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MASTER

Building asset valuation in a circular ecosystem
A guide to circular trading and procurement

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Construction Management and Engineering

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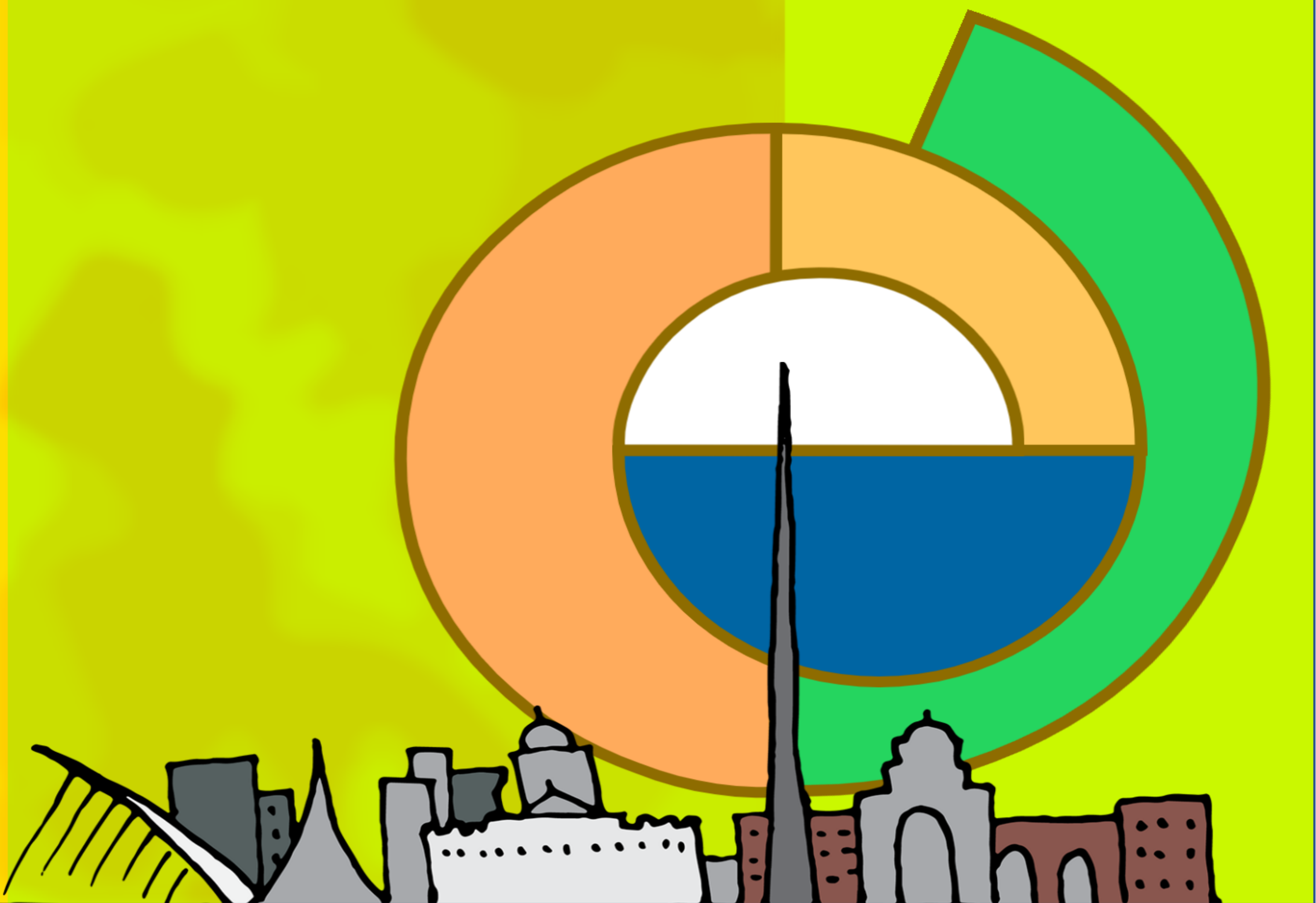
BUILDING Asset Valuation in a Circular Ecosystem

A guide to circular trading and procurement

MSc Thesis
Siddharth Panjwani



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BUILDING ASSET VALUATION IN A CIRCULAR ECOSYSTEM

A guide to circular trading and procurement

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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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1. Chapter 1: Introduction

Human consumption has been increasing rapidly. This trait can be seen when we look outside the window; we observe a concrete jungle. This image implies that our construction industry is quickly churning out products that need a lot of raw materials as input. Since the earth's resources are finite, it is high time to look at the construction supply chain and make it much more sustainable. This project tries to achieve the first step by proposing a circular trading ecosystem.

1.1 Need for a Circular Trading Ecosystem

In the Netherlands, the construction industry has been working to transit to a circular ecosystem. The raw materials go through a circular loop but with residual waste, as shown in Figure 1. Nevertheless, construction and demolition waste (CDW) are among the heaviest waste streams. The sector accumulates about 25% - 30% of all waste in mass (kg) generated in the EU (Oorsprong, 2018). Hence, it has been crucial to focus on the circular transition. However, shifting to a circular economy (CE) has not been a straightforward process as it requires substantial changes in the value chain.

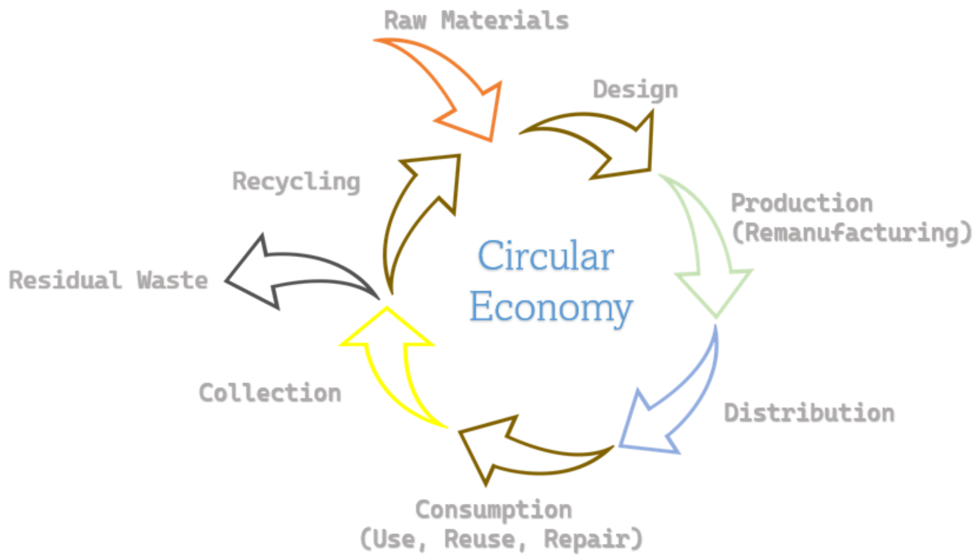


FIGURE 1 CIRCULAR ECONOMY MODEL SOURCE: (EUROPEAN COMMISSION, 2015)

"Transitie Agenda - Circulaire Economie, 2018" (Rijksoverheid, 2018) describes the strategy for achieving a circular economy for the construction industry in 2050 and contains the agenda for the 2018-2021 period with a proposal for a monitoring ecosystem. According to Rijksoverheid (2018), the recommended strategy to introduce circular practices in the construction industry is to upscale and achieve high-quality reuse. This task should be done while focusing on recycling and refabricating costs. Following are the critical points from the agenda to make the circular building economy successful (Rijksoverheid, 2018).

- To make the circular ecosystem tangible, measurable, and transparent,
- To develop a common language that defines the terms and definitions related to circularity,
- Moreover, to measure a set of supported measurement methods to measure circularity levels (circularity indicators).

One of the attempts to achieve this objective came from Platform CB'23. They achieved a number of goals of *"Transitie Agenda - Circulaire Economie, 2018"* and had working agreements with the

Transition Team (Platform CB'23 - Actieteam 'Framework Circulair Bouwen,' 2019). They created a new action team investigating circular procurement ('circulair inkopen') and what it means to set up a circular purchasing process (Platform CB'23, 2021). The second example framework to transit to a CE and implement a circular procurement strategy is provided by Ellen MacArthur Foundation (Ellen MacArthur Foundation et al., 2021). The third standard framework developed by the European Union to incorporate CE is Level(s). It "*provides a common language for assessing and reporting on the sustainability performance of buildings. It is a simple entry point for applying circular economy principles in our built environment.*"(European Commission, 2021). In short, this levels framework allows the buildings to be evaluated on different sustainability indicators, as shown in Figure 2.

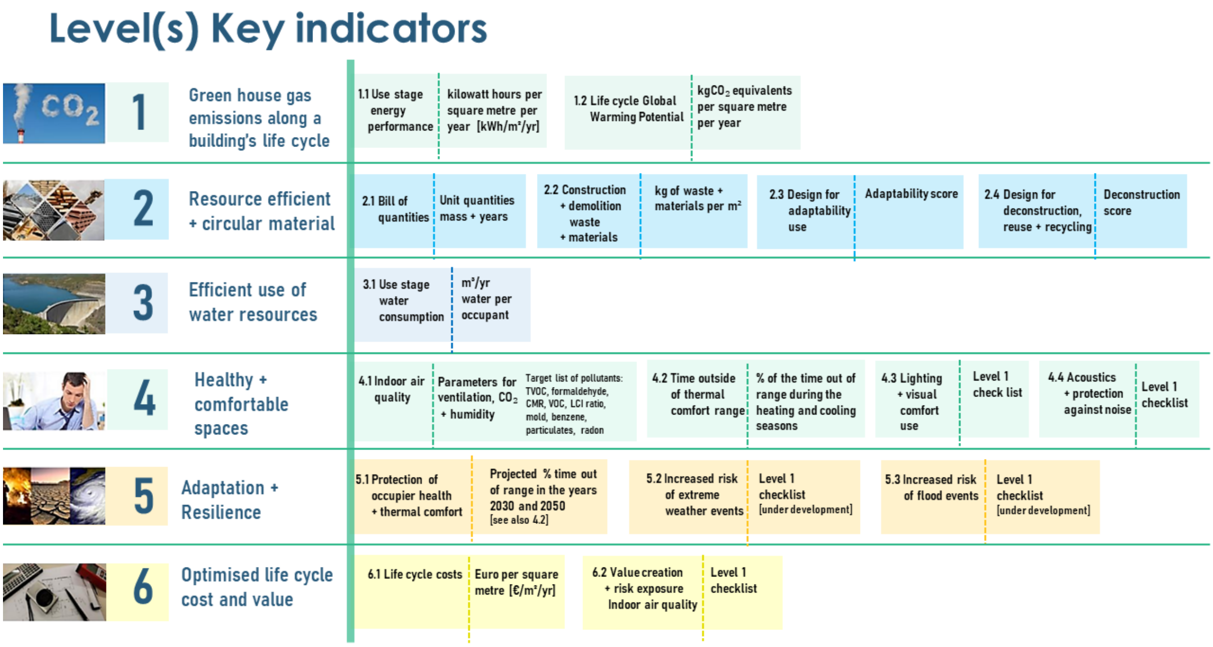


FIGURE 2 LEVELS, EXAMPLE OF A CIRCULAR FRAMEWORK(EUROPEAN COMMISSION, 2021)

Considering the above, it is evident that there is a need for an ecosystem that provides trading solutions and tools that enable the purchasing manager to retrieve pertinent information regarding the quality and immediate worth of commodities to be acquired.

As shown in Figure 3, some of the online trading solutions that enable material procurement in the construction industry are Ashlar(Formerly Vogueboard) [1], Material Bidders [2], Enviromate [3], Lafargeholcim [4], Insert [5] by Buroboot, Construction Retail [6], Find Building Material [7], Construction Marketplaces [8], Oogskart [9], Gebruiktebouwmaterialen [10], Restado [11], and Excess Material Exchange [12]. These solutions vary based on the materials they offer and their pricing approach. Some are open for all, but others are exclusive to businesses and impose registration costs. Their pricing strategies vary

[1] https://www.ashlarsales.com/market/
[2] https://www.materialbidders.com/
[3] https://www.enviromate.co.uk/
[4] https://www.lafargeholcim.com/digital-helps-build-new-normal
[5] https://www.insert.nl/
[6] https://www.constructionetail.com/about-us
[7] https://findbuildingmaterial.com/
[8] https://constructionmarketplaces.com/
[9] https://www.oogstkaart.nl/
[10] https://gebruiktebouwmaterialen.com/
[11] https://restado.de/
[12] https://excessmaterialsexchange.com/nl/

based on material quality, market demand, logistics, transaction costs, and the base price of items. Most of them do not provide enough information on the environmental impacts or material quality to encourage the procurement of circular materials. There are exceptions to the case when marketplaces sell bio-based products. However, purchasing second-hand materials on an online marketplace such as concrete and steel for reuse is not the norm.

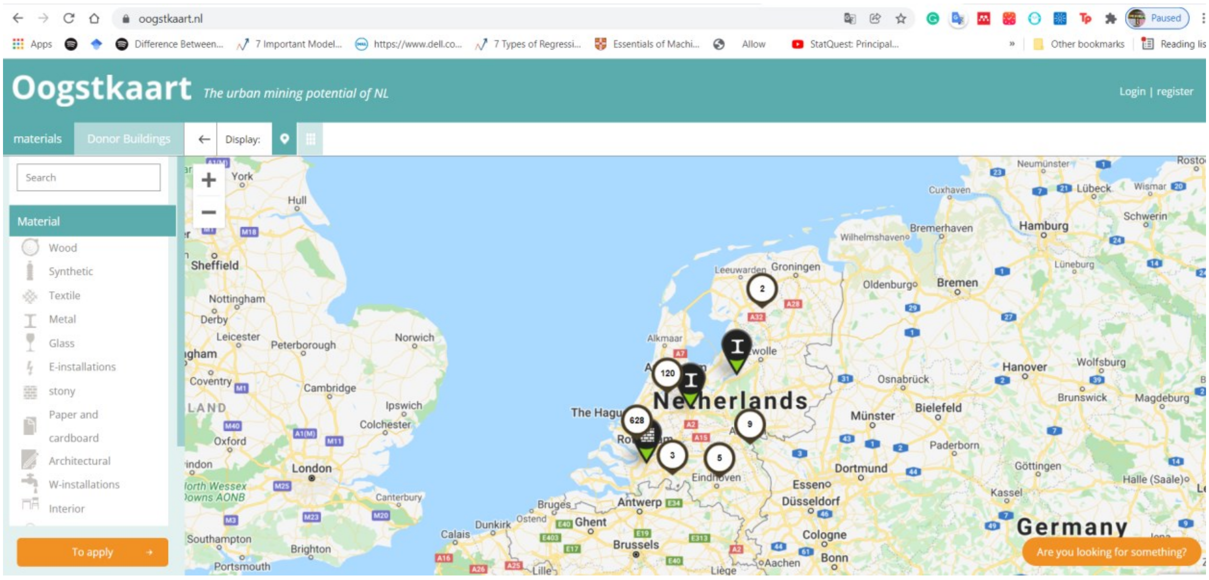


FIGURE 3 EXAMPLE OF A TRADING PLATFORM FOR SECOND-HAND MATERIAL

Many tools in the market provide information on material's lifecycle and circularity, such as one-click LCA, Madaster, Upcycle EA, GPR Gebouw, MPG toetshulp, and MPG Calc[13], MRPI- MPG software[14], DuboCalc[15], Mobius[16], Environdec, [17]and more as shown in Figure 4. These tools indicate product performance based on product lifespan, lifelong carbon emissions, circularity score, demountability potential, and more. These parameters may assist in giving users relevant information to make relevant decisions on buying second-hand construction material, but these are not linked to the online marketplaces.

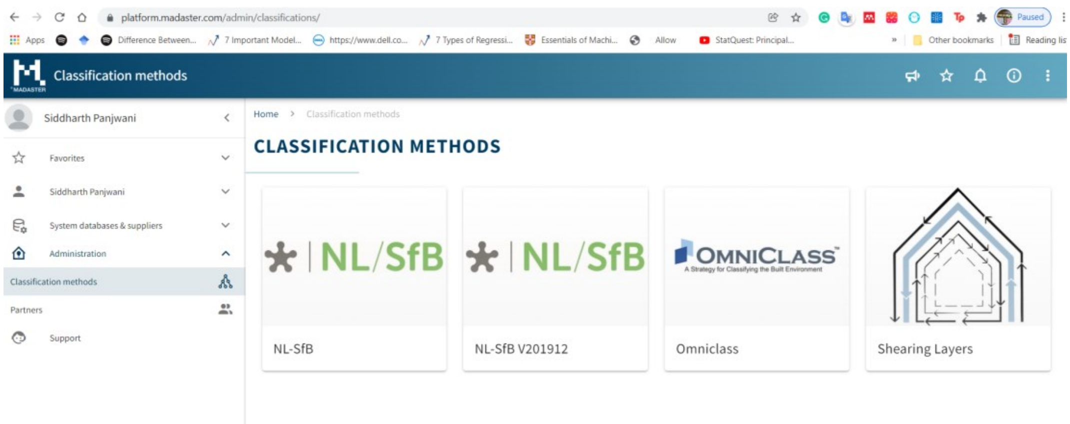


FIGURE 4 EXAMPLE OF A TOOL AVAILABLE FOR STORING INFORMATION OF A BUILDING

[13] https://dgmrsoftware.nl/producten/gebouw-en-installatie/mpgcalc/
[14] http://www.mrpi-mpg.nl/Home/Home
[15] DuboCalc
[16] https://ecochain.com/solutions/product-environmental-footprint/
[17] https://www.environdec.com/

Furthermore, the quality of a material to enable its second use is also an important aspect that is not clearly stated on e-commerce websites such as those stated above to have a transparent judgment. Moreover, it is usually not clearly stated in the individual discussion between a buyer and a seller before finalizing a trade contract. This omission can occur due to the complex relationship between the quality of material and its further use.

