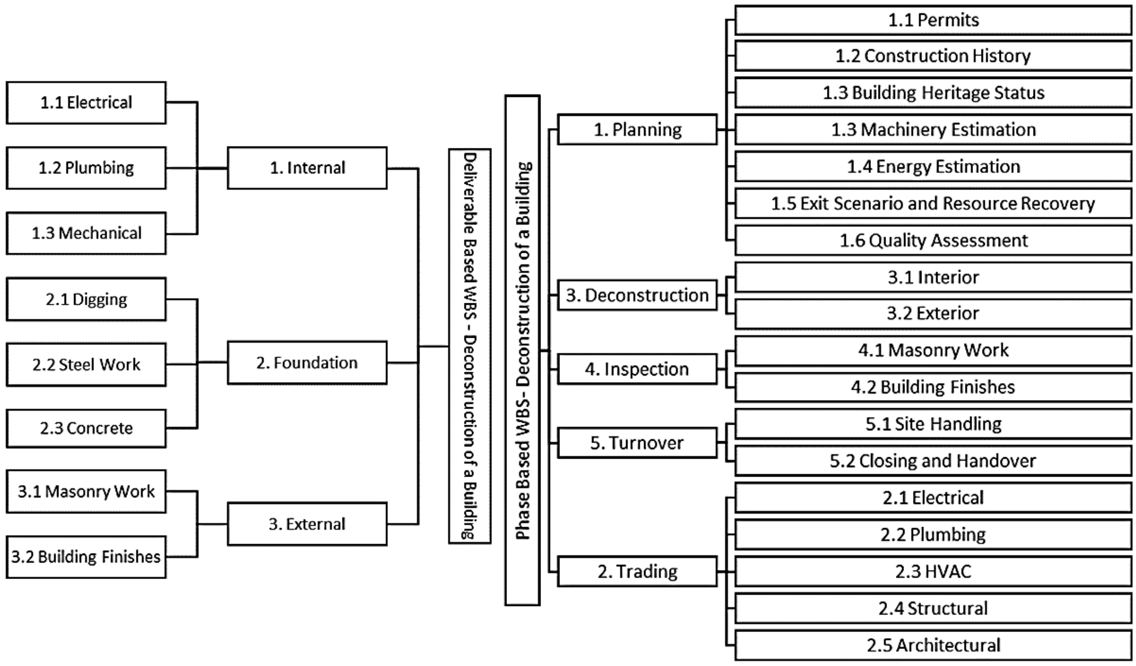

FIGURE 71 TYPES OF WBS FOR DECONSTRUCTION OF BUILDING

Once the level 1 elements are identified, it is necessary to verify that all the scope of work is included based on the contract guidelines. Then the process is broken down further till the level where each component of that hierarchical structure is unique and can be defined, managed, estimated and measured easily. The building decomposition categories discussed in section 4.3.2 such as NL/Sfb can be used based on the ease of the team to map the workflow and reports delivered by previous teams. Once the WBS structure is broken till unique work packages, the WBS dictionary can be formed. This includes description of work package level with detail covering the entire scope of the project. The information such as boundaries, milestones, risks, liability, owner, costs, and more are included in this dictionary.

After the constitution of WBS, it is important to constitute an organization breakdown structure with the key players identified earlier. The integration of OBS with the WBS ensures that all project tasks are identified and that appropriate levels of responsibility are assigned to each element of the work for purposes of planning, monitoring progress, tallying costs, and reporting.

Once a WBS and OBS are established, a CBS can be proposed. It is a document that details all the costs that are going to be incurred in the entire project. This is important as it helps in finding hidden costs. Furthermore, if resource trading is involved in the scope of the project, then additional processing cost of upscaling, transportation and storage can also be included in the project for that unique building asset. Based on the unique code for the building asset, and following a bottom-up cost analysis, deconstruction cost per asset can be found and recorded as the ownership cost that plays a key role in the resource trading that follows. After WBS is made, direct costs for each task or activity can be identified. Using disassembly time and other time prediction formula the time for each activity or task is determined. Based on the estimated time, the labor cost can be determined. It is also important to add some cost contingency in the CBS for issues that can be predicted beforehand such as labor issues, breakdown of machinery and more. The final step in a CBS is to check for economic sensitivity. This implies checking the CBS amount with initial estimates and control costs where necessary. If a BIM model of the building has been generated using existing drawings and or point cloud, BIM's 4D and 5D capability can help create a cost estimation and project schedule quickly.

Once these are determined a cost estimation and project schedule can be planned and resource trade planning and risk associated with deconstruction can be determined much like any construction process. After the detailed partial deconstruction plan is formed, the rest of the process follows the actual deconstruction activities that are explained in section 4.4.

5.6 Resource Trading Ecosystem via an Online Marketplace

5.6.1 Resource Trading

In this part of the process, as the name suggests, building assets are traded based on the resource recovery plan and deconstruction strategy adopted. The processes in Figure 72 are important while considering resource trading. These processes involve collection of personal belongings and inventory by the building owner and a discussion of actual trade plan with the contractor. Based on the exit scenario and resource recovery report, a price estimate is also drawn for the building assets that are considered worth selling. Once it is done, based on the resource recovery plan, the assets are traded for value restoration and selling or disposal after the quality assessment is performed after deconstruction. Some assets are sold to local vendors including resource upscalers, procurement managers of nearby construction projects and building owner's other projects, waste management and energy generation companies. Others are stored until the right buyer is not found and can be listed on an online platform for selling. As stated in the research scope, the focus of this part of the process is on trading of secondhand products using an online marketplace. This process is like the one stated by Breteler (2022) for the deconstruction company Bnext.nl[44].

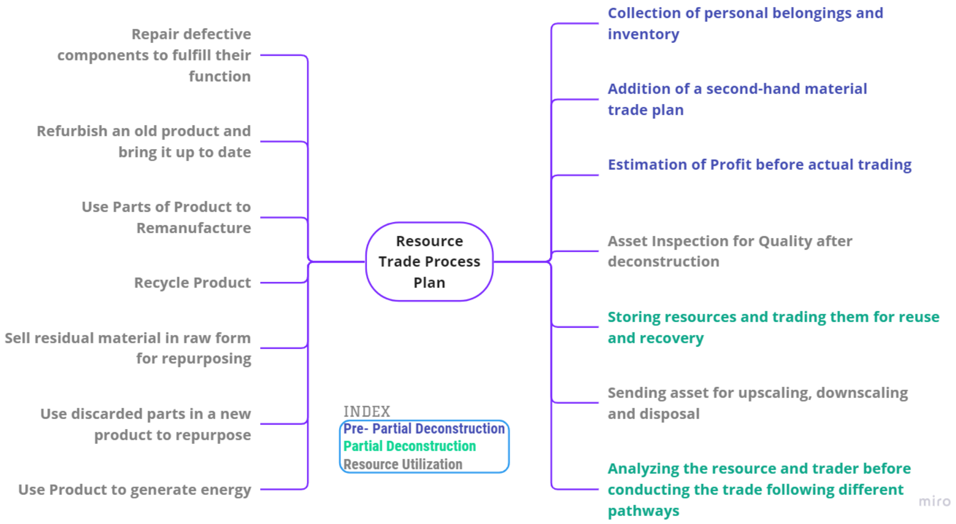

FIGURE 72 PROCESSES THAT CAN INFLUENCE RESOURCE TRADING

Before trading of any form can occur, it is essential to identify and preserve information for that particular asset to regulate and monitor asset inventory. A simple way of doing this is through QR codes. It is essential to tag each building asset leaving the site with a **QR code** for effective inventory management. This QR code can be used to monitor inventory leaving the deconstruction site along with the necessary asset information using a tracking application. One example of such app is Bnext.nl App[45]. This tag helps in keeping account of the stock and can help trace it by tracking its geo-location. It should also lead to a building asset passport as discussed which list location of deconstruction, previous owner information, analysis summary stating the environmental impact, deconstruction, and reassembly instructions if any, supplier, and quality report, along with technical information pertaining to the building asset and respective logistics to ease further trading and / or disposal.

[44] www.bnext.nl
[45] https://bnext.nl/over-bnext/bnextnl-digitaal

5.6.2 Second-Hand Product Trade in the Construction Industry

Basic Elements of a Second-Hand Product Trade

In general, with the rise in prices, lowering purchasing power due to diversifying interests and decrease in supply potential along with the trend to be sustainable, the demand for second-hand products is increasing widely as they are traded alongside new products. The trade can be categorized based on type of buyer as seller to direct user or seller to supplier. In the first case, there is usually no change in utility of the product but in the second case, there is a chance that the supplier may modify the product resulting in change in the utility function of the product. Also trade conditions may vary based on type of product. If a product is common, the pricing and trading conditions alongside product warranty are straight forward. If a product is unique, then pricing strategies and trading conditions are guided by the value of product in the market based on its unique selling point.