Therefore, an exploratory study into the possibilities, usefulness, and necessity of a phased realization of a publicly accessible framework that can serve as a baseline for numerous additional circular frameworks is required. In addition, this framework should emphasize the use of existing building material stocks for circular construction, as well as their environmental impact, demand, quality, and market value.

1.2 Research Objective

This research project proposes a framework for a circular ecosystem that guides in valuation of building's components.

Based on the research objective stated above, the ecosystem should allow building's components to be valued and restored prior to their deconstruction and should enforce a circular loop. The value of an asset, according to Damodaran, (2015) is a prerequisite for making wise investment choices. The asset's value determines the appropriate selling price. Figure 5 highlights three key principles for creation of valuation model and has been considered while proposing the circular ecosystem.

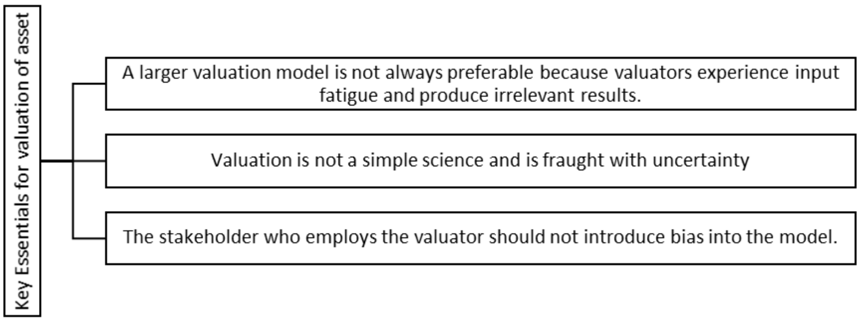


FIGURE 5 ESSENTIALS FOR ASSET VALUATION

Moreover, the main problem in this research is two-fold in nature. First, it focuses on proposing a framework for a circular trading ecosystem. Second, it proposes essential elements for assessing value of product listed for trade in that circular trading ecosystem. Hence, the research objective deals with challenges stated as follows:

- *To make a usable framework that generates relevant output for a circular ecosystem.*
  The primary function of the ecosystem is to facilitate accessibility and compatibility with various industry-wide tools. Consequently, an examination of the tools utilized by designers, engineers, asset managers, contractors, and waste management companies are necessary, and the adoption of standards that facilitate information sharing should be the objective.

- *To assess the product's lifecycle cost, which considers the second generation of the product and circularity score.*
  Life cycle costing is not a novel concept. However, with circularity introduced, it is necessary to realize this ideal state, a total life cycle cost model (TLCCM), which considers the first generation of the product use and its most likely second-generation(s) use. This model should consider product's environmental impact and financial value during its first-generation use

along with the cost that can be incurred while transiting to the subsequent generation for its next use (Bradley et al., 2018). Therefore, a framework for subsequent creation of such a cost model is presented in this thesis.

- *To assess the residual value that depends on the asset's quality at the transition stage in the asset's lifecycle.*
  As Iacovidou et al. (2019) indicate "*quality measurements vary across different sectors and products. Existing regulations, legislation, and standards often impose these measurements, and other quality assurance and testing protocols, or they are arbitrarily defined based on stakeholder expectations regarding what properties quality should reflect*". Furthermore, lifecycle of an asset needs to be analysed, and its degradation predicted to assess its quality. Kwok et al. (2016) state that quality prediction does not always address degradation mechanisms and corresponding kinetics or defects in material. For non-composite materials like concrete or metal, quality prediction is well documented. Nevertheless, it becomes an arduous task for composite materials like fiber reinforced concrete. Hence, the integration of a quality assessment framework is a challenging task. Therefore, a primitive visual quality assessment framework alongside the use of NEN2767 standard have been proposed in this thesis. Moreover, relevant existing studies suitable for quality assessment have been presented in this research.

1.3 Research Questions

The following research question will be answered throughout the research project based on the abovementioned problems.

"What is an ideal framework for valuation of building components for the construction industry in a circular ecosystem?"

The following sub-questions will be used to answer the main research question.

TABLE 1 SUB QUESTIONS FOR RESEARCH PROJECT

SQ#	QUESTION
1.	*Why is there a need for a circular trading ecosystem?*
2.	*How is circularity measured in the construction industry, and what circularity parameters are relevant while valuating building assets for procurement in a circular ecosystem?*
3.	*How does the valuation of second-hand products occur in the circular ecosystem?*
4.	*How does the environmental impact of building's component affect its value?*
5.	*How does the changing quality of building's component affect its value?*
6.	*What are the essential requirements for an application to use circularity parameters and BIM that guide the decision of stakeholders to procure second-hand products?*

1.4 Relevance

Although resource management and its utilization has already been a much-discussed research topic for years, with the advent of smart technology in the past decade, it becomes quite important to understand how they have been and can be used to limit our resources and replenish them at any concerning level and for any specific industry or ecosystem. As stated by Kate Raworth in an interview (Hens, 2019) with Tine Hens, a journalist on climate change for MO*, it is essential to redesign institutes and align them with the cycles of the living world to create an economy that regenerates when the wealth is distributive rather than concentrated without any compromise.

The construction industry and its suppliers of raw material in the complex supply chain are parts of the institutes that are in dire need to align themselves with the regenerative cycles of the world we live in. And smarter and environmentally friendly procurement of resources is one step forward. van den Bergh (2020) states that "*circular economy denotes the aim of achieving high rates of material recycling and product reuse to reduce or prevent resource scarcity.*" Hence, the terms of equal distribution, smart and optimized utilization and sharing of resources, and sustainable regeneration are common while dealing with circularity as a concept.

As discussed before, the construction industry is a resource-intensive industry so planning and creating mechanisms for smart resource utilization becomes important. One can see that a lot of sectors associated with the built environment have started using AI, big data, BIM, cloud services, and more. However, stakeholders involved in the procurement of resources find it difficult to implement digital infrastructure relevant to make the process circular mainly because:

a) Procurement occurs in many stages staggered along the project lifecycle and;
b) Procurement process is not a standardized or transparent process with the demand and needs changing based on the function that a product (building's component) serves, and the monetary value it demands.

Furthermore, Sönnichsen & Clement (2020) state that *"Awareness and knowledge of circular procurement principles have a profound effect on stakeholder behaviour and practices. These factors are even more important to the implementation and dissemination of circular procurement than additional financial resources."*

Hence, this explorative research is necessary to understand and hopefully provide some clarity to enforce these digital tools and theories and define a framework consisting of possible solutions to introduce circular principles into second-generation procurement or material procurement in general.

1.5 Research Design

This research is divided into three stages as shown in Figure 6 and will aim to answer the six sub-questions of the research.

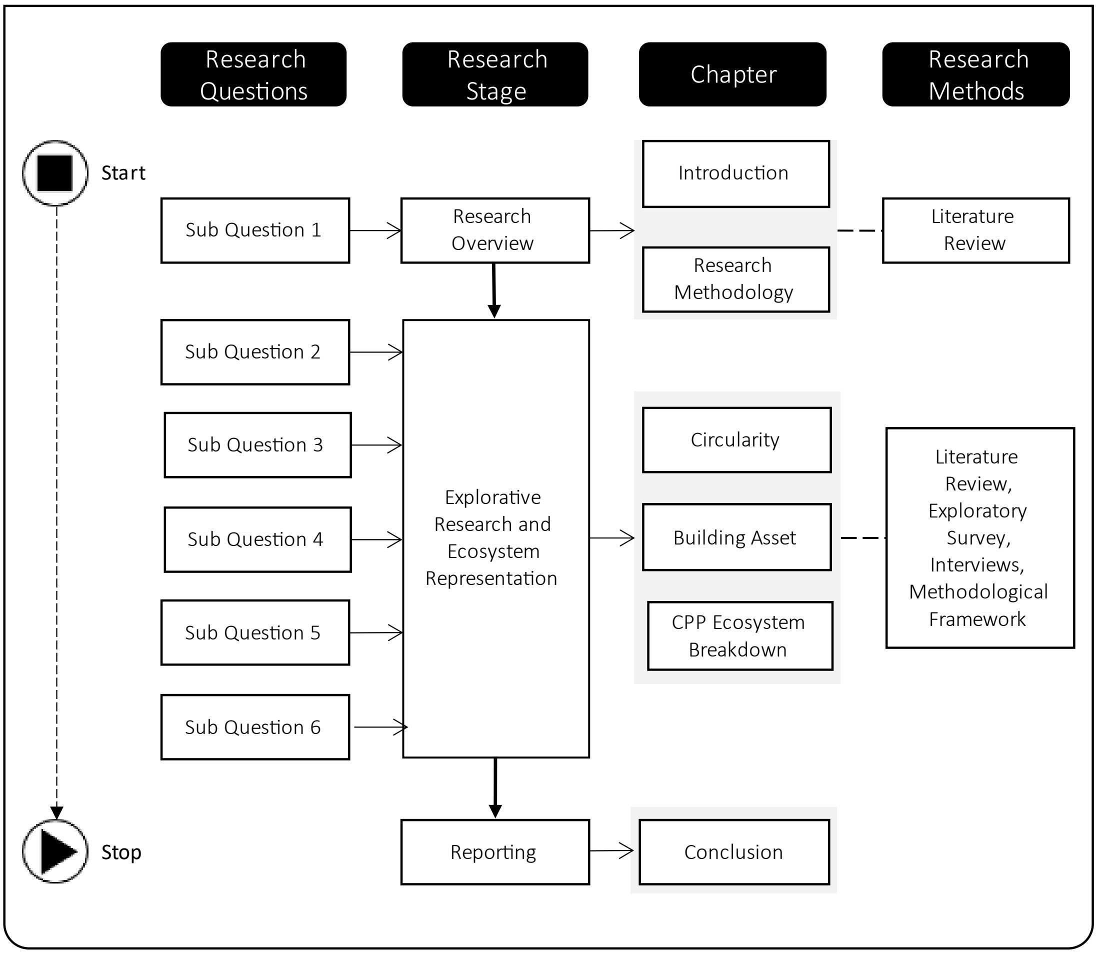


FIGURE 6 RESEARCH DESIGN MODEL

1.5.1 Research Overview

This stage presents the background of the research project along with the methodology. In addition, this stage provides an answer to the sub-question Q1. It comprises of the first two chapters discussing the relevance of the research and the research methodology adapted.

1.5.2 Explorative Research and Ecosystem Representation

The stage aims to provide the parameters that define the value function given in the project alongside relevant information that guides those parameters. This stage comprises an exploratory survey, interviews, and an extensive literature study, and comprises of three chapters and discuss theory of circularity in context of circular procurement process (CPP), proposes deconstruction process with the focus on a building's component as its asset and further details the essential elements of the proposed framework to find gaps and limitations in it.

The first chapter is about circularity and introduces principles that led to or influenced the concept of circularity. It also discusses how circularity is defined and what a circular building asset is. It also discusses the parameters to measure the circularity of the building components. Furthermore, it discusses the different approaches organizations in the built environment have taken to achieve the circularity goals. Interviews alongside a literature study give the readers sufficient expertise to understand the current situation of circular practices in the construction industry.

The second chapter is about building assets. It starts with topics such as building components as assets and building lifecycle in a linear economy. It further discusses how demolition stage is realized and what an ideal demolition process in a linear ecosystem looks like. It further discusses an ideal deconstruction process in a circular ecosystem. From the lessons learnt from the explorative research part of this stage, an ecosystem is presented, and a process map highlights how the circular trading framework will work.

The third chapter breaks the proposed ecosystem down. It discusses what asset information is needed for deconstruction to happen. It also tackles role of asset passports, BIM Data, and external databases in asset information querying. Further this chapter uses principles of second-hand economics and product valuation along with lifecycle cost analysis, environmental impact of building's component, its quality of an element, possible exit strategies, and transition cost when transitioning from one lifecycle to another to propose value of building component for different stakeholders in the CPP. This stage answers the sub-questions *Q2- Q6*.

1.5.3 Reporting

This stage entails the finalization of the research project and consist of one chapter. In this stage, the conclusions to the research are drawn, and the limitations of this project are discussed in brief. It concludes with recommendations for further study in the field of deconstruction and trading of building asset after this explorative study. It should be noted that Chapter 7 contains a list of all references used for this research, and that chapters 8 through 14 comprise the appendix.

2. Chapter 2: Research Methodology

The following research methods have been used to answer the research question and the sub-questions.

2.1 Interviews

Before assessment for a need for the framework, it was important to gain some perspective on whether a trading platform is necessary and what are the key requirements of the platform. Following questions were formulated to conduct a semi structured interview.

- What do you understand by sustainability and circularity in construction industry?
- What do you think about circular economy?
- What is the market trend of reusing construction materials?
- How does the trading of construction and demolition waste work in the industry?
- While doing a construction project, do you look for materials from the industry or yet to be demolished?
- How do you think second-hand material is procured for use in construction projects?
- What can you say about the quality of reused material in construction industry? What sort of assessments are there, if any, to assure the quality of construction material?

Out of 11 industry experts specializing in circularity and sustainability, material sciences, online trading, contracting in built environment, project, and supply management, 5 experts agreed for the interview, and 3 interviews with consent to publish are listed in Appendix A (Chapter 8).

The following process was followed to publish the interviews as shown in Figure 7.

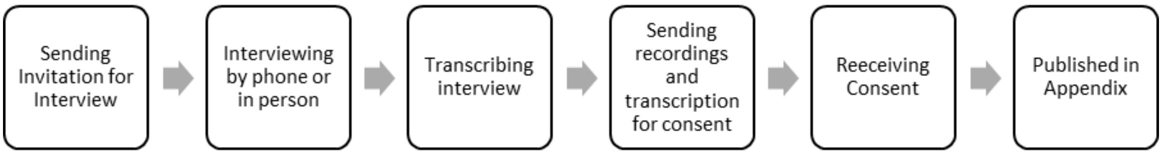


FIGURE 7 INTERVIEW PROCEDURE

The findings of interviews are used as the principles to investigate the relevant aspects of the project and play a key role in shaping of the proposed ecosystem in the subsequent chapters.

2.2 Literature Review

The review helps in developing relevant theory and find research gaps in the context of building asset valuation to deliver a trading ecosystem that not only enable circularity but provides enough information to ease decision making while procuring second-hand products. In the research, the guidelines given by (J. Webster & Watson, 2002) and (Snyder, 2019) have been used to conduct the literature review. An integrated approach is predominant in most of the work as the review aims to summarize various research fields. The methodology is highlighted in Figure 8. The research is conducted using Google Scholar for student thesis and Science Direct and their affiliated databases with a year range from 2010 to 2021. See Appendix B (Chapter 9) for the layout and the process of obtaining bibtex/.csv files from the primary databases. For some sections, the Eindhoven University of

Technology's online library search[18], Research gate [19]and other online sources were also used to further expand the areas that are not covered by the above-mentioned platforms and refer to books, articles and relevant articles that are published online.

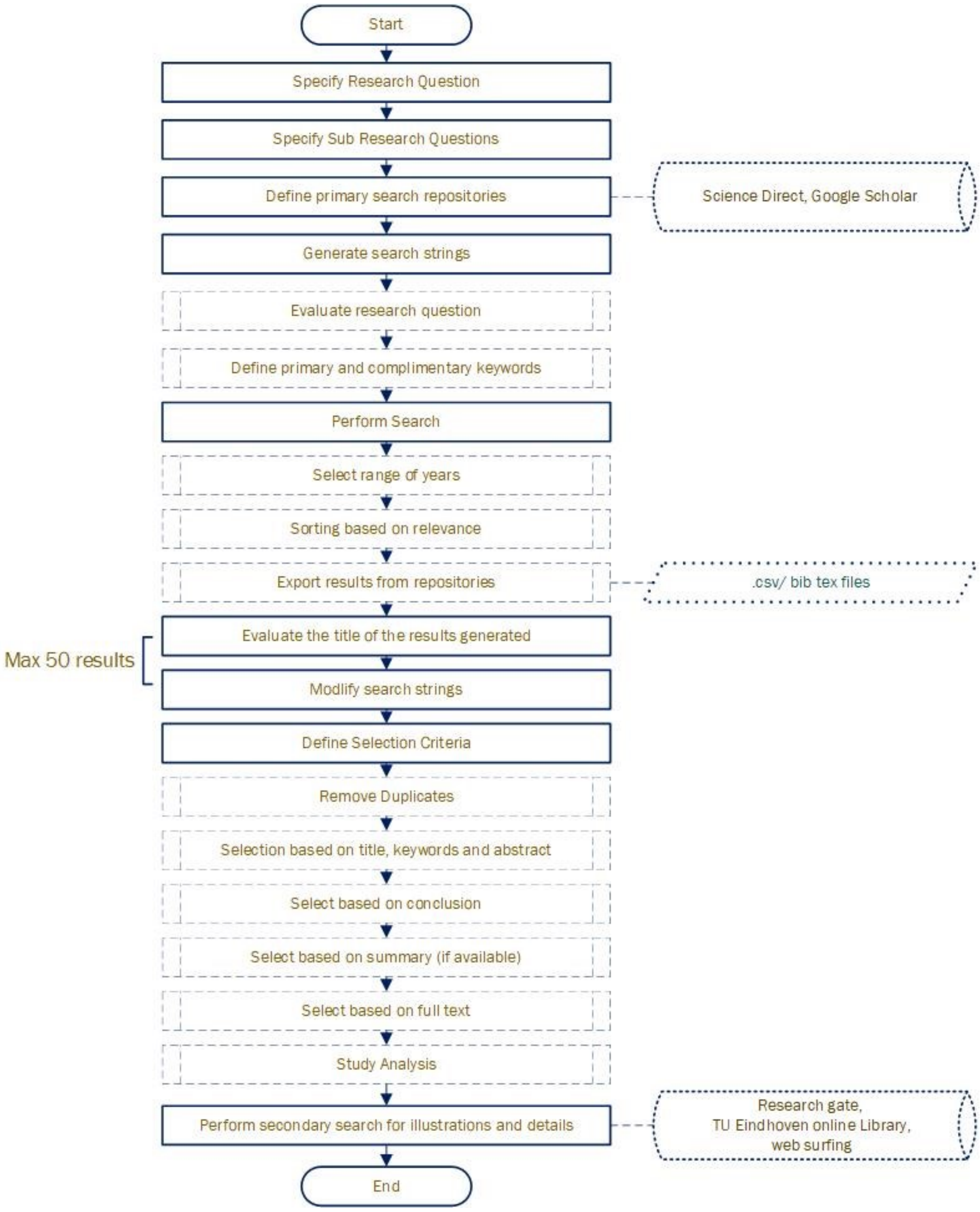


FIGURE 8 LITERATURE REVIEW METHODOLOGY

2.2.1 Pilot Search

The strategy employed in this integrated literature review is to find all relevant academic literature to answer the research questions. Based on the research sub-questions, primary and complimentary keywords (search strings) are defined so that they satisfy the relationships as shown in Figure 9. These search strings are tested by conducting a pilot search. These strings were modified based on the results

[18] Eindhoven University of Technology Digital Library - https://tue.on.worldcat.org/discovery
[19] Research Gate - https://www.researchgate.net/

of the pilot search. Selection criteria were also formed to find the relevant studies as highlighted in Figure 8. Hence, the pilot search provided additional information to sharpen these criteria.