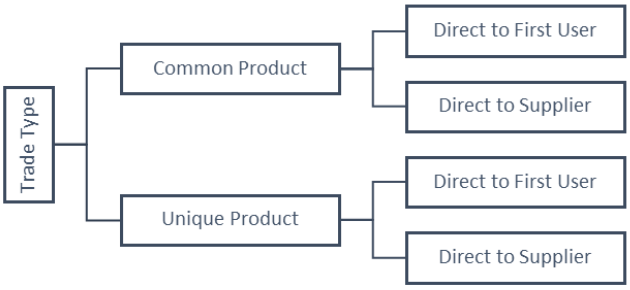

FIGURE 73 TRADE TYPES IN SECOND-HAND MARKET

The most common type of trade in secondhand market is a common product trade being sold to the first user. This type of second-hand trade is prevalent in vehicles electronics, educational products, clothes, clothing accessories and much more. This type of trade does not usually lead to change in second use of the product and the product have the same utility. They are sold off in physical markets such as auctions, in social chatting platforms, with a post on social media platform and more. According to X. Wen & Siqin (2020), companies like Amazon offers their clients the option to buy new or used merchandise. For example, a laptop is the most common and easy to sell product. When sold by an online retailer like Amazon and similar online retailers, a few common themes such as a picture of the used product from different angles, the name of the product, its technical features, its price (with and without shipping) alongside price of the brand-new product. Furthermore, there is a list of similar products with a comparison table for common features, the supplier and its user rating, the product reviews and buyer rating, answers to frequently asked questions and warranty information from the online platform that is guaranteeing its trade. Before such a product is listed by the online platform, there is selling request along with some specific quality benchmarks that the seller must comply to make the product available.

Online Market Places

The construction industry is also in the race for online trading of second-hand building products, but the online trading is not as easy as it is for the common trade type mentioned above. As the product can be quite complex despite being a common item, there is a chance that the utility function may vary on the second use, or the product can be so unique that it can't be traded further. To enable successful trading, it should also have information accustomed to a common second-hand buyer as established above. Furthermore, there is a need to solve the issues that are specific for the construction industry. One instance is that online purchases of used materials like steel and concrete for reuse are uncommon.

TABLE 25 COMPARISON OF DIFFERENT ONLINE PLATFORMS THAT FACILITATE RESOURCE TRADING OF SECOND-HAND MATERIALS

S.NO	ESSENTIAL INFO.	ONLINE PLATFORMS												
		1	2	3	4	5	6	7	8	9	10	11	12	13
1	**Accessibility to platform**	Yes	Yes, with restriction	Yes	No	No	Yes	No, site inactive	Yes	No, site inactive	Yes	Yes	No	Yes
2	**Registration Costs to access platform**	No	Yes	No	-	Yes	No	-	Yes	-	No	No	Yes	No
3	**Product Distribution across platform**	Project Location Based	-	Material Based such as Wood, metal and more	Only Floor	Tender for material procurement for buyer between supplier	Product Based such as Carpentry, Plumbing and more	-	Product Based	-	Material and Location Based	Material Based	-	Product Based
4	**Product ID**	Yes	Yes	Yes	-	No	No	-	No	-	No	Yes	-	Yes
5	**Product Photo**	Yes	-	Yes	-	No	Yes	-	Yes	-	Yes	Yes	-	Yes
6	**Amount**	Yes	Yes	Yes	-	No	Yes	-	Yes	-	Yes	Yes	-	Yes
7	**Title**	Yes	Yes	Yes	-	No	Yes	-	Yes	-	Yes	Yes	-	Yes
8	**Product Description**	Yes	Yes	Yes	-	No	Yes	-	Yes	-	Yes	Yes	-	Yes
9	**Availability**	Yes	Yes		-	No	No	-	No	-	Yes	No	-	No
10	**Product Measurements**	Yes	Yes	Yes	-	No		-	Yes	-	Yes	Yes	-	Yes
11	**Environmental Impact**	No	No	No	-	No	No	-	No	-	No	No	-	No
12	**Ads to go Circular**	No	No	No	-	No	No	-	No	-	No	No	-	No
13	**Quality Standards**	Yes, for some products	-	Yes	-	Yes	Yes, general quality account	-	No	-	Yes, for some products	Yes, general quality	-	Yes. General
14	**Price**	Yes	Yes	Yes	-	-	Yes	-	No, via email	-	Yes, for some products	Yes	-	Yes

15	**Sender Details**	No	Yes	Yes	-	Yes	Yes, Posted By	-	Yes, Posted by	-	Yes	Yes, based on product	-	No
16	**Possible Uses**	Yes, based on products	-		-	-	Yes, based on product	-	No	-	No	Yes	-	No
17	**Project Location**	Yes	Yes	Yes	-	-	Yes	-	No	-	Yes	Yes, based on products	-	No
18	**Shipping Cost**	No, Email for enquiry option	-	No, call for shipping cost	-	-	Yes, a calculator is available	-	No	-	No	No, but mention of pickup or not	-	No
19	**Instructions for reuse**	Yes, based on products	-	No	-	-	No	-	No	-	No	Yes, based on products	-	No

Legend –

#. Name of Online Platform – Source of Information

1. Beelen Next - Breteler (2022) and https://bnext.nl/shop-circulair
2. Insert by Buroboot - https://www.insert.nl/ and Breteler (2022)
3. Gebruiktebouwmaterialen - https://gebruiktebouwmaterialen.com/
4. Ashlar/ Former Vogueboard - https://www.ashlarsales.com/market/
5. Material Bidders - https://www.materialbidders.com/, https://www.youtube.com/watch?v=9US8dYfy4OA
6. Enviromate - https://www.enviromate.co.uk/
7. Construction Retail - https://www.constructionetail.com/about-us
8. Find Building Material - https://findbuildingmaterial.com/
9. Construction Marketplaces - https://constructionmarketplaces.com/
10. Oogskart - https://www.oogstkaart.nl/
11. Restado - https://restado.de/
12. Excess Material Exchange - https://excessmaterialsexchange.com/nl/
13. Rotor Deconstruction - https://rotordc.com/shop

As established in Section 1.1, despite the issues stated above, there already exist some solution for online trading. Some services that sell or facilitate resource trading are listed in the Table 25. These platforms differ according to the materials they provide and how they set their prices. Some are accessible to everyone, while others are only for businesses and require registration fees. Their pricing policies change depending on the item's base price, logistics, market demand, and material quality. Most of them don't offer sufficient details on the effects on the environment or the caliber of the materials to promote the use of circular materials. When marketplaces sell goods made from biological materials, there are some exceptions in terms of specification of their environmental and social impact which may make buyers tend towards considering them for further use.

CBMs in Online Trading

Section 3.4.4 provided a brief description of these CBM elements - circular supplies, resource recovery, product life extension, sharing platforms and product as a service. For an online platform to be successful in establishing a circular ecosystem, the inclusion of these CBM elements is important while designing it due to the following reasons.

- A product that is circular and sustainable can be a better choice on a trading platform as compared to a product which is harmful to the environment or is composed of non-circular materials.
- Additionally, creating a platform to initiate upscaling and trading materials can help in utilizing the recovered resources. For example, online marketplaces for reused or recycled building materials (CirMar, Oogstkaart, Excess Material Exchange, Circle Market (textiles) not only sell circular and sustainable material but also create a link between resource upscalers, although unintentionally.
- Moreover, products with extended lifespan and those require least maintenance can also have better residual value at the end of their life and hence would be a great choice for trading at an online platform that supports circular procurement.
- Furthermore, an online platform that can create sharing of tools and resources rather than selling them ensure optimum and continual utilization of sources and create new business opportunities.
- Also, using product as a service creates an opportunity to use second-hand materials and encourage better resource management and hence is an essential model to help in CPP.

5.6.3 Essential Elements necessary for a CPP Marketplace

In section 3.5, the list of indicators and assessments that can be relevant for CPP medium were presented that helped in identifying certain elements of CPP. Furthermore, section 5.6.2 further expanded certain elements that may prove useful for the online marketplace. Figure 74 showcase these elements along with relevant CPP indicators that can be used while using some elements.