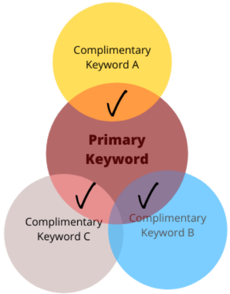


FIGURE 9 KEYWORD RELATIONSHIP

2.2.2 Search Strings

Sub Q1. Why is there a need for circular trading ecosystem?

Based on the interviews conducted and the circular transition agenda which highlighted the need for a monitoring system and the lack of standard approach or a basic framework to procure material, it was important to investigate further whether a circular trading ecosystem exists in the industry or what guides material procurement in a circular ecosystem within the context of building and its components. Hence a market study was conducted using secondary search methods as highlighted in Figure 8.

Sub Q2. How is circularity measured in the construction industry, and what circularity parameters are relevant while valuating building assets for procurement in a circular ecosystem?

To answer the above questions, it is relevant to understand what are the factors that led to a circular economic model and the relevant definitions of circularity. It was important to define a circular building asset. Furthermore, it was vital to understand the approaches for attaining circularity in the built environment before focusing on parameters that characterize a circular building asset and how they affect its value in a CPP. Based on the information above, the following search strings were defined as shown in Table 2.

TABLE 2 SUB QUESTION 2 SEARCH STRINGS

S.NO	THEME	SEARCH STRING
1	Guiding Principles for Circularity	Sustainability, circularity
2	Guiding Principles for Circularity	Circular economy and doughnut economics
3	Circularity and a Circular Building Asset	Defining circularity
4	Circular Approaches in the Built Environment	Circular Building Products
5	Circular Approaches in the Built Environment	Circular business models
6	Measuring Circularity in Building Components	Disassembly, buildings, circularity
7	Measuring Circularity in Building Components	reuse, recycle, refurbish, repurpose
8	Measuring Circularity in Building Components	R framework, circularity, exit, materials

Sub Q3. How does the valuation of second-hand products occur in the circular ecosystem?

To answer this question, it is important to understand the lifecycle of building component and why it is classified as an asset. Further, it was important to understand the factors that are used to do price valuation of a product. Furthermore, a study on second-hand market economics was conducted to get an idea about how it is different from a newly manufactured product. Terms such as lifecycle analysis, product quality, salvage value, product depreciation, market demand were seen in the pilot search.

Based on that, further literature research was conducted alongside a small explorative survey to understand the dynamics of what influences the valuation of second-hand products. Based on the information above, the following strings were defined as shown in Table 3.

TABLE 3 SUB QUESTION 3 SEARCH STRINGS

S. NO	THEME	SEARCH STRING
1	Building element as an "Asset"	lifecycle stages of a building
2	Building element as an "Asset"	Material passport and buildings
3	Asset Valuation in construction industry	Second-Hand Economics
4	Asset Valuation in construction industry	Second-Hand Market
5	Asset Valuation in construction industry	e-commerce, construction industry
6	Asset Valuation in construction industry	Asset Management, construction industry

Sub Q4. How does the environmental impact of building's component affect its value?

To understand the environmental impact of an element, detailed research on lifecycle analysis of a building element was conducted. Databases and tools were investigated and terms such as shadow costs, lifecycle cost, lifecycle analysis, NMD, MPG, NIBE, Damage Cost, Prevention Cost, PBL, MKI, ECI, were common in the pilot search. Based on the terms following search strings were defined as shown in Table 4.

TABLE 4 SUB QUESTION 4 SEARCH STRINGS

S. NO	THEME	SEARCH STRING
1	Lifecycle Cost Analysis	Lifecycle cost, building, materials
2	Lifecycle Assessment	Lifecycle Analysis, building materials
3	Lifecycle Assessment	Shadow Cost, building materials

Sub Q5. How does the changing quality of building's component affect its value?

Based on research done for sub-question Q3 and results of the explorative survey, a pilot search was done. Terms such as quality assessment, quality framework, salvage value, depreciation, exit scenarios were found common. Based on this information, the following search strings were defined as shown in Table 5.

TABLE 5 SUB QUESTION 5 SEARCH STRINGS

S. NO	THEME	SEARCH STRING
1	Quality of Material	Quality Assessment, building materials
2	Quality of Material	Salvage Value, building materials

Sub Q6. What are the essential requirements for an application to use circularity parameters and BIM that guide the decision of stakeholders to procure second-hand products?

To answer the question, it was important to understand what BIM is, and how it has been used in relationship with circularity. Hence some key terms in the pilot search found were building data, BIM Data Querying, IFC, Building Smart, BIM and LCA, BIM and LCC. Based on the terms found, the following search strings were defined as shown in Table 6.

TABLE 6 SUB QUESTION 6 SEARCH STRINGS

S. NO	THEME	SEARCH STRING
1	Building Data Querying	Building Data Querying, BIM
2	BIM and LCA	BIM, LCA
3	BIM and LCCA	BIM, LCCA

2.3 Exploratory Survey

An exploratory survey, shown in Appendix C (Chapter 10) was conducted using LimeSurvey to investigate how a building's component's value is perceived on a trading platform by the buyers and sellers. The purpose of the survey is to explore perception of people on the factors that may affect their decisions while trading building components salvaged from a demolished site. Hence, a scenario-based survey was conducted.

Furthermore, an investigation was performed about consumer and user's awareness of some common online trading platforms and initiatives that deal with selling materials salvaged from demolition sites. This decision was made based on the interviews conducted before to understand if people are aware of such online platforms or initiatives.

2.3.1 Target Group

The survey was broad and targeted all people who are in the built environment. This includes people who are associated with Architecture, Engineering, Construction (AEC) industry, the Operation and Maintenance (O&M), and the demolition industry, along with people associated with circularity initiatives or those with online trading platforms. Hence, anyone who can provide their views on what they would prefer if they were given a chance to buy or sell material salvaged from a building associated in the following categories was included. This step was taken to create awareness about such platforms and initiate discussion on circular procurement. Hence, students, recent graduates, industry professionals and academic researchers were all encouraged to participate. The participants were given a consent form to sign before entering the survey. This form was included to make the subject aware of the usage of the data and give them a chance to stop filling the survey if they wish to stop prior to providing personal data.

2.3.2 Survey Data

Based on the aim of the survey, three different types of information were needed as stated below.

1. **Personal Data**

   The aim of this data collection was to first understand the subjects, their role in the industry, and the type of organization the subjects may represent. The primary aim was to better understand their responses about the preferences and awareness in context of their role, in the context of the type of organization to which they belong and the country where they work or study. Some other considerations for personal data collection were taken because of the following cases.

- Name of the subject was collected to validate that the data is filled by real people as it would be done to validate the results by the author by randomly selecting some responses to filter out data which is deemed irrelevant. This is an optional question.
- The name of the organization was collected to understand what type of organization he or she or they belong to.
- The email address was asked to send them the result of the survey in form of the final thesis to create transparency and make them aware of the result that they contributed to.
- Furthermore, a remark section was added as an option for them to understand whether they want to add some more information that the subject may perceive relevant to better understand their function in the organization or their study background if they deemed it necessary.

- Furthermore, the name, email addresses, name of the organization they belong to, and the role they play along with their remarks won't be made public with the thesis work.
- The roles are categorized into the following categories based on the sole discretion of the author
    - Academic Expert – If they hold positions such as researcher, lecturer, or any other related positions.
    - Learners – If they are studying relevant courses or have just completed their studies. Also, it is requested in the survey if they can add the studies they are pursuing or pursued in the optional remarks section if they are willing to include that.
    - Industry Expert – If the subject is involved within the organization in a role of material procurement such as purchasing managers, asset managers and other related experts or has a role in one of the online platforms that are available for trading building materials
    - Industry Professional – If the subject has worked in the industry but does not fall into the category of Industry experts.
- The organizations would be categorized into two categories based on the sole discretion of the author.
    - Academia – If this organization is a school, university, research institute, research group or any related entity.
    - Industry – If this organization is a construction company, an architectural firm, a sustainability firm, a online digital platform or any related entity.
- Any comments in the remarks section that may contain personal or sensitive data will be deleted if not relevant for our research or if relevant will not be made public.

2. Subject's Preference Data

This is the data collected to understand subject's opinion based on the scenario where they act as a buyer and a seller.

- *Scenario 1 – Buyer on The Platform*

In this scenario the subject is asked to assume the role of a buyer of an organization wanting to procure materials from a hypothetical online trading platform that were salvaged from a demolished building. It was also stated that the material is procured after being processed using one of the 9R of the R framework strategies (Kirchherr et al., 2017; Potting et al., 2017)and ready for use.

The first question was asked to investigate what the subjects would prefer to buy from the online platform and four options with a multiple-choice option was given – "architectural components like tiles, windows, doors etc.", "structural components like concrete, steel bars etc.", "mechanical and plumbing components like pipe, heat pumps, AC's etc" and "others" with an option to specify what that means. The subject was asked to select at least one of the four choices.

The second question of the scenario 1 asked the preference of the subject while choosing the information they may value more while deciding whether to buy the components chosen in the first question of scenario. Furthermore, an instructional aide was provided to help them assist in the questions. Based on the pilot search for research sub question- 3 and the interviews, eight factors were chosen and listed as follows

1. Price of the component
2. Demand for the component

3. Urgency in procuring the component
4. Shipping Cost
5. Delivery Time of the component
6. Quality of material
7. Grants and subsidies associated with the material
8. Lifecycle Cost

To include user's other choices that were not considered in the previous question, an optional question was added to include those parameters. This was done to include choices that the author may have missed while conducting the pilot search. The answer to this question would be checked for frequency. The parameters that are frequent in responses stated in the question would then be included in the study as it progresses. Also, this question helps highlight options that are like the parameters above but may be perceived in a different manner by the subject. This may also help reduce bias in the survey.

- *Scenario 2 – Seller on the Platform*

In this scenario the subject is asked to assume the role of a seller from an organization wanting to sell materials on a hypothetical online trading platform that were salvaged from a demolished building. It was also stated that the material is being sold after being processed using one of the of the 9R of the R framework strategies (Kirchherr et al., 2017; Potting et al., 2017) and ready for use.

Furthermore, similar to the previous scenario, the first question of the second scenario was asked to investigate what the subjects would prefer to sell on the online platform and four options with a multiple choice options were given – "architectural components like tiles, windows, doors etc.", "structural components like concrete, steel bars etc.", "mechanical and plumbing components like pipe, heat pumps, AC's etc" and "others" with an option to specify what does that mean. The subject was asked to select at least one of the four choices.

The second question of the scenario 2 asked the preference of the subject while choosing the factors they consider while deciding on the price of the components chosen in the first question of scenario they want to sell. Furthermore, an instructional aide was provided and limit per column was limited to 1 to avoid giving same ranks to two factors.

Based on the pilot search for research sub question- 3, five factors were chosen and listed in rows.
1. Price of the new component
2. Demand for the component in the market
3. Quality of material
4. Grants and subsidies associated with the material
5. Effort in removing the component from the building during demolition

Like the scenario 1, in scenario 2, also, an optional question was added to include to include user's other choices that were not considered in the previous question with the same intention as for scenario 1.

3. **Subject's Market Awareness Data**

Based on the pilot search for sub-question Q1 and secondary search, some online platforms that deal in trading of construction material after their first lifecycle were used as the choices in the final question of the survey asking the subject if they have heard or used any of the materials from the trading platforms. Multiple answers were accepted. Furthermore, for the case, that the subject has not used any of the platforms, the option “None of the above was chosen”. In case that the subject may have used or heard of any options other than the ones listed in the question as possible choices, the option “other” was used with a blank space to fill the name of that particular online platform. The restriction of at least one response was necessary was made. The choices listed in the question are “Material Bidders”, “Environmate”, “Insert by Buroboot”, “Construction Retail”, “Find Building Material”, “Marketplaces”, “Greenshed”, “Excess Material Exchange”, “Oogskart”, “Gebruikektebouwmaterialen”, “Restado”, “None of the above” and “Other”.

2.3.3 Platforms to Reach the target group

The target group was reached through the following ways:

- Social Media Platforms like LinkedIn, Facebook and messaging services like WhatsApp, Discord.
- Email to companies and platforms that include the target group using their contact details
- Using relevant platforms of Eindhoven University of Technology
- Emailing student teams, associations, and relevant research groups.

2.3.4 Processing of Survey Data

After the responses are stored in a secure drive, the following process is followed to evaluate the data and derive some results. The survey data was downloaded as .csv and the following process was followed as shown in Figure 10. The personal data was categorized using Excel. Based on the categories the data was grouped and some patterns were detected in the responses relevant to the categories in Excel. Based on the patterns and the total responses, charts were generated, and results were used alongside literature research wherever relevant.

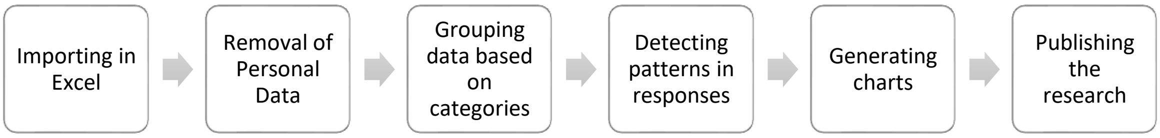


FIGURE 10 PROCESSING OF SURVEY RESULTS

2.4 Framework Design

To formulate a trading platform’s framework based on the explorative research, a research-based approach is used. However, instead of creating an application prototype, a methodology is proposed highlighting the processes (BPMN diagrams) to be used to reach to the proposed framework alongside the key concepts that can guide the design of the trading platform. Based on the waterfall model as shown in Figure 11, the requirement analysis was the focus of this research, and it concluded with a breakdown of the proposed methodological framework. Furthermore, other existing real-life applications that can be used or refined to make the proposed framework were also discussed at various stages of the ecosystem breakdown.

FIGURE 11 FRAMEWORK DESIGN USING WATERFALL DIAGRAM

In conclusion, this chapter provides the research methodology adopted to find the answers to the research questions in section 1.3.

3. Chapter 3: Circularity

3.1 Introduction

The chapter begins with the introduction of the guiding principles behind circularity in Section 3.2 and a brief discussion on scope of circularity in Section 3.3. Section 3.4 demonstrates how circularity has been applied to the built environment, with a particular emphasis on the circular procurement process. Moreover, the various methods to measure circularity are briefed in Section 3.5 that can be used as CPP indicators. The chapter concludes with the key elements summarized and used further along in the study in Section 3.6.

3.2 Guiding Principles of Circularity

The society we live in can seem irrational and short sighted at times. This has not only led to irreversible damage to humanity but also to the space we occupy. Many assert that the only way to eliminate inequality in society is to alter economic theory and policy by replacing concepts such as gross domestic product (GDP), which has been used to measure the growth of a country or community, with a vision that is uncompromising, regenerative, and distributive by design. This thought has taken many forms, that are proposed, to elevate and sustain humanity. It shows us the dire need to change our perspective on many things. One such proposed perspective is circularity.

The thought of circularity relates to the change caused by human advancement driven by the exploitation of natural resources and subsequent failure of replenishing them. To understand circularity, it is important to understand the concepts and models that deal with the same theme. The current circularity models can be seen as an amalgamation of many concepts and models given over the decades.

One concept that goes hand in hand with circularity is sustainability. Circularity is inspired from many old and new sustainability models (Washington, 2015). In 2015, the UN member states called for action to eliminate poverty and other scarcities faced by humankind, lessen discrimination, improve health and education, and spur economic growth by adopting 17 Sustainable Development Goals (SDGs). Furthermore, climate change must be addressed, and the ecosystem preserved according to the 2030 Agenda for Sustainable Development (United Nations, 2015). A few years prior to this, Johan Rockström led a group of internationally renowned scientists to identify nine processes that regulate the stability and resilience of the planet Earth at the Stockholm Resilience Centre (Stockholm Resilience Centre, 2009). This was further updated in 2015 by Steffen et al. (2015) where they introduced control variables for the planetary boundaries.

These planetary boundaries by Johan Rockström (Stockholm Resilience Centre, 2009) combined with the complementary concept of twelve social boundaries inspired from the 2030 Agenda for Sustainable Development and its 17 sustainable development goals have given rise to and have been influenced by many models and led to many more economic models as shown in Table 7. These concepts and models promote closing resource loops in one way or another, hence influencing both the economic and ecological circular models suggested since the inception of circularity.

TABLE 7 CIRCULAR ECONOMY AND ECOLOGICAL MODEL PRECURSORS

S. NO.	PRECURSORS TO MODELS OF CIRCULARITY	OVERVIEW
1	Spaceship Earth (Boulding, 1966)	It discusses the inputs and outputs of open and closed systems in terms of energy, matter, and information systems.
2	Steady-state economy (Daly, 1968)	It states that economy must be made of constant stock and population size which can be achieved by government intervention.
3	Laws of Ecology (Commoner, 1971)	It states four laws to address the environmental crisis and humans and nature's interaction that are "*Everything is connected to everything else; Everything must go somewhere; Nature knows best;* and *There is no such thing as a free lunch*".
3	Urban mining (Hideo Nanjyo, 1980s)(Yu et al., 2011)	It was initially implemented for the recovery of rare metals stocked in electrical and electronics wastes. Now, it has grown into recovery of other materials.
4	Industrial ecosystems (Frosch & Gallopoulos, 1989)	In such a system the consumption of energy and materials is optimized, waste generation is minimized and the effluents of one process serve as the raw material for another process.
5	Natural Capitalism (Costanza & Daly, 1992)	It refers to the world's natural assets such as air, water, soil, and other organisms. It aims to increase this natural capital and aims to devise business strategies and supply chains to achieve this goal.
6	Reversed Logistics (Stock, 1992)	The prime focus is to reuse material and products while focusing on returns management. The key focus is costumer relationship and how products after use can be easily returned to the supply chain (Geisendorf & Pietrulla, 2018).
7	Industrial Metabolism (Ayres, 1994)	It means that the whole integrated collection of physical processes that convert raw materials and energy, plus labour, into finished products and wastes in a (more or less) steady-state condition.
8	Regenerative Design (Lyle, 1994)	Lyle (1994) gives a practical approach to using regenerative systems who have a self-renewing process and have end products that can be used as raw materials in a sustainable system. Lyle (1994) calls for *"calls for a societal shift to regenerative flows that increase ecosystem order and shift societies from high- to low entropy states*(Motloch, 1995)*."*
9	Biomimicry (Benyus, 1997)	This economic model takes inspiration from natural systems and consider the economic systems prevalent in the society as sub-systems of life on the planet. The aim is to create products and processes that become a part of natural ecosystem without any negative impacts (Bragdon, 2021).
10	Closed Supply Chain (Krikke et al., 2001)	Closed loop supply chain focuses on closing the resource loops much like CE. However, as stated by (Kovacs, 2017), it focuses only on "*the processes related to a material, whether with the aim of dematerialization, or materials flow analysis"* in a way that material and products are used well. The focus on energy exists but is not prevalent.
11	Cradle to Cradle (Braungart & McDonough, 2002)	Everything is a resource for something else. In nature, the "waste" of one system becomes food for another. Everything can be designed to be disassembled and safely returned to the soil as biological nutrients or re-utilized as high-quality materials for new products as technical nutrients without contamination.
12	Performance Economy (Stahel, 2010)	The performance economy focuses on optimised utilization of mainly manufactured capital. It focuses on generating revenue from providing services rather than selling goods(W. R. Stahel et al., 2016). (Geisendorf & Pietrulla, 2018) states that *"It represents a utilization-focused service economy through resource efficiency and product-life extension."*

13	Blue Economy (Pauli, 2010)	In this economic model, the focus is on learning from surrounding natural ecosystems that can lead to way of designing synthetic systems that are interconnected and complex and utilize local resources as a way to make the synthetic systems sustainable.
14	Doughnut Economy (Raworth, 2017a)	A set of social and environmental boundaries that help assess the progress of humanity in the 21st century that by considering resource availability and distribution as the parameter of growth rather than parameters like Gross domestic product (GDP).

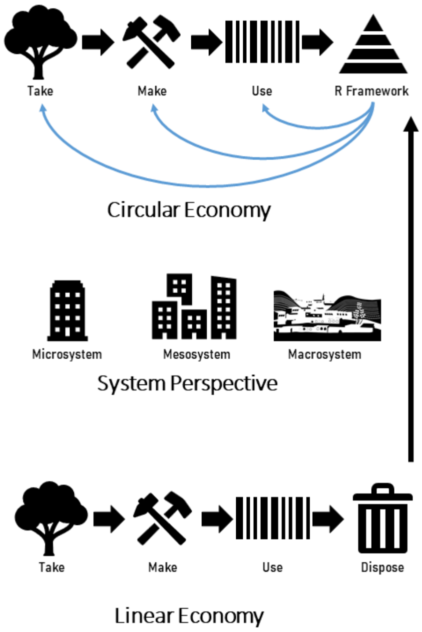
Hence, it can be stated that the idea of an uncompromising, regenerative, and distributive economic model is not new. This idea started from the steady state economics model (Daly, 1968) of the early 1970s, which stated that the economy must be made of constant stock and population size and can be achieved by government intervention. It has now expanded to social and ecological wellbeing, as proposed in the doughnut model (Raworth, 2017b). The models proposed in the Table 7 above are ways to replenish resources and optimise our usage. This is something that the circularity as a strategy deals with. It is said enough that we need new laws and regulations to enforce a drastic change in our processes. European countries are putting policies, directives, and strategies such as Waste Framework Directive (European Commission, 2018), Circular Economy Action Plan (European Commission, 2020), Level(s)(European Commission, 2021) in place that aim to take us back within the climate change boundaries, decreasing soil deprivation, reducing biodiversity loss, regenerating living systems. But policies are not the only part. The key element, as stated by Kate Raworth (Hens, 2019) is to shift the mindsets and perspectives of not only individual but also society.

3.3 Scope of Circularity

Adopting circularity can be seen as the first step to move towards an equal and sharing society and a sustainable earth. But since its introduction, there have been many variations of how circularity is perceived. This is because the concept of circularity has been studied with a broad and diverse perspective. *It has been studied in terms of ecology, clean production, zero waste economy, closed loop economy, environment, and others"* as stated by Momete (2020). Furthermore, some perceived notions and agendas that the stakeholder find themselves in further complicate the process that is relatively simple.

> *Circularity at its crux is about utilizing resources responsibly, minimizing waste and staying within limits that sustain life on earth by methods of closing loops.*

Despite that, circularity has had no clear and agreed upon definitions when applied on different systems due to the forced perspective of that system. Usually when there is a policy passed to implement an approach, model or strategy, there are clear definitions given that are legal in nature. However, when it came to circular economy (growth model that follows circular principles), in 2015, despite the adoption of an Action plan by the European Commission to boost employment, innovation and a resource-efficient economy, there were no legal definitions given to define circular economy. This resulted in a plethora of definitions. It has also been said many times that circularity is what closes the loop on the 'take',' make' and 'waste' linear economy. But Kirchherr et al. (2017) conducted a detailed study to understand the perception of circular economy by examining 114 definitions based on a particular coding system on the R framework (seen in Figure 12) and the corresponding waste hierarchy and reference system perspective. The system perspective includes microsystem (products, companies, consumers), mesosystem (eco-industrial parks) and macrosystem (city, region, nation and beyond) as shown in Figure 12.



R Framework Strategies

R0 REFUSE	Make product redundant by abandoning its function or by offering the same function with a radically different product.
R1 RETHINK	Make product use more intensive e.g., by sharing product.
R2 REDUCE	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials.
R3 REUSE	Reuse by another consumer of discarded product which is still in good condition and fulfil its original function.
R4 REPAIR	Repair and maintenance of defective product so it can be used with its original function.
R5 REFURBISH	Restore an old product and bring it up to date.
R6 REMANUFACTURE	Use parts of discarded product in a new product with the same function.
R7 REPURPOSE	Use discarded product or its parts in a new product with a different function.
R8 RECYCLE	Process materials to obtain the same(high grade) or lower (low grade) quality.
R9 RECOVER	Incineration of material with energy recovery.

Smarter Product use and Manufacture
Extend Lifespan of Products and Parts
Useful application of Material

FIGURE 12 R FRAMEWORK STRATEGIES (KIRCHHERR ET AL., 2017; POTTING ET AL., 2017)

The coding system also includes the scope of circular economy namely, “economic prosperity”, “social equity”, “environmental quality” and “impact on future generation”. Furthermore, it also considers “enablers” of circular economy, such as business models and consumer behaviour, to understand the perception of various researchers that defined CE. This review by Kirchherr et al. (2017) showcases the scope of circularity in a few lines by highlighting the themes that the definitions miss. It should be noted that there is not one way to define a thing. Even definitions that have a legal status are not perfect as they may miss one point or another. However, for the sake of understanding circularity, the coding system provided by Kirchherr et al. (2017) is employed in this research.

Of those 114 definitions examined based on the coding system, the one by Buren et al. (2016) scored the highest. They defined CE as follows: “*The focus point in a circular economy is to not unnecessarily destroy resources. This implies far more than the reduction of waste through recycling, stresses the following focal points: reducing the consumption of raw materials, designing products in such a manner that they can easily be taken apart and reused after use (eco-design), prolonging the lifespan of products through maintenance and repair, and the use of recyclables in products and recovering raw materials from waste flows. A circular economy aims for the creation of economic value (the economic value of materials or products increases), the creation of social value (minimization of social value destruction throughout the entire system, such as the prevention of unhealthy working conditions in the extraction of raw materials and reuse) as well as value creation in terms of the environment (resilience of natural resources).*” However, this definition does not mention the impact on future generations or the enabler of CE in its scope. This is important because despite defining multiple factors to create a whole definition of what a circular economy should be, it still misses two important aspects while transitioning to a CE. In this case, it misses which medium should act as the enabler of CE and how the transition would impact the future generations.

Based on the interviews conducted during the thesis as shown in Appendix A (Chapter 8), the common element when asked about the interviewees’ opinion on circularity was “(re)usage of resources”, with the variation in what “resources” constitute Some focused on reusing energy, while others focused on reusing materials These were ad-hoc definitions. Hence these were not clear in terms of defining circular economy. One clear theoretical definition of circular economy in one of the interviews which can also be approached as a definition of sustainability mentioned was by Huesemann & Huesemann (2011). They defined circular economy based on three conditions:

1. *All energy comes from renewable sources at or below renewable rates.*
2. *All materials come from renewable sources at or below renewable rates.*
3. *Waste can only be released at or below assimilation rate, without negative impacts for the ecosystem or biodiversity.*

However, this definition only provides the aim to achieve the rates of waste but does not clearly include the other dimensions. With respect to the coding system by Kirchherr et al. (2017), this definition also does not include the enabler of CE, systems perspective, or the R framework. The above definition focuses on material circularity while not clearly stating the underlying theme of energy, and this further shows that the scope of circularity is difficult to grasp.

Finally, Ellen Mac Arthur Foundation (2013), which is quite popular with regards to circular economy also defines CE as "an *industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models."* Based on the coding system by Kirchherr et al. (2017), it does not mention the impact on future generations or provide the system perspective or consumer behaviour as enabler but mentions the business models as the enabler of circular economy.

Just by analyzing the above three definitions only, it can be stated that circularity has a huge scope that varies not only at one scale but at every scale from macro systems to micro systems as the perspective changes. The example of one system is the economic model or CE. As stated by Grafström & Aasma (2021), "*The fact that the existing definitions of a CE are broad, and include all activities carried out in a society, may explain why there is no consensus among scholars about the interpretation of a CE."* This broad scope is an issue. But like all other broad issues, it gives enough room to work on circular strategies based on the processes and the stakeholders involved, provided the terms of approaching circularity are clear for the involved parties. Since this research focuses on material procurement, the scope for this research in terms of circularity pertains to material usage after assessing its viability within the construction industry as shown in Figure 13.

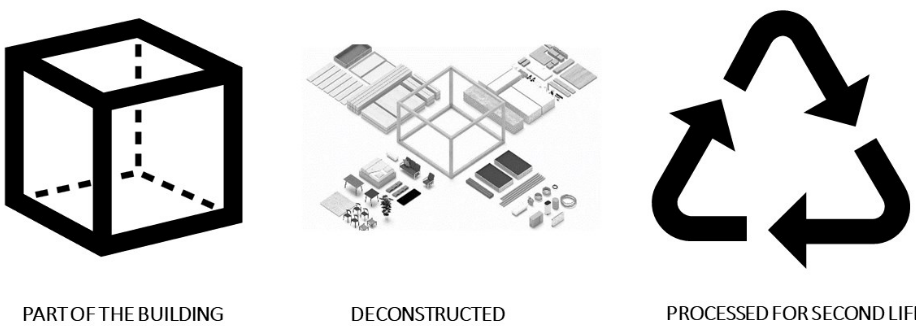


FIGURE 13 SCOPE OF CIRCULARITY

3.4 Circular Approaches in the Built Environment

3.4.1 Challenges and Opportunities

The broad scope of circularity models is due to the complexity and variation in understanding circularity as a concept and its use in that model. Furthermore, different industrial settings and dependencies result in a diverse material and energy system dynamics. Fogarassy & Finger (2020) states that *"The complex nature of material and energy systems and the changing economic and technological conditions depend on regional settings and accordingly result differently in developed and rapidly developing countries of the world."* It can be inferred that since every industry is categorized by different ecosystem of material and energy systems, their approach may vary while transitioning to a circular business model. It can be seen summarized in the Figure 14.

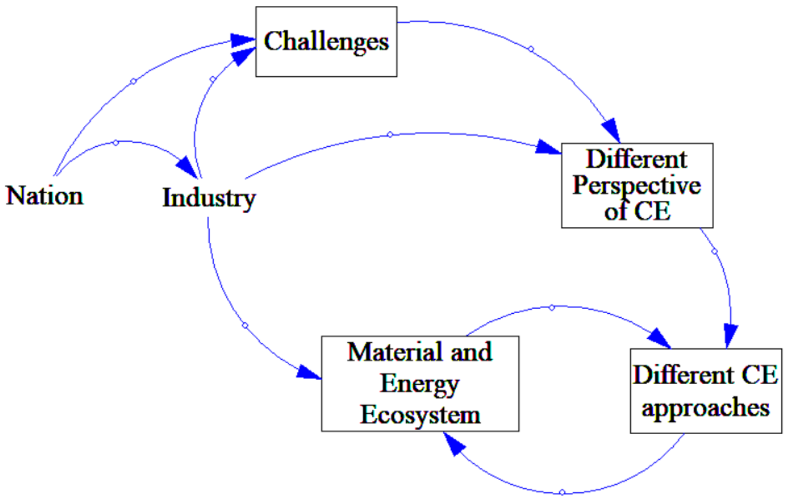


FIGURE 14 INFLUENCE ON APPROACHES TOWARDS CIRCULAR MODELS SUCH AS CE

In the construction industry, this diversity towards approaching circularity is prevalent not only based on how it is perceived. It is also influenced by the different perceived challenges to enforce circularity and issues that are otherwise prevalent in the industry. These challenges change the goal with which a group of stakeholders involved in a building, or an infrastructure project will want to transit to a circular business model so that this transition helps solve their respective problems.

To investigate the hindrances and different approaches in the construction industry to transit to a circular ecosystem, interviews as shown in Appendix A (Chapter 8) were conducted with industry experts on topics such as material procurement, sustainability and circularity in building industry and issues of trading and ownership of building elements in a commodity market. Based on those interviews, following can be stated as the key points that highlight the problems faced in the construction industry.

1. Contractors are limited by *the requirements laid down in the contract*, which is usually for only one phase of the construction process. With circular procurement, this issue is being dealt with, however, concrete terms of contract to reuse building components require a thorough analysis of building elements and their quality.
2. Reuse of materials is considered usually when there is an immediate benefit in the cost of construction. Usually, there is *no immediate benefit to reuse*. The profits are seen in the longer run which is considered out of scope for the contractor.
3. Detachability of materials is a key factor when reusing them. However, the existing buildings are *not designed for disassembly* making reuse of materials much more difficult. Masi et al. (2018) state that products are not designed for reuse, recycle or recovery due to no immediate benefits.
4. Quality assessment of reused materials is done but since it is a new concept there is *no standardized method* yet resulting in inconsistencies and disagreements.
5. The procurement of reused materials is *limited to the network* of the purchase manager, project manager or project director.

6. There is *not much attention paid to the reuse of materials during the demolition of a building from a developer's or client perspective*. The demolition of a building is mostly tendered to several companies and the lowest bid wins the contract. The demolition company which can salvage most of the material cheaply offers a lower bid amount. The salvaged material's second-hand market is not standardized.
7. All the material that can be salvaged from the buildings that are going to be demolished *is not enough* to satisfy the requirements of new construction projects. So, it is important to focus on cross industry material exchange and bio-based materials.
8. *The market demand of material compared to its reuse is usually unclear.* Hence, it is also important to understand market demand of material and how cost of assessment of a material validates it to justify its reuse.

From the interviews conducted above, the following four key barriers can be stated as the reason for hesitation towards implementation of a second-hand market of materials in construction industry. These barriers can be summarized as follows:

1. Lack of understanding of exit scenarios of material and its quality at end of life.
2. Issues in detachability of building materials due to no immediate benefits at demolition phase of building.
3. Unclear market demand of second-hand products.
4. Absence of demand of circularity in contractual agreements between stakeholders.

The four barriers stated above are congruent with the findings of Masi et al. (2018). The findings of that study state that the implementation of green purchase practices is difficult because firms hesitate *"selecting suppliers using environmental criteria and corporation with other firms to establish eco-industrial chains"*. The study further states that *an "absence of clear, standardized, quantitative measurement to assess the circular business models"* and "*limited attention to end-of-life phase in current product designs"* are some of the major reasons for this hesitancy. Hence, this study focuses on the first two of the four key barriers established in the interviews and discuss the latter two in brief while establishing a clear and quantitative framework that consider the end-of-life phase of the building components.

3.4.2 Circular Procurement and its breakdown

The procurement of resources is a significant task in the construction industry, and it continues throughout the building lifecycle in different capacities. The process of obtaining a resource has been a linear one since humans started building things. However, since the scale of manufacturing increased manifold after the Industrial Revolution of the 18th century, this linearity has negatively affected the world. This effect has given rise to the notion of circular procurement, where materials and resources obtained are utilized again after their first use in the same or a different manner.