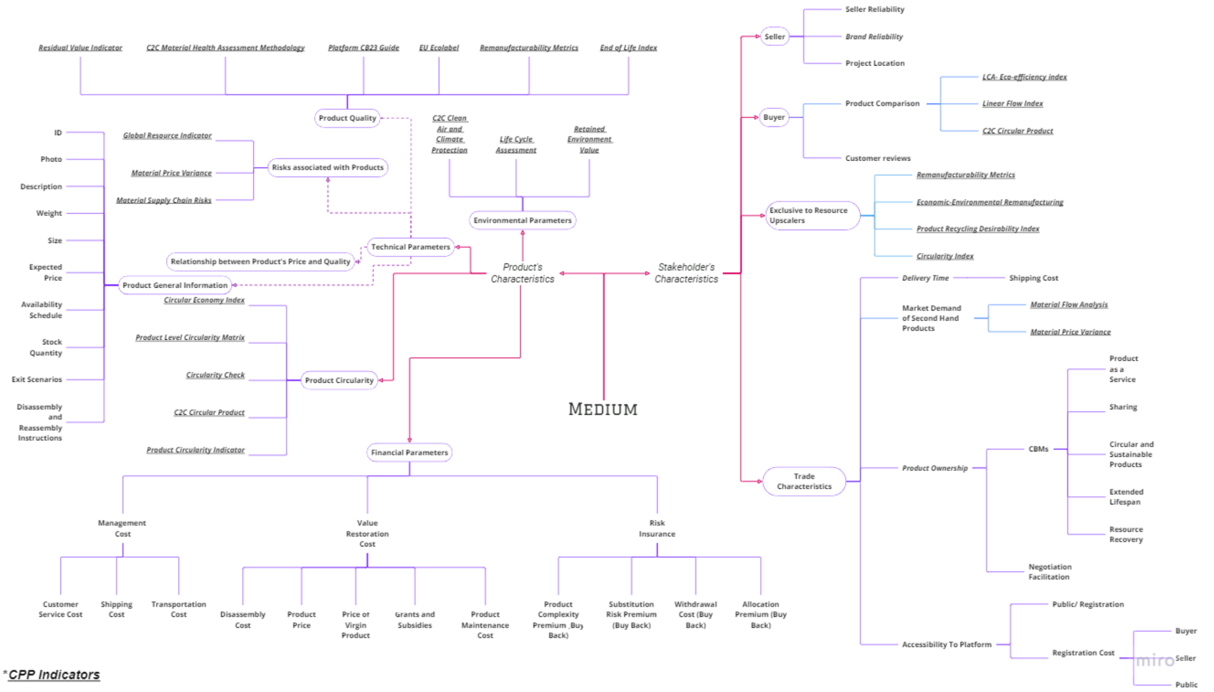

FIGURE 74 CPP ELEMENTS THAT CAN INFLUENCE THE ONLINE MARKET PLACE

Based on the Figure 74, the key aspects to design an ideal CPP online marketplace are summarized below.

1. **Seller Registration** – This entails providing the correct information and performing the necessary checks that the seller must go through to be eligible to use the platform. It can involve registration costs and user verification for providing authenticity to the trading platform. These generally include name, company, role, age, country of operation, address, company email address, phone number, valid ID copy to be uploaded while making an account as a verified seller.

2. **Buyer Registration** – This entails basic details for a trade to happen that a new platform user must enter. These generally include name, company, role, age, country of operation, address, company email address, phone number, valid ID copy to be uploaded while making an account as a buyer on the platform. Usually, credit card information is asked at the end of transaction.

3. **Type of Buyer and Seller** – As stated before, CPP is a process that involves a seller and a buyer selling a product over a medium through some process. In a CPP, based on the proposed methodological framework, the following trade parties can be involved as stated in Table 26.