Circular Procurement - GPP - Environment - European Commission (n.d.) states that "*Circular procurement sets out an approach to green public procurement (GPP) which pays special attention to "the purchase of works, goods or services that seek to contribute to the closed energy and material loops within supply chains, whilst minimizing, and in the best case avoiding negative environmental impacts and waste creation across the whole life-cycle.*"

For establishing circularity in the procurement process, it is essential to understand the preconditions needed in an organization. Sönnichsen & Clement (2020) state *"The creation of pre-conditions for more and better circular procurement practices is considered an effective tool to promote more environmentally, socially and ethically friendly modes of production and consumption than business as usual."* They concluded for a successful circular procurement process (CPP), three aspects need to be considered – organizational aspects, individual behaviors and operational tools used as shown in Table 8.

TABLE 8 PRE- CONDITIONS TO ENFORCE CPP (SÖNNICHSEN & CLEMENT, 2020)

Organizational Aspects	
Size	The **organization's size does not affect** the adaption of a **CPP** if internal resource allocation (human and finance) supports organizational capabilities to implement CPP.
Strategy and Top-Level Management	CPP goals should align with organizations' political, cultural, administrative, and funding measures. Furthermore, **top-level managers should support CPP**.
	Highly innovative solutions that are in demand are easier to implement.
	The less resistant a procurer is to pay a premium for CPP practices, the more successful the process would be. Hence **the inclusion of policy goals for CPP in the contract is necessary**.
Policies and Quality of Contracts	**Quality of contracts** is a result of a contingent **process of negotiation**, market dialogue**,** and enhancement of **technical, legal, and economic capabilities of procurement staff**.
	National differences in rules and laws define the **mandatory or voluntary implementation**. The private sector follows the public sector in **CPP.**
Individual Behaviour and Practices	
Agency and Cross-Departmental Management	**Exchange of information and strategic transfer of knowledge** are important aspects of transforming the behavior practices of individuals and enhancing **cross departmental management.**
Beliefs Awareness, and Individual Guidance	For successful CPP, **establishing structures of individual learning and training concerning CPP** opportunity is important alongside a work environment that enables CPP discussion and practice.
Operational Tools	
Process and Prioritization Rules	It is like linear procurement process in terms of calls for tender, selection, awarding, and contracting.
	The CPP differs while developing internal policies, setting purchasing criteria, creating internal procedures for assurance practices, establishing supplier relations management, and building internal circular public procurement capacity.
Calculation and Criteria setting tools	**Process and decision outcomes** are evaluated by **using life cycle assessment, costing, eco-labels**, and other strategic circular economic tools in general.
	Including carbon emission calculations as evaluation criteria in tenders act as market communication and **stimulate eco innovation among suppliers**.
Standards, Standardization and Legal Aspects	Public procurers are therefore encouraged to use a defined, operational innovation space to reduce risk when innovating complex circular public procurement processes or eco-label if products are off-the-shelf solutions.
	Award criteria must be associated to the contract's subject matter and value for money is defined as a combination of **quality, quantity, risk, timeliness, and cost from a life cycle perspective**.
	The **inclusion of** all the **parameters of value for money**, enhance the most economically advantageous tenders, defined as the **best relation between price and quality from a long-term perspective**.
Supplier Selection	It describes the four specific strategies named "ignore", "incorporate", "insist", and "integrate" to select suppliers. Environmental criteria are an example of this kind of decision tool. However, it is rarely an influencing aspect of supplier selection.
	A competitive dialogue procedure with suppliers mitigates perceived risk among procurement professionals.

3.4.3 Material Flow in a Circular Procurement Process

As procurement of resources is a never-ending process, it becomes essential to understand how to make it circular. Ellen Macarthur Foundation (2016) proposed a butterfly diagram which divided the possible resource flow in a circular system based on renewable (left side) and non-renewable resources (right side) as shown in Figure 15.

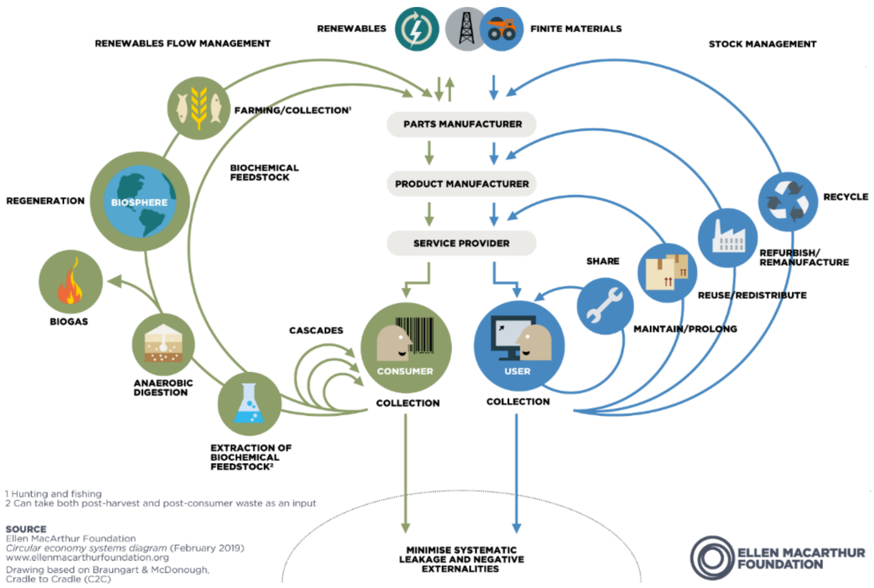


FIGURE 15 CE BUTTERFLY DIAGRAM (ELLEN MACARTHUR FOUNDATION, 2016)

Based on the CE butterfly diagram by Ellen Macarthur Foundation (2016) and drawing parallels for Circular Procurement processes, the three key concepts – Preserve and Enhance, Resource Loops, Design for System Effectiveness play an effective role for the two stakeholders.

1. **Preserve and Enhance** – From the perspective of both buyers and sellers, the idea is to preserve and enhance while purchasing or selling second-hand materials respectively to obtain continuous value from a building. The critical focus is to sell sustainable materials from an existing one that a prospective buyer may need for any future project. The cheapest finite material (for example sand, that is used to make concrete) is always considered first in a linear procurement process to maximize profit margins. However, the circular procurement strategies incentivize durable and easily recaptured materials (for example bamboo, wood, mycelium and more). These strategies ensure that a building and its elements can be collected and transformed into a value proposition through the various resource loops. Hence, this concept leads to optimum utilization of resources and prevent resources being wasted away.

2. **Resource Loops** – For a building owner looking to make profit from deconstructing a building, it becomes essential to understand how the building component will be used further and what is the market demand. If the product is bio-based and is renewable, it can be converted to energy or cascaded (used for different purposes without any regenerative process). E.g., *a timber beam could be used in the building structure, then reused as a non-structural element, then formed into a fibreboard before being composted to generate biogas*(Cheshire, 2016). For a finite stock, there are many ways the value can be restored using the R Ladder as shown in Figure 12. In the worst-case scenario, it is sent to a landfill or incinerated without energy recovery.

3. **Design for System Effectiveness** – Circularity(Ellen Macarthur Foundation, 2016) focuses on minimising systematic leakage and negative externalities. As discussed before, these negative externalities can be poorly recovered material or downscaling of materials, increasing cost of transition as one goes down the levels of the R Ladder (Figure 12). Furthermore, extensive time for deconstruction or rebuilding can also hamper the circular ecosystem.

3.4.4 Circular Business Models in a Circular Procurement Process

In a CPP, stakeholders deploy many circular business techniques. Hence, for a successful CPP, an understanding of circular business models (CBM) is necessary. Frishammar & Parida (2018) defines it as *"a circular business model is one in which a focal company, together with partners, uses innovation to create, capture, and deliver value to improve resource efficiency by extending the lifespan of products and parts, thereby realising environmental, social, and economic benefits".* However, a circular business model is never perfectly circular and comprise of both linear and circular parts.

The few basic elements commonly seen in a CBMs that are relevant in a CPP and mentioned in (Circle Economy & ABN AMRO, 2017; J. Verberne, 2016) can be seen in Figure 16.

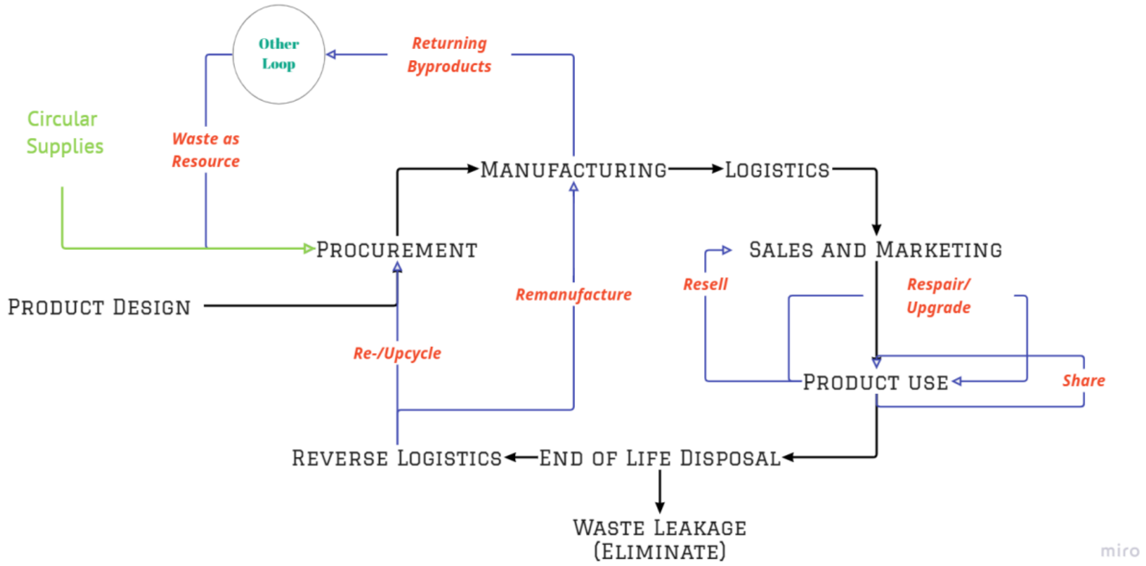


FIGURE 16 BASIC CIRCULAR BUSINESS MODELS FUNDAMENTALS IN WORK

Based on Figure 16, the CBMs can be briefed as follows:

1. **Circular Supplies:** Circular supplies are products that use materials that can be renewed, or those who come from direct reuse of complete construction elements or from high value recycling. Materials that are produced from a renewable and/or sustainable source that have minimum negative impact on environment are also considered circular inputs. This model is essential for a buyer when searching for materials for their new product. For example, Wooden skyscrapers (HAUT[20]), Bamboo wall panels (BamCore[21]), Tiles made from recycled raw materials (Mosa[22]), Bricks and building blocks of recycled materials (Stonecycle[23], ByFusion[24]).
2. **Resource Recovery:** Using this business model, one can recover useful resources/energy out of disposed or biproducts using resource recovery part of the R framework. For example, high-quality recycling concrete can be obtained using Smart Crusher/SlimBreken[25].

[20] https://hautamsterdam.nl/en/
[21] https://www.bamcore.com/how-it-works/
[22] https://www.mosa.com/en/campaign/cradle-to-cradle-certified-gold-milestone-for-mosa
[23] https://www.stonecycling.com/
[24] https://www.byfusion.com/

[25] https://slimbreker.nl/

3. **Product Life Extension:** Using this CBM element, one can extend working lifecycle of products and components by repairing, upgrading, and reselling using IoT, Big Data and by planning maintenance in a smart way. Some relevant design principles for extending lifespan are modularity, detachability, standardisation (of dimensions and materials), adaptability and the 'LEGOlisation' of components. One such example is climate systems of buildings provided by OC Verhulst[26]. These systems being modular can be disassembled, upgraded and added back to the building easily. Life-cycle costing, the integrated calculation of construction, operational and environmental costs are indispensable for making the proper design choices can help the product's to have low maintenance and an extended lifespan.
4. **Sharing Platforms:** This CBM element enable increased utilization rate of products by making shared use or ownership possible. For example, during construction, resources such as services and people (Floow2[27]), tools and machinery (EquipmentShare[28], Dozr[29], Getable[30], Klickrent[31]) can be shared.
5. **Product as a service:** This CBM element let the buyer pay for the service rather than the product and product ownership stays with producer. Product is designed in such a way that it is easy to repair and has a maximum residual value. This is accomplished through a lease contract or pay per use policy. The supplier acts as the buyer in this case. Some examples of such an arrangement are solar panels by Ampus[32]. The dutch mountains [33]in the Netherlands use facades by Alkondor, elevators by Mitsubishi based on this business model (Ligtenberg & Kruger, 2021).

3.4.5 Stakeholders in a Circular Procurement Process

3.4.5.1 Introduction

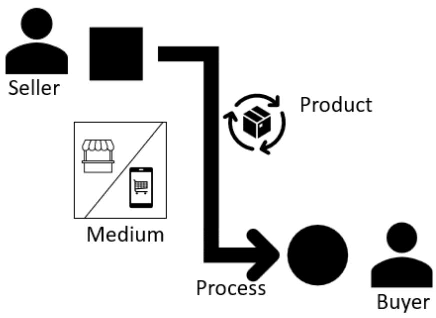


FIGURE 17 BREAKDOWN OF A PROCUREMENT PROCESS

In Figure 17, the CPP process is shown having two main stakeholders: a seller and a buyer. In the construction industry the seller can be a demolishing company or the owner of the building or even a user (in case of a renovation). The buyer can also vary. Based on the extended product responsibility, the **manufacturers can collect them back** which can be a challenging task in the construction industry due to composition of products. This take-back policy leads to a reverse supply chain where the product goes back to the manufacturer. This is also the basic principle of closed loop supply chain

[26] https://orangeclimate.com/nl/ocverhulst/producten
[27] https://www.floow2.com/
[28] https://www.equipmentshare.com/
[29] https://dozr.com/
[30] https://www.getable.com/
[31] https://www.klickrent.de/
[32] https://amplussolar.com/
[33] https://www.thedutchmountains.nl/en/#circulair

(CLSC) where *"a system is designed, controlled or operated to maximize value creation over the entire lifecycle of a product with dynamic recovery of value from different types and volumes of returns over time.*(Guide Jr. & van Wassenhove, 2009)*".* This is where a supplier comes into play. The **resource's ownership is transferred to another party who can restore its value** over the entire lifecycle with static recovery of value from a finite stock. This is where a prospective buyer comes into play.

When the conditions are in favour of a CPP, the interests of a stakeholder influence the models that the organization can take while figuring their circular business strategies based on their dominance in the organization (Circle Economy & ABN AMRO, 2017) as shown in Table 9.

TABLE 9 CIRCULAR BUSINESS MODELS RELEVANCE TO BUILDING STAKEHOLDERS(ABN AMRO & CIRCLE ECONOMY, 2017)

S. NO	STAKEHOLDER	RELEVANT CIRCULAR BUSINESS STRATEGIES	TOOLS AND METHODS
1.	Client	Providing Scope in tenders to implement any CE strategy during design, realisation, and operation of a building	Rapid Circular Contracting
2.	Real Estate Developer	Product Lifetime Extension through repair and maintenance	Material Passports, Blockchain, Circular Index
3.	Architects	Using Circular Materials, Designing for Value Recovery after use, Design for Durability	Material Passports in BIM, Design Thinking, VR/AR, LCA, LCC
4.	Suppliers	Using Circular Materials and providing products as a service while retaining ownership rights	Material Passports, LCA, Blockchain, Circular Economy Service Companies
5.	Wholesalers	Using Circular Materials	Raw Material Bank, LCA, Blockchain
6.	Construction Companies	Providing products as a service while retaining ownership rights and designing for disassembly	Circular Economy Service Companies, Blockchain, Material Passports in BIM
7.	Installation Companies	Product Lifetime Extension through repair and maintenance and providing the product as a service	Circular Economy Service Companies, Blockchain
8.	Demolition and Recycling Businesses	Using Circular Materials, Designing for Value Recovery after use, Design for Durability	Online Market Places

These stakeholders mentioned above act as or influence the buyers and sellers in a CPP. Their dominance in the CPP defines the strategy of a CBMs that are used and followed in a CPP. Now it becomes necessary to understand the different ideologies to make a CPP happen where not only the product but the ownership rights our transferred.

The essence for procurement is that two organizations and their representatives enter into an agreement to transfer or retain ownership rights of a product and make an ethical agreement. The first thing before entering the agreement is to understand what each organization understands by circularity and align it to their goals and ambitions, then create some KPIs to achieve the aims that they have regarding circularity and CPP and create a possible roadmap. Once these organizations have a clear understanding of what they want to achieve in the process and their needs and requirements match, then CPP between the organizations can be discussed successfully.

3.4.5.2 Buyers in a CPP

To understand a buyer in a CPP, it is essential to first understand the intentions of an organization who the buyer represent and then the characteristics of the procurer within the company. Mostaghel & Chirumalla (2021) studied the role of customers in a circular business model as shown in Figure 18. The organization's characteristics influence the perceived value of a CPP and its ability to comprehend and implement it. These characteristics also influence its goals and actions regarding an ethical CPP.

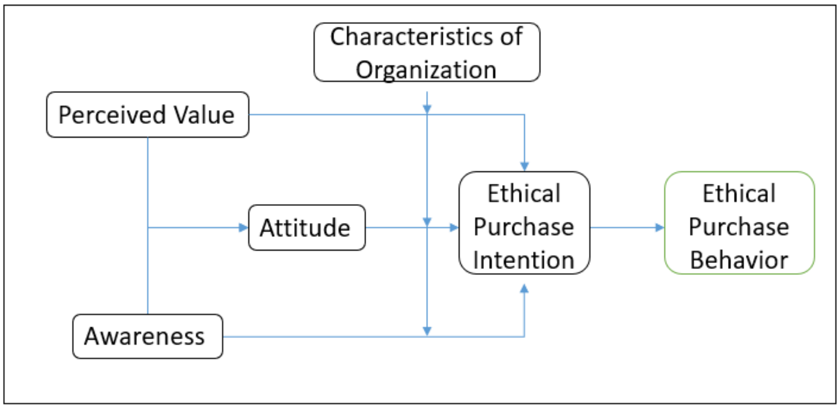


FIGURE 18 ETHICAL PURCHASE BEHAVIOUR OF AN ORGANIZATION IN A CPP (MOSTAGHEL & CHIRUMALLA, 2021)

The research was about consumers in retail sector and their ethical purchase intention to purchase those products. However, the key concepts proposed can be applied to the building industry as customers can be the organizations willing to buy building "products". In a CPP, it is the buyer or the procurer who acts on behalf of the customer i.e., an organization. The ethical intentions of organization are important when they intend to buy products in a CPP. Based on (Mostaghel & Chirumalla, 2021), following attributes are essential in an organization for the CPP to happen as shown in Table 10.

TABLE 10 FACTORS AFFECTING ETHICAL PURCHASE INTENTION AND BEHAVIOUR OF ORGANIZATION TOWARDS CPP (MOSTAGHEL & CHIRUMALLA, 2021)

CRITICAL FACTORS	VARIABLES	DESCRIPTION
Awareness	Environmental Awareness	The organization understands the environmental impact that the construction industry is making and has the aim to reduce the impact that their projects make.
	Ethical Product Awareness	The people who are working in the factories producing the product are of legal age, have benefits provided to lead a healthy lifestyle and are working in a healthy and comfortable environment.
	Brand Awareness	The buyers are aware of the company's market position and their brand value from whom they are buying products from and understand their sustainability principles and can see if they align from their own values.
Perceived Value	Social	The act of buying a product or service circularly would impact their own brand value and status in the industry.
	Functional	The product being bought is of good quality and serves their function really well. Furthermore, it can still be utilized in one form or the other down the line.
	Epistemic	The product comes with metadata that gives an understanding of its technical characteristics such as product passport and its impact so far in the environment.
Attitude	Willingness to pay premium	The extent to which an organization is willing to pay to buy a product in CPP

	Attitude towards CPP	The extent to which an organizations goal and deliverables pertaining to CPP align with the offerings from a seller
Characteristics of Organization	Education level of people involved in CPP	The understanding of circularity among people who represent the company in a CPP or are involved in a CPP process.
	Maturity of Organization	The market understanding and the maturity with which an organization perceives its sustainability and circularity goals along with the number of projects that the organization has handled before.
	Budget for CPP	The amount of money the organization has set aside to integrate CBMs that lead to a successful CPP.

The human factor has always been a big factor while implementing a CPP. Sönnichsen & Clement (2020) state that "*The procurer's beliefs and values are of high relevance in a transformation towards circular public procurement, simply not going for the lowest price, but finding an optimum combination that includes risk, timeliness, and cost on a life-cycle basis*".

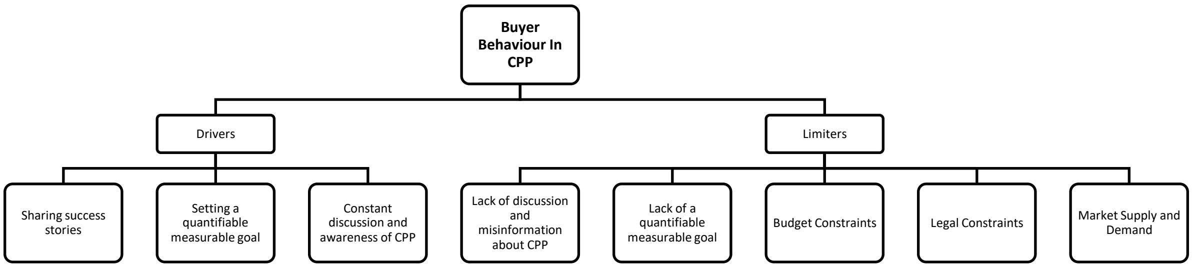


FIGURE 19 BUYER BEHAVIOR AND CPP (NEESSEN ET AL., 2021)

Neessen et al., (2021) studied the role of a buyer involved in a circular process from a human centric approach as shown in Figure 19. The study focused on the role, behavior, and characteristics of the purchaser within the circular purchasing process, and the environment that influences them. The study by Neessen et al., (2021) concluded that usually a person who goes to buy second-hand products is "*intrapreneurial, sustainability-minded and knowledgeable*" and can successfully complete a CPP when they are involved with budget making decisions. Furthermore, what drives a buyer to do a circular purchase apart from perceived profits and notion of being sustainable is **sharing success stories**. This process "*creates a certain awareness"* among people in the organization apart from people who are responsible for circular purchasing *"about circular purchasing and minimize barriers of uncertainty"*. Apart from that, **setting a quantifiable measurable goal** and a roadmap among stakeholders is an important key factor. Furthermore, small steps in **discussing complexities of circularity** among the stakeholders in an organization further help in a successful circular purchase. Apart from **lack of discussions and measurable circularity parameters**, **budget constraints and management's hesitancy** can hinder CPP. Furthermore, **market readiness** is essential for CPP to happen. Lack of coherence between product demand and market supply can be a restraint for CPP to happen. Suppliers' hesitancy to incorporate CE principles of 9R and lack of awareness are major contributors to resist CPP and going against their wishes can lead to **legal issues**.

Based on the CBM's mentioned in Section 3.4.4 , there are three different types of buyers that can exist as shown in Figure 20.

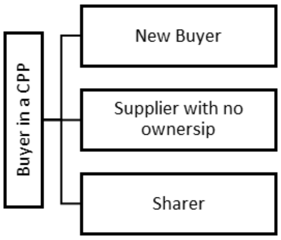


FIGURE 20 TYPE OF BUYERS IN A CPP

There is a *"new buyer"* who wants circular inputs for their project, then there is a "*supplier"* who has supplied product as a service to the seller and then the third is a *"sharer"* who shares the product with the seller. In a CPP, the sharer is non-existent in construction or renovation phase, until and unless the product shared is a machinery being lent or knowledge being shared which is not in the scope of this research.

For a new buyer, to implement CPP, it is essential to have a process defined in the company that leads them for the CPP process. Ellen MacArthur Foundation et al. (2021) proposed a circular procurement framework that provides an "*overview of the intervention points organizations can use to make their purchasing choices more circular and engage their suppliers in conversations about circular principles and collaborative circular partnerships*".

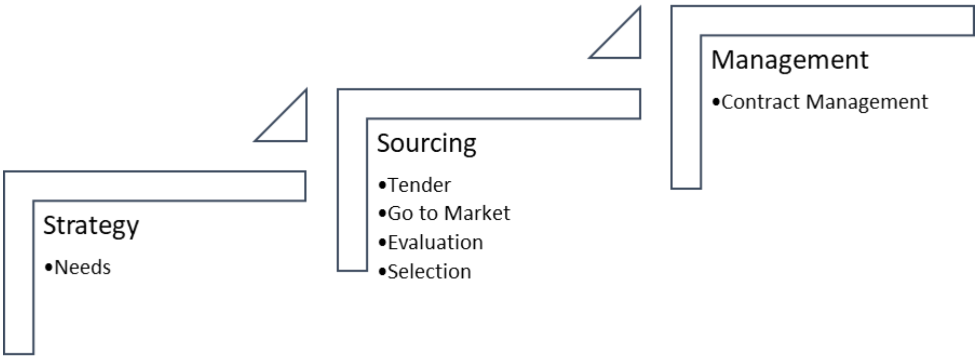


FIGURE 21 STANDARD CIRCULAR PROCUREMENT PROCESS (ELLEN MACARTHUR FOUNDATION ET AL., 2021)

The procurement process is divided into strategizing, sourcing, and management as shown in Figure 21. The first part deals with identifying needs of the buyer and making decisions based on that. The second part deals with aligning the sourcing process to the circularity principles. The final part as the name suggests deals with maintaining the circular agreement made with the suppliers. Table 11 gives a brief description of the various processes in this three-part process.

TABLE 11 STANDARD CIRCULAR PROCUREMENT PROCESS (ELLEN MACARTHUR FOUNDATION ET AL., 2021)

S. NO	NAME	DESCRIPTION
Strategy		
1	*Needs*	The step involves listing and validation of the sourcing need with the stakeholders withing the organization and create a risk assessment report.
1.1	Leveraging Strategy	The strategy of the company's circularity principles should align with the need of the company to procure new materials for the building project. Based on the process being implemented while procuring a specific resource, the time and money invested in CPP vary. For example, a take back process differs from a process where a product is used as a service. This involves reframing the needs, looking into alternative business models, and involving right stakeholders in the right time.
1.2	Tactical Decisions	This involves deciding if a resource already available can be reused or repurposed, or if the sourcing needs to be done for a resource externally with or without ownership and deciding on the due diligence you need to conduct on circularly

		procured products. If the ownership of product is with the buyer, then, it is important to think of end-of-life possibility by a third party and how it can be circular in its second life use. If the ownership of the product is shared, it is essential to know if the payment is per use or per outcome. If the ownership is with the supplier, then the payment is for a fixed period and involves looking at the supply chain in an entirely different manner.
1.3	Risks and Opportunities	The risks and opportunity for a CPP process varies from one type of product to other. Hence it is essential to understand the products' technical aspects, compliance culture, sourcing locations, supply chain capability/capacity, and the need to develop an aftermarket.
1.4	Internal Buy in	This part involves providing all the internal stakeholders and the parties responsible for the product over its complete lifecycle with clear knowledge of the value for adopting a CPP.
1.5	Achievable Circularity	The aim to achieve an entirely circular process is a gradual process and hence, it is essential to understand and manage a partial circular process. Hence it should be clear on how to achieve circularity and monitor the transition to an entirely circular process.
Sourcing		
2	*Tender*	This step includes defining the tendering criteria, analyzing the market where the buyer exists and listing suppliers.
2.1	Data Collection	This involves first making a CE criterion that is measurable, objective, transparent and verifiable, so that it creates a fair competition especially for small and medium enterprises. It is also necessary to understand how far in the supply chain the ripples would be caused based on the criteria It also involves how much can the candidates applying for the tender can amend to enforce CE practices not thought of by the buyer in the first place. Second, based on the criteria, it is essential to list what sort of data is needed for evaluating proposals based on the tender criteria.
2.2	Longlisting suppliers	This involves listing the present capability of the supply market to meet the buyer's sourcing needs and CE criteria, time of engagement with potential suppliers to understand their intents if selected in the tendering process, new technologies and business models that would help the buyer to implement CE, existing supplier's capabilities, reverse logistics structures, market maturity towards CE, certification systems to certify the whole chain of custody and the impact the resource's (used or virgin) extraction, production and transport has on climate.
2.3	Criteria for technical aspects	According to Ellen MacArthur Foundation et al., (2021) the requirements for technical characteristics split the items into three categories: products that can be used more, products that can be created again, and products made from safe and renewable inputs.For the first category, products may have 9R techniques to extend their usage at scale, be innately durable, or be used waste-free.The second group includes products with market-based collecting methods and packaging that is reusable, recyclable, or compostable.The third group consists of non-hazardous chemical-free products. This category also includes products that are (partially) made from virgin materials, utilize inputs from renewable feedstocks and are sourced from environmentally beneficial regenerative resources, or use renewable energy during various lifecycle processes, or maximize resource efficiency during production.Therefore, it is vital to comprehend and simplify the technological factors in order to incorporate product selection flexibility.
2.4	Criteria for biological items	This category when pertaining to construction industry includes the biobased materials, that have material constituents that can be grown regeneratively, or made form by products of other processes, or obtained locally.
2.5	Criteria for packaging	This includes packaging of resources in materials that can be used as well or can be returned back to another circular loop.
3	*Go to Market*	This part involves shortlisting the possible suppliers and enforcing the tendering process
3.1	Shortlisting questions	This step involves listing questions regarding selection criteria and needs that the suppliers must fulfil to win the tender agreement. Furthermore, it also involves

		demanding from suppliers the part of supply chain they cover and their influence on upstream supply chain regarding circularity principles. Also, this stage includes asking questions to assess the suppliers' capabilities to develop new circular capabilities, their understanding of circularity principles and the standard compliance that the suppliers can possibly fulfil.
3.2	Briefings on Circular economy	This stage involves briefing suppliers on CE requirements and opportunities, buyer's commercial expectation, potential future collaboration, and communicating selection criteria and objectives.
4	*Evaluation*	This step involves the responses to tender and clarifying the proposals in case of doubts from the potential candidates.
4.1	Evaluation Process	This stage involves conducting supplier doubt clarification workshops, site visits, circulation of evaluation templates and debriefs for suppliers upon disqualification
5	*Selection*	This step involves making the final selection for the supplier to be involved in the CPP.
5.1	Selection Process	This stage involves combining total cost of ownership and CE related value in one analysis, negotiation environment to provoke CE innovation and trade off and sensitivity analysis to understand scenarios with varied CE value and up-front monetary cost.
Management		
6	*Contract Management*	This step involves reviewing supplier performance to ensure mutual value generation.
6.1	Performance Review	This involves development of CE KPIs to create an open communication with supplier to periodically evaluate CE needs of both parties involved.

Stigter (2016) states that while dealing with agreements with suppliers of products and buyers of product, the ownership rights can become blurry. If the agreement made between suppliers and buyers state that the right of ownership would be transferred at the beginning of procurement to the new buyer, then in a CPP, at the end of first use of the product, the suppliers may become new buyers. Such a case is seen in buyback agreements as studied by Djoegan & van den Reek (2016). The following are the key points to consider under a sale and a buyback agreement.

- The contact between client and supplier is maintained throughout till the end of first use cycle as inspections by supplier are common to check for the quality of the product. The frequency and purpose of contact defines the amount of revenue generated and money spent.
- During the initiation of an agreement, supplier and client should discuss on certain terms. For a buyback to happen, the product must be in good condition. Hence, while product is in use, **customer service costs** come into picture for regular maintenance of products that a client may have to bear.
- On the other hand, the supplier has other risks to deal with. There is a risk that a new alternative product would come in the market and a **substitution risk** is in place. Third, there is cost in buying the products again. Furthermore, the suppliers can either be obligated to buyback, or they can disagree on buying back the products and must pay for **voiding the contract**.
- In case of common product, the supplier needs to be aware of the current demand for the building product. Based on this, the supplier can decide if a new -production process should be started, or a building product sold to the client can be retrieved.
- In the case of a custom product, the production process initiates when a new client demands for such products.

In a CPP, the sharer is non-existent in construction or renovation phase, until and unless the product shared is a machinery being lent or knowledge being shared which is not in the scope of this research. Also, in terms of governance and resource sharing, the sharer usually exists based on inter and intra organizational agreements and organizational structure of built environment stakeholders existing in the region such as hierarchies, markets, and networks.

Preferences of a Buyer

Another important part in any procurement process is the preference of a buyer regarding the product they intend to procure. To get a better understanding of it, a scenario asking what type of products one would prefer to buy was proposed in a small survey where 99 responses were recorded. Figure 22 shows the type of product people preferred. Around 65.7% of respondents of the survey had no problem with reusing an architectural component, compared to 55.6% who preferred MEP systems and 52.5% who chose structural systems.

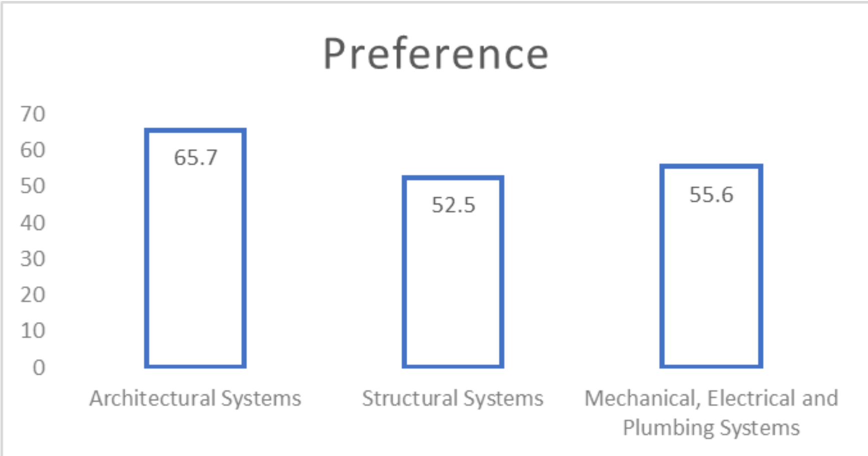


FIGURE 22 PREFERENCE OF A BUYER FOR A SECOND-HAND CONSTRUCTION MATERIAL

Furthermore, based on the interviews conducted, some common decision variables were highlighted. In the survey, to understand perspective of different users, those variables were ranked as shown in the Figure 23.