TABLE 26 POSSIBLE SELLERS AND BUYERS IN A CPP

S.NO	SELLER	BUYER
1	Owner/ Real Estate Developer	New User (Architects, Builders)
2	Owner/ Real Estate Developer	Resource Upscalers
3	Contractor	New User

4	Contractor	Resource Upscalers
5	Contractor	Waste Management Companies
6	Resource Upscalers	New User
7	Resource Upscalers	Resource Upscalers
8	Resource Upscalers	Waste Management Companies
9	Manufacturer / Supplier of (Semi/non/fully) Circular Products	New User
10	Manufacturer / Supplier of (Semi/non/fully) Circular Products	Resource Upscalers
11	Manufacturer / Supplier of (Semi/non/fully) Circular Products	Waste Management Companies
12	Supplier (with Buy Back Option)	New User (Owner)

For a trade to happen, a seller needs to provide enough information that can entice the buyer to buy that product which solves their purpose for the product in question. The CPP indicators relevant for buyers could help in the process to identify the needs of the buyer as stated in as shown in section 3.4.5.2, and information that is relevant for the buyer to be put on an online platform as shown in section 3.5. If the sale is done between a seller and a resource upscalers or waste management companies, the product information needed while making the sale changes as compared to other a normal traditional sale of a product between a new buyer such as an architect or procurement agent and a seller. However, the changes are dominant on the seller side in terms of the intent to sell and not the buyers as they see all products that they can use for their varied purposes after sale.

Another important case is the trade agreement happening with a supplier and a buyer with option of buy back as discussed in sub section 3.4.5.3. For such products, a mark showing buy back option must be listed and the necessity to agree on trade and maintenance agreement becomes necessary during the negotiation phase. The online marketplace can make profit by entering a quality moderator to check for maintenance during use and proper replacement process as agreed upon.

4. **Product Catalogue Classification Criteria** - The product catalogue classification is necessary to define the user interface such as material, product, geographical location, external database. As shown in the Table 25, it is usually divided based on material, product, or location. Other categories can be based on systems such as architectural, MEP and structural or based on exit scenarios such as reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover.

5. **Product Search** - This part involves how buyers search generate results and the backend processes to make the user interface convenient and easy to search based on parameters like proximity to user location, relevant product type and the smart search algorithms that identify the right products based on needs provided by the buyer such as type of exit scenario, type of product, type of material, circularity, sustainability, price, and others. It also involves scraping and crawling queries based on keywords provided, or by specifying product size, weight, quantity, and quality.

Breteler (2022) developed a matching application where new architects and contractors can upload their BIM models or specific BIM model objects to find similar products. The application employs similarity matching to match reusable stock items with JavaScript Object Notation (JSON) data from BIM models. This makes it easier to locate things with several uses, and each criterion may be used to narrow or broaden the search. Breteler (2022) claimed that in the corresponding app's proof of concept, the user must manually manipulate JSON data. Further, it was said that the automatic connection of data between two environments of a BIM model and the corresponding application, where JSON data is given back and forth in the back end without much interaction simplifies the process, and it was suggested that it be improved prior to deployment.

6. **Similar Product Suggestions** – Based on the product search, the buyer can navigate and select a product that might match the buyer’s need. Once on the product page, the list should be displayed

showcasing products of different sellers that are similar and the virgin product with price information to guide the buyer during decision making.

7. **Product Filter and Sorting** - Order of product listing on the online platform – This entails checking the better performing product sales, putting a certified mark on the seller, creating filter options for the list of products based on parameters that the buyers may wish to choose the product upon such as environmental impact, circularity score, amount of virgin material in the product, price of the product, presence of disassembly instructions and quality score based on the quality assessment during product registration.

8. **Product Registration and Product Passport** – Once the seller registers, they are eligible to upload products that need to be sold. While uploading products, basic product information such as ID, photo, description, its geometric information, project location and others can be asked. Once the product with the minimum information is uploaded, it is verified by the moderators of the platform.

The information provided by the seller on registration will be used to create a product passport. This passport also includes information on the quality score/residual value, circularity score, MKI value, expected lifespan and use instructions and the predicted price of the product based on the wishes of the seller and information that the seller is keen to make public for prospective buyer.

9. **Price of the product** – Based on the explorative research, it can be stated that the price of a secondhand product should be set in such a way that the if the marginal utility of the second-hand product is more than the marginal utility of the virgin product with the similar performance. Hence, a closer look at the valuation of a second-hand product is necessary and should include not just the base price, but also factors such as its impact on the environment calculated in form of shadow price, the product's utility after first use and depreciation, calculated in form of residual value, and the lifecycle cost of the product with focus on cost to restore its value and make it eligible for second use, calculated in form of transition cost. Also, with secondhand products there are certain risks and selling a product on an online platform requires some capital. Furthermore, selling a product on an online platform requires some capital. Hence, while determining the pricing of the secondhand product, the following should be considered.