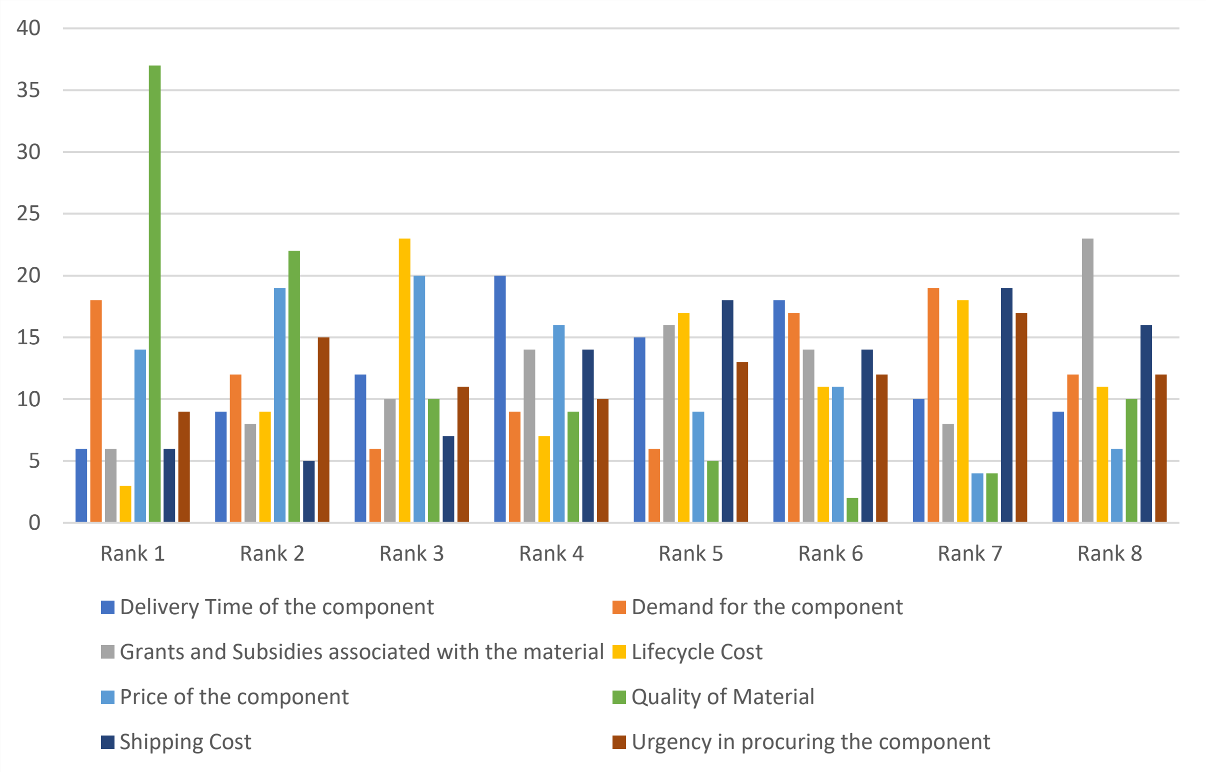


FIGURE 23 RANKING OF DECISION VARIABLES WHILE BUYING SECOND-HAND PRODUCTS

From the chart, if we follow in order while excluding already ranked variables, the most important factor is quality of the material being bought followed by price of the component, lifecycle cost, delivery time of the component, shipping cost, demand for the component, urgency in procuring the material and least important factor is grants and subsidies associated with the material being bought.

While the factors in the survey based on the interviews taken were stated, some other essential variables were added by the survey respondents as follows

- **Product specific factors** like durability of the product being sold, instructions to disassemble, reassemble and install product, its history and environmental impact, product brand, quality research supporting reuse of demolished materials, feedback on material quality, appearance of the product, performance efficiency and effectiveness of a product
- **Supplier specific factors** like seller reliability, image of the company selling the component, customer reviews for suppliers
- **Trading specific factors** like mode of payment, safety during handover of materials, ability to contact the owner via video conferencing tools, quality of sample product provided
- **Market and Societal factors** like obligation to use reusable materials, insurance schemes available to mitigate risks, client demand, the extent to which a product reuse contributes to the sustainability goals of industry.

3.4.5.3 Sellers in a CPP

The sellers in a CPP are the one who owns the product. It can be a supplier who retains the ownership rights or an owner of the building that is about to be deconstructed as shown in Figure 24.

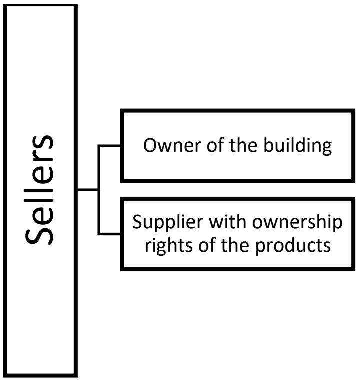


FIGURE 24 TYPES OF SELLERS IN A CPP

As an owner of the building, they can sell the product in a traditional manner after deconstruction. As a supplier they can lease the product as a service and use the performance-based economy model to keep track of the product. If the product buyer has agreements with building product suppliers at the beginning of the use cycle of a product under a business model such as Product as a service (PAAS), the supplier and buyer switch roles while the product reaches the end of its first use. Stigter (2016) assumes that with the rise in resource prices, suppliers may tend to keep the ownership rights of the product to maximize profits. However, this means that the suppliers are responsible for upkeep of the products. This performance-based business model leads to business models like pay per service where the ownership is retained with the supplier and the user pays for the service. This revenue model can be divided in two categories – pay per month or pay per use. This business model also requires upfront costs but when supported with a financier can generate profits sooner rather than later. This upfront cost is usually with the supplier, or they must take loans. Furthermore, suppliers must take care of chain partners such as the raw material providers, and assemblers who are their supplier chain partners making this a careful business process.

In both cases, some new cost elements must be considered, like

- ***(Dis)assembly cost*** for (dis)assembling products,
- ***Storage costs*** to store products as inventory before a sale can occur,
- ***Transportation costs*** to transport products after first use to a storage space and or to the new site for its second use,
- ***Financing costs*** to finance their business activities,
- ***Monitor costs*** to monitor the products,
- ***Management costs*** to manage business activities like customer relationships, allocation of products after first use, sales team upkeep and more,
- ***Maintenance costs*** to maintain product quality,
- ***Product renewal cost*** to renew a product after its first use for its second use,
- ***Withdrawal cost*** to return products that can't go through the R framework to be returned to biological cycle,
- ***Economical risk premium*** to cater to inflation, insecurity in exchange rates, price fluctuations,
- ***Substitution risk premium*** to incur cost that cover the risk of arising substitution goods,
- ***Allocation premium*** to cover for market imperfections while transitioning from a linear economy to a circular economy, and
- ***Complexity premium*** to cover to be added to 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.

Preferences of a Seller

In the survey conducted for the study, among the sample group, it was found that if the product type is architectural (67.7%) or MEP (64.6%) in nature, the sellers are more willing to sell as compared to structural elements (59.6%) as shown in Figure 25.

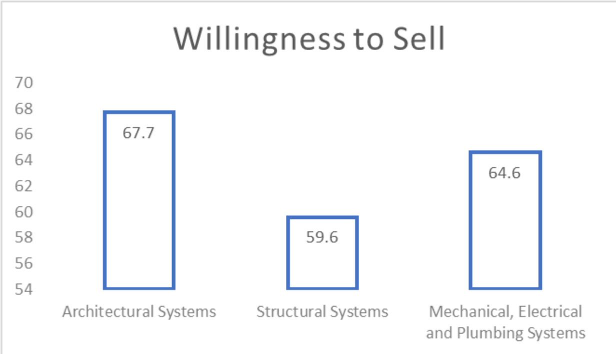


FIGURE 25 PREFERENCES OF A SELLER WHEN SELLING THEIR CONSTRUCTION MATERIAL

The reasons behind this choice could be systemic in nature or presence of business opportunities prevalent in the market or could be comfort or ease of selling one type of material over the other. Furthermore, the lack of quality standards may be a reason of hesitating while selling structural elements or lack of a market for such used products. To understand the factors that hold priority over others while making sales decisions, following results were obtained as shown in Figure 26.

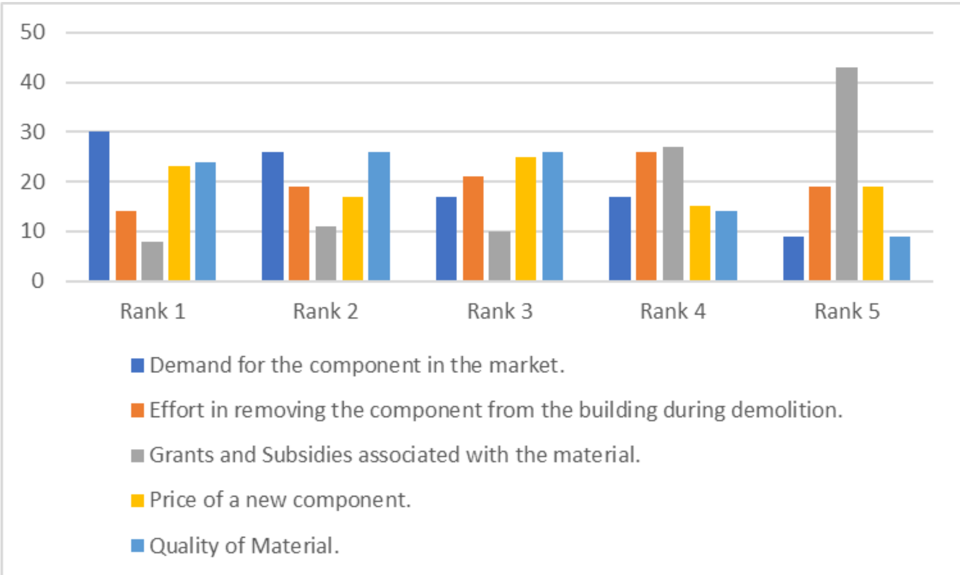


FIGURE 26 RANKING OF DECISION VARIABLES WHILE SELLING SECOND-HAND COMPONENTS

Figure 26 shows that the demand for component in the market is the priority as marked by the sample size of the survey. From the chart, if we follow in order while excluding already ranked variable the second rank is Quality of material, followed by Price of a new component, grants and subsidies associated with the material and effort in removing the component from building during demolition.
While the factors in the survey based on the interviews taken were stated, some other essential variables were added by the survey respondents as follows

- **Product specific factors** like durability of the product being sold, product passport, deconstruction time specific to the product, its design, rarity, functionality, product reliability, quality assurance from certification authorities,
- **Supplier specific factors** like seller reliability, image of the company selling the component, supplier's ability to collect and clean the components, inventory storage costs
- **Trading specific factors** like mode of payment, delivery costs,
- **Market and Societal factors** like obligation to sell reusable materials, insurance schemes available to mitigate risks of dead stock in inventory, alternatives to product being sold, quick return on investments.

3.5 Essential Indicators for a CPP

Despite the simplicity of circularity, which can be stated as optimizing resources and energy and eliminating waste leakages and keeping the resource consumption in limits that are healthier for sustaining life on earth, it is not easy to measure an object's circularity. There is nothing wrong with the circularity principles but the perspective of stakeholders and the context in which it is put makes it a difficult process. Rahla et al, (2019) stated the factors as shown in Figure 27, that make it a daunting task.

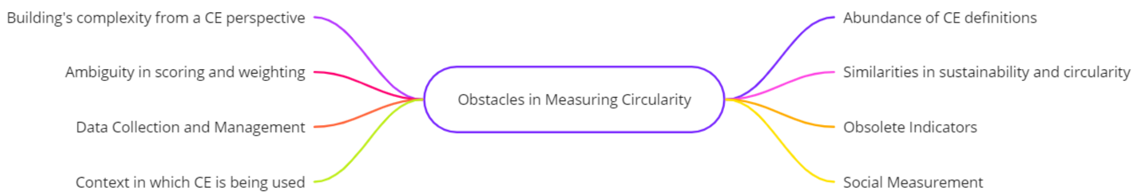


FIGURE 27 OBSTACLES IN MEASURING CIRCULARITY

As specified before, there are a lot of ways circularity is perceived. Since there is a **plethora of definitions,** the way it can be measured changes as well. In addition to that, the need for circularity and the **context in which circularity is being used** is also important. Also, a circular lifecycle means looking into different phases and different lifespans of sub-levels of buildings as explained further in the next chapter. This **building's complexity from a CE perspective** can also be an obstacle while defining tools to measure CE. Additionally, **circularity and sustainability concepts overlap** as evident from the interviews as shown in Appendix A (Chapter 8). This concept overlaying implies that there are similar indicators to measure both circularity and sustainability. Hence, it is important to understand this overlap. A solution to this is prioritizing some indicators over the others and assigning weights as proposed by Rahla et al, (2019). This solution also results in another obstacle which is **ambiguity in weighting and scoring**. The methods to evaluate CE at micro, meso or macro level usually follow the approach of single scores that are based on context of measurement. Furthermore, in terms of weighting methods, methods like "*Average weighting, Principal component analysis, Analytic hierarchy process, Fuzzy synthesis appraisal, Grey correlation degree, and the Full permutation polygon synthetic indicator method*" are commonly used (B. Su et al., 2013). This varies based on the scope of the project and expertise and preference of solutions. Hence, using local circumstances and conditions and being transparent about the method used can give a better understanding of the methodology for the potential users. **Data collection and its management** also is an important part to measure CE and provide an assessment tool. There can be either not enough relevant data or overabundance of it, it is important to plan for its acquiring and management. BIM processes may help in easing the hindrances related to this specific challenge. Furthermore, if the data and the indicators are not updated then the CE assessment becomes invalid due to **unrelated, obsolete, and arbitrary indicators.** Rahla et al, (2019) states that "*the CE-indicators should aptly describe the complex cyclic, closed-loops and other Building's performances that are in line with CE principles, while being constantly updated to match the pinned goals of CE practices in*

Buildings without exposing them to subjective and thus arbitrary assessments." Last but not the least, the CE indicators are usually environmental or economic in nature and lack the social measurements due to the addition of subjectivity in the final measurement. Hence, it is important to have **social indicators** such as post occupancy evaluation that are objective rather than subjective to measure user satisfaction with reused components.

Majority of the factors discussed above are relevant and can be seen as obstacles to measure circularity of a product or a process. However, the focus of this research is understanding circular procurement and the context is a bit different from defining if a process or a product is circular. To understand this, it is important to understand the context in which CPP works. In a linear approach, the end of a building is usually approached with demolishing a building which is much more cost effective than deconstruction in a circular phase. The common element is using materials from the site and usually sell it to someone who needs it. The change in a circular approach is usually how can we remove elements from the site without damage with least cost and time and most ease. Further circular approach is about how much of energy, time and money is consumed while disassembling the materials, storing them, and shipping them to the place where it is needed. Hence, it becomes essential to investigate indicators which help in giving this information to the stakeholders involved in this process.

Based on Section 3.4, CPP entails a buyer, seller, a medium and a process. As stated, before a seller is the one who owns the building material or component, and buyer is the one who trades it for money and uses it or upscales it. The medium is the platform where trading occurs, and the process is the part which involves the resource restoration and trade agreements. The different decision variables discussed in the previous section were distributed under these four categories for CPP. This categorization can be seen in Figure 28.

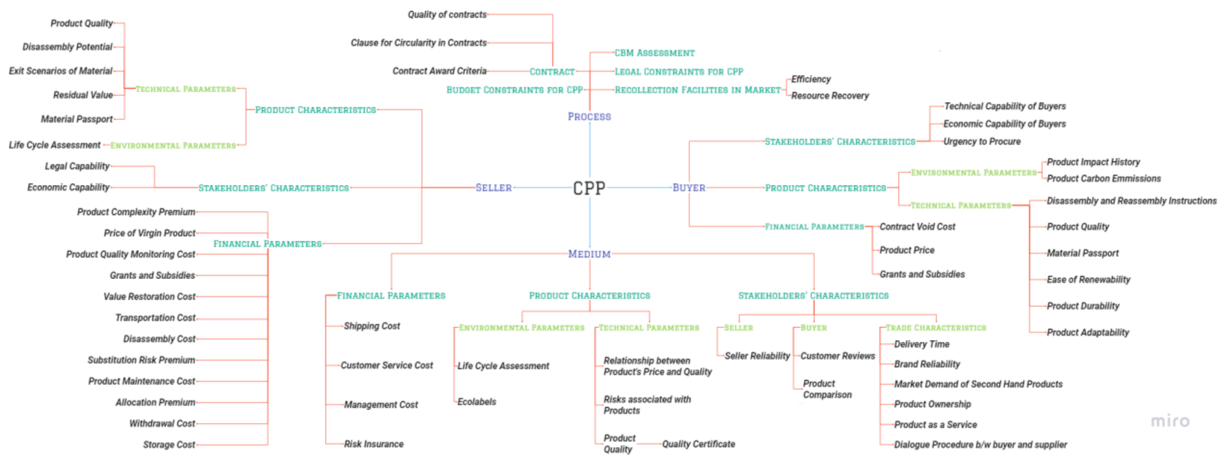


FIGURE 28 ESSENTIALS ELEMENTS OF A CPP

While focused on building component procurement, it is crucial to have indicators that can help make circular procurement happen, such as indicators that can help define a product's utility for a function, its perception for a prospective customer, and its impact on economy, market, and environment. These indicators are not meant to define the circularity of a product or process, but rather to help implement the CPP process.

There have been many indicators, assessments, tools, and procedures to measure other circularity contexts. They are either analyzing a product or process's circularity (using objective or subjective metrics) or projecting its environmental, social, and economic impact during its lifecycle. These tools and techniques are either unique or combine assessment and impact indicators. It is relevant to see if the indicators already created to measure other objectives can be used as CPP indicators. 50 of 78 such indicators were analyzed as shown in Appendix D (Chapter 11) and categorized based on CPP elements. Appendix D (Chapter 11) also lists the reasons for rejecting the 27 papers the author deemed irrelevant based on the present state of research. These arguments are subjective to the researcher and may be valuable depending on another measurable selection method.

Seller: As the seller is the one who owns the building material or component, he or she can be real estate developer, building owner, demolition contractor and resource upscalers or waste management agencies looking to sell after upscaling. The elements relevant for the seller are product's technical or environmental parameters, their legal expertise and economic standing apart from all the financial parameters relevant for a resell as shown in Figure 28. Table 12 showcases the CPP indicators relevant for a seller.