TABLE 27 ELEMENTS AFFECTING SECOND-HAND PRODUCT PRICING

S.NO	PRICE ELEMENT	DEFINITION
1. Competitive Pricing		
1.1	Price of virgin product with similar purpose	This is the market price of a product that has the same functional value and is available for sale alongside the second-hand product. If it is more than the price of a second-hand product, it is positive influence on trade of the second-hand product.
1.2	Shadow Cost of the virgin product with similar purpose	This is the MKI based environmental impact value for the virgin product that has the same functional value and is available for sale alongside the second-hand product. If the MKI value of virgin product more than the secondhand product, it would be a positive influence on trade of the second-hand product.
1.3	LCC of virgin product with similar purpose	This is total lifecycle cost incurred by the virgin product that has the same functional value and is available for sale alongside the second-hand product. This is not necessary in terms of determining price but can be used to influence the buyer's decision to choose the secondhand product over the virgin product if there is not enough intensive provided using the shadow cost and market price parameters.
1.4	Shadow cost of the product	This is the MKI based environmental impact value of the second-hand product. When everything else is constant, a secondhand product with higher

		MKI will have lower chances to sell than a similar product from a different supplier.
1.5	Operational energy for value restoration	This is the energy consumed to restore the product to its original or new value for its next lifecycle. A high operational energy than the one to produce a new product implies unsuccessful circular procurement.
1.6	Subsidies and Certification Benefits	This is the benefit that a product may incur due to its eligibility to a certain subsidy or the added value due to a certificate attached to it. A product eligible for subsidy has more likeliness to be bought that one without it. Hence, a high-priced secondhand product with subsidy can still have a fair chance to be traded.
2. Value Restoration Cost: If the value restoration cost is less than the cost to produce a virgin product, then it has higher chance to be sold given that economies of scale don't influence the price of the virgin product.		
2.1	(Dis)assembly cost for (dis)assembling products	This is the cost incurred to disassemble the product from the deconstruction site.
2.2	Storage cost	This is the cost incurred to store products as inventory in a warehouse before a sale can occur.
2.3	Transportation costs	This covers the cost to transport the product from deconstruction site to the storage till resource trading occurs.
2.4	Transition Cost for value restoration	The transition cost of the product is the cost to restore the product to a desired value for making it eligible for trade. It can be expressed in forms of the amount of money to fill the quality gap that a product has based on its current residual value and the desired value or quality threshold. Verberne (2022) used system dynamics to formulate residual value based on factors such as quality, disassembly, legislation and culture. Jiang (2020) calculates the residual value as a function of efficiency of circular design strategies and deterioration factor.
3. Trade Commission: These are fixed cost due to use of a mediator for resource trading and should be considered while pricing a product.		
3.1	Trade Handling and Management Cost	This is the cost that is incurred while providing services to manage the trade of the product through the online platform. It can include the registration costs, legal expenses and other expenses that are incurred to make the resource trade successful.
3.2	Shipping Cost	This covers the cost to transport the product from storage site to the new buyer after resource trading occurs.
3.3	Taxes	This is the taxes that are levied by the government and other parties on a
4. Risk Insurance Premium: These are fixed cost due to risk associated with trade and economics and must always be considered while pricing a product.		
4.1	Economical risk premium	It caters to inflation, insecurity in exchange rates, and price fluctuations due to economic changes.
4.2	Liability Insurance	This covers the cost due to accidental damage to goods and can cover time before trading negotiations start till the time of handover to the buyer.
4.3	Substitution risk premium	It incurs cost that cover the risk of competitive goods. These costs are covered only during a buy back agreement.
4.4	Allocation premium	It covers for market imperfections while transitioning from a linear economy to a circular economy. These costs are covered only during a buy back agreement.
4.5	Complexity premium	It covers risk on the selling price in terms of 'likeliness' a product can be retrieved from the owner. The less complex a product is 'packed' in a building, the more likely it is to change in objects and therefore enlarges the future potential of a product. These costs are covered only during a buy back agreement.
4.6	Withdrawal cost	It covers the risk if return products that can't be cascaded or go through the R framework to be returned to biological or technical cycle. These costs are covered only during a buy back agreement.