TABLE 12 INDICATORS, ASSESSMENTS, METHODOLOGIES AND TOOLS FOR MEASURING CIRCULARITY (AND ITS SUBSIDIARY CONCEPTS) RELEVANT CPP SELLERS

S. NO	TERM	INPUT	DESCRIPTION
1	Remanufacturing Metrics (Hammond & Bras, 1996)	Disassembly Potential, Reassembly Potential, Quality Assurance data, Removing Potential of Foreign Materials	It provides a relatively efficient and effective means for a product designer to obtain feedback with respect to the remanufacturability of a product. Hence, sellers can use it assess the remanufacturability of the product provided the product details are present with them giving their product an extra edge. **Limitations:** The accuracy of the metrics is restricted to products that can be disassembled, reassembled, and tested on a worktable using standard hand tools. Other product types, notably larger systems, can be judged but tend to score somewhat lower. The metrics only describes the aspects of remanufacturability that are directly under designer's control.
2	Disassembly Potential (Arko van Ekeren, 2018; Durmisevic, 2006; van Vliet, 2018)	Bill of Materials, Bill of Disassembly Potential, Detail Drawings, Relational Pattern	This indicates the factors that could help in determining whether a product can be disassembled and is scored between 0 and 1. **Limitations:** It uses surveys for factor's weighting. It can get subjective based on the survey participants and authors to determine which factors are selected and how they are weighed to determine a disassembly score.
3	Reuse Potential Indicator (Corona et al., 2019; de Pascale et al., 2021; Park & Chertow, 2014)	Amount of waste generated. Amount of waste that can be reused based on available technologies	The reuse potential indicator helps management make decisions regarding waste based on technical ability to reuse materials in commerce, not perception. This new indicator measures technological innovation and commercial use of identified reuse techniques. **Limitations:** Numerous difficult-to-obtain scientific parameters, such as material quality and substitution ratios, are required to calculate the reuse potential indication. Insufficient data makes estimating substitution ratios uncertain. Hence, wider use of reuse potential requires more data on reuse.
4	End of Life Index (de Pascale et al., 2021; Lee et al., 2014)	Disposal Scenario of Product, Disassembly Potential, Recovery Potential	The procedure captures, characterizes and analyses the information from the End-of-Life stage into a product-based End-of-Life Index. The index permits designers to make informed choice on design alternatives for optimum product End-of-Life performance using info from the End-of-Life stage. It helps in mapping the product's end-of-life scenario before the design starts. **Limitations:** The fundamental variables that guide this index can be used by resource upscalers and sellers. However, it is made for designers.

5	Lifecycle Assessment (Hauschild et al., 2018; Vale, 2017; Verberne, 2016)	Bill of Materials, GHG Emissions, Product Material Database	It involves accounting for the energy required for the production, maintenance, operation, and disposal of a building component. It may include operational and embodied energy, carbon footprint, greenhouse gas emissions, eco-indicators, embodied land, maxergy, and so on. A main strength of LCA is its comprehensiveness in terms of its life cycle perspective and coverage of environmental issues. Furthermore, based on Eco chain (2021), it can be used for different procurement purposes such as hotspot analysis, scenario analysis, MKI assessment and monitoring. Since, it takes environmental impact into consideration, hence, it is especially advantageous when paired with LCC to construct a CPP decision-making checklist. **Limitations:** LCA can be undertaken in a variety of methods, and its assumptions can vary. LCA's comprehensiveness is also a constraint, as it requires simplifications and generalizations in the modelling of the product system and environmental impacts that preclude LCA from calculating actual environmental impacts. LCA models are based on the average performance of processes and do not account for the risks of occasional but problematic events, such as marine oil spills and industrial disasters. LCA can determine what is better for the environment, but not what is "good enough." Hence, it is incorrect to assume that a product is environmentally sustainable based on an LCA showing that it has a lesser environmental impact than another. In addition, LCA results are meaningless if they are based on unvalidated assumptions, are incomplete, or fall outside the scope of the analysis.
6	Product Circularity Indicator (J. Verberne, 2016)	MCI and Disassembly Potential	The PCI of a product is a realistic value since the interfaces and connections between products is of great importance for indicating the circularity of a system. Of all the 17 Design for Disassembly factors, that are subdivided into functional, technical, and physical decomposition, the relevant ones are weighed together and multiplied by the MCI to give the value. **Limitations:** The project's disassembly factors were considered independent; thus each variable has the same influence. This doesn't happen in real life, but it's assumed because there's no research to the contrary.
7	System Circularity Indicator (J. Verberne, 2016)	PCI and mass of Products	SCI is the product of PCIs or MCIs multiplied by a normalised factor such as weight to get the indictor for the system in a building such as those categorized under NL/Sfb including all the MCI's and PCI's for each product and the weight variable (kg), a SCI has been established. **Limitations:** During the SCI validation process, it was discovered that a product's weight variable has an unintendedly large effect. During the expert interviews, this variable was also a topic of conversation. However, this weight variable is debatable; other options (such as sales revenue, number of materials, volume (m3), etc.) are also debatable.
8	Circularity Index (Corona et al., 2019; Cullen, 2017)	Recovered EOL Material, Material Demand, Energy required to recover material, Energy	It is an estimation of material circularity that takes into consideration both quantity and quality losses during reprocessing. **Limitations:** This is not a pre-process indication, but rather data provided by CPP agencies involved in repurposing. Therefore, it is somewhat subjective and not universal, but rather local, which can be both a boon and a bane if caution is not exercised.

		required to produce virgin material	
9	Circular Pathfinder (ResCom & IDEAL and CO Explore, 2017; Saidani et al., 2019)	Questions about possible repurpose and current use	It is a web-based tool for identifying an appropriate strategy for the subsequent use of a product based on a survey of ten qualitative product-related questions. **Limitations:** This is a subjective, qualitative measurement instrument. There is insufficient information about the determination of next-use paths.
10	End of Life Indices (de Pascale et al., 2021; Favi et al., 2017)	Material properties, Cost of repurposing and transporting	These indices are fundamental metrics for the correct EoL management of industrial products, considering the opportunities offered by new circular economy business models and measure end of life scenarios such as recycle, remanufacture, reuse, recovery, and disposal. **Limitations:** These indices need disassembly cost and time before calculation and there is a likely chance that such expertise is subjective to the contractor's knowledge of building components and connections which is difficult to amass but not impossible.
11	Product Recycling Desirability Index (de Oliveira et al., 2021; Mohamed Sultan et al., 2017)	Bill of Materials, Material Separation Complexity, Material Security Index, Technological Readiness	It is a combination of Complexity Index (Material Separation), Material Security Index and Technological Readiness. **Limitations:** It has been considered that all materials must be recovered to recycle items. In actuality, disassembly happens and certain materials are lost. In this instance, the bill of materials can be amended to exclude the lost components while still allowing evaluation using the established technique. The separation of materials is not a simple dichotomous problem and can be influenced by connecting technologies. In research, it has been assumed that separation is a possibility. It may be required to consider varying weights based on the reversibility of the joining/welding process employed. There is no consideration of partial dismantling.
12	Economic-Environmental Remanufacturing (de Oliveira et al., 2021; van Loon & van Wassenhove, 2017)	Number of reused components, Number of used products	It is a straightforward tool that allows vendors to rapidly determine whether remanufacturing is economically and environmentally preferable to making new components. **Limitations:** The tool lacks inclusion of energy consuming products, and scenarios like direct reuse, refurbishment.
13	Ease of Disassembly Matrix (de Pascale et al., 2021; Moraga et al., 2019; Vanegas et al., 2017)	Disassembly sequence of components and their connectors, Number of Connectors, Number of Product Manipulations, Tool Type, Identifiability	It measures disassembly time in seconds using the Maynard operation sequence method. It facilitates reuse, recycling, and maintenance. It divides disassembly jobs into six categories and identifies the most time-consuming task. Utilizing the development of activities and basic product information, a spreadsheet is created to estimate disassembly time. **Limitations:** It overestimates the time required to identify connectors because, in actual scenarios, selective extraction and/or replacement of components is performed as opposed to complete disassembly. It does not account for the work required to disassemble components. It only considers screws to be fasteners and requires additional items with different connections to identify eDim more precisely.
14	Potential Recycle Index	Material Data provided from	It predicts the degree of potential recycling of components within the product family. The recycle of components

	(Mesa et al., 2018)	repurposing agents, Bill of Material	contributes to reducing the primary extraction of raw material; therefore, the material follows a circular path in a new product lifecycle. **Limitations:** Nevertheless, the material flow balance is not 100% conservative in the product lifecycle due to the recycling process efficiency, which involves an unrecoverable waste fraction that is generated. During use and EOL stages, the data is difficult to gather due to the different customer profiles, the intensity of use and consciousness about final sustainable disposal.
15	Potential Reuse Index (Mesa et al., 2018)	Material Data provided from repurposing agents, Bill of Material	It estimates the degree of potential reuse of components between different product variants within the product family. **Limitations:** It is a simplified reuse index and there is not sufficient information that quantifies the subjectivity of a user to reuse.
16	Effective Disassembly Time (de Pascale et al., 2021; Marconi et al., 2018)	Disassembly sequence of components and their connectors, Number of Connectors, Product CAD Model	It is a method for calculating the effective disassembly process time for industrial items using five steps to define component connections and obtain the most efficient disassembly process and time. A data mining procedure employs the DSP methodology and a well-defined repository (called Liaison DB) of information about fundamental disassembly processes. **Limitations:** This is used for mechanically connected industrial products. Adapting the industry to adhesives used in built environment products may prove to be a significant challenge.
17	BIM-based Whole-life Performance Estimator (Akanbi et al., 2018; de Oliveira et al., 2021)		It helps in appraising the salvage performance of structural components of buildings right from the design stage and can help demolition experts to generate a pre-demolition audit using a mathematical model and requires quantifiable parameters. **Limitations:** Various building components have different service lives and respond differently to various environmental conditions. Estimating the salvage performance of an entire building system is complex and may be difficult to assess objectively for a variety of reasons. Moreover, the focus of this study is limited to the material analysis of the structural components of buildings under normal operating conditions. This study did not include the building's function as a criterion in determining its salvageability.
18	De milieukosten indicator (Ecochain, 2022; Stichting Nationale Milieudatabase, 2020)	Raw Material, Products and Related Processes, Energy, LCA of Products, Environmental Databases such as NMD and EcoInvent.	MKI indicates the environmental impact of a building material or component in terms of shadow cost resulting from 11 environmental indicators. By providing an environmental cost indicator for a project, the contractors can receive concessions and rebates. MKI focuses on the impact categories and predict the environmental impact only. **Limitations:** It is essential for product based MKI to have brand related data from specific suppliers and producers (Category 1) or tested generic data from industry (Category 2). Using untested generic data (Category 3) is not recommended as input while using MKI for CPP. It is also possible to levy a 'penalty' on the MKI for category 3 data. Also, the information contained in MKI calculations and LCAs is confidential to the company.
19	Lifecycle Cost Assessment (Braakman, 2019)	Costs incurred during lifetime	LCC aims to quantify all costs associated with the life cycle of a product that is directly covered by one or more of the actors in that lifecycle. For a CPP, It is a method for assessing the total cost of element ownership. It considers all costs of acquiring, owning, and disposing of a building or building system. LCCA is

			especially useful when project alternatives that fulfil the same performance. requirements, but differ with respect to initial costs and operating costs, must be compared to select the one that maximizes net savings. **Limitations:** For CPP, the essential part of LCC is End of Life and future costs in a circular ecosystem and that has not been included in the research.
20	Product Recovery Multi-Criteria Decision Tool (Alamerew & Brissaud, 2019; de Oliveira et al., 2021)	EoL Impact Indicator, CO_2 Emissions, SO_2 Emissions, Energy Consumption, Net Recoverable Value, Logistic Cost, Disassembly Cost, Product Cost. Employees required to accomplish the scenario, Exposure to hazardous substance	PR-MCDT is proposed for assessing product circularity strategies (remanufacturing, recycling, repair, and reuse) of a product at the end of its life. The six basic steps that guide the approach and are as follows: (1) selection of potential end of life strategies, (2) scoping of end-of-life strategies, (3) selection of relevant indicators, (4) assessment of end-of-life strategies, (5) analysis and evaluation of end-of-life strategies, (6) refinement of strategies and final evaluation. The strategies are assessed according to relevant economic, environmental, and social indicators. The proposed method does not take into consideration of rebound effects. **Limitations:** One of the limitations of this MCDM method employed in PR-MCDT is a lack of linkages between the criteria.
21	Material Durability Indicator (Mesa et al., 2020)	Flammability resistance (limit oxygen index), Resistance to UV radiation, Resistance to water and Solvent, Yield strength, Fatigue strength, Carbon footprint, Energy consumption	The material durability indicator integrates into a single calculation chemical and mechanical durability, together with environmental impacts associated with the material. The proposed indicator incorporates parameters such as flammability resistance, resistance to UV radiation, water resistance, resistance to organic solvents, mechanical strength, energy consumption, and carbon footprint. This also makes for some quality testing of the material. **Limitations:** The material being tested is plastics and other material such as ceramics, metals, polymers, and composites are not added. The analysis of differentiated durability requirements for parts or components within a product is not considered. The implementation of the indicator largely depends on the type of material considered in the selection process. In the case of combining different types of materials (e.g., composites), attention must be paid to the establishment of reference values.
22	Residual Value Indicator (Jiang, 2020)	Volume of materials without secondary finishes, Volume of material without hazardous content, total volume of material in a building component,	Residual value Indicator assumes that the residual performance of building components can be predicted during the design phase and affected by the deterioration factor. Hence, residual value is expressed as a function of circular design strategies (Design for Disassembly and Design for Recovery) and deterioration factor. **Limitations:** Different strategies such as Design for Durability and Design for Adaptability are not considered as design strategies for residual value indicator. The price fluctuation and tax effects of material disposal are ignored.

		deterioration rate of material	
23	Reusability Potential (Kentie, 2021)	Bill of Materials	The reusability potential determines the possibility that a building product may be reused at the end of the lifespan. The factors used are disassembly potential, availability of material passport, material toxicity, technical lifespan, residual value, and transportability of building product. Apart from this, the guarantee to return a product is one of the influencing factors to measure the indicator. **Limitations:** Factors affecting reusability potential were only briefly investigated, and correlations were not considered. No real-time project information was used.

Figure 29 depicts the indicators (in bold) beside the CPP elements. Among all the CPP elements that are significant to a Seller, it is evident that these indicators can only be employed for Product-based characteristics. In addition, these indicators are solely applicable for describing the technical and environmental characteristics of a product.

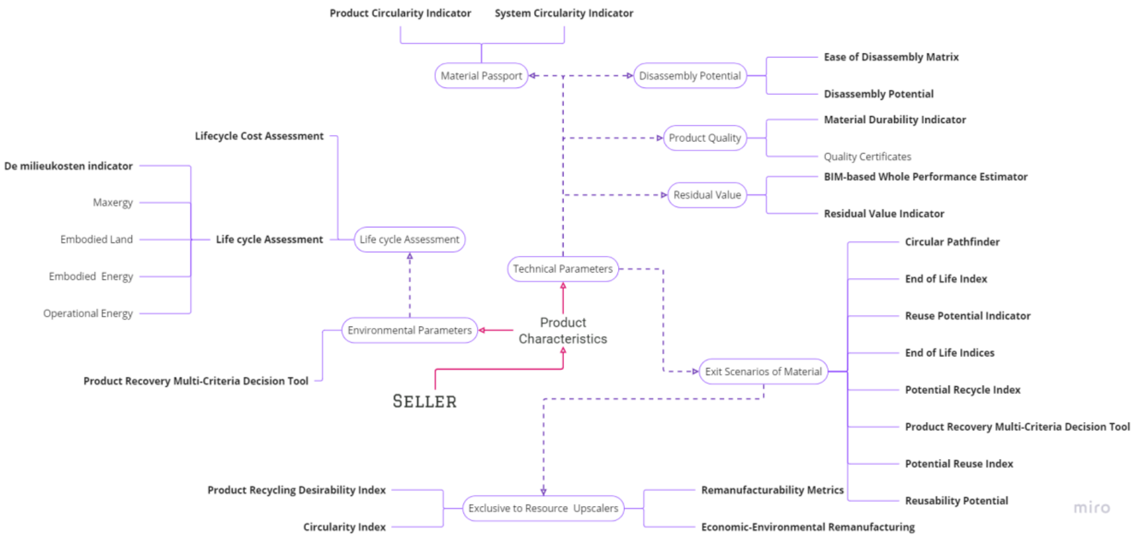


FIGURE 29 CPP INDICATORS MAPPED AGAINST CPP ELEMENTS FOR A SELLER

Process: The process means the whole circular procurement process. It also includes the effectiveness and efficiency the resource restoration process. It also contains the process of contractual agreements between stakeholders and the relevant legal and financial constraints of CPP. Table 13 shows the indicators relevant for the Process part of CPP.

TABLE 13 INDICATORS, ASSESSMENTS, METHODOLOGIES AND TOOLS FOR MEASURING CIRCULARITY (AND ITS SUBSIDIARY CONCEPTS) RELEVANT CPP PROCESS

S. NO	TERM	INPUT	DESCRIPTION
1	Remanufacturing Framework (Ferrer, 2001)	A three-level bill of materials: modules into final product and assemblies into modules, sub-assemblies into assemblies.	It is a framework for identifying the routine for remanufacturing a generic widget. It seeks to strike a balance between the need for an optimal product recovery system and the difficulty of acquiring full data on the value and wear state of the numerous components processed in a remanufacturing factory. The framework is built on two design criteria: reusability and disassembly capability. The design measures are established with the specific intent of facilitating the selection of the most suitable product recovery method. Whenever a component's reusability is promising, it should be refurbished and reused without further disassembly. If the component's reusability is negative but it can be disassembled, it should be deconstructed at one level and its subcomponents evaluated independently. These values depend on the technological prowess of the remanufacturing facility and the condition (state of wear) of the typical widget arriving at the site. Therefore, whenever these capabilities or product profiles change, they must be updated. **Limitations:** The evaluation is confined to the initial levels of assembly, including the value added, material values, predicted wear, and the loss in the event of a poor decision. More study is required to provide a solid foundation for the process of gathering parameters and the value of used components or assemblies.
2	Multi-Dimensional Indicator Set (de Oliveira et al., 2021; Nelen et al., 2014)	Material compositions of the input and output of a WEEE recycling process, the purity, market price and functionality of the output fractions.	This indicator set analyses how well a European WEEE recycling system matches with strategic sustainability goals. This set of indicators is based on the OECD sustainable materials management principle, 'preserve natural capital'. It is based on a product centered approach. The preservation ideas underlying this principle into four touchstones for assessing and monitoring recycling system impacts: 'weight recovery of target material(s)';'recovery of critical materials'; 'closure of material cycles'; and 'avoiding environmental burden'. **Limitations:** It can be used for electronic and electrical system for recycling. This is a rather small context and needs to be complimented with recycling directives for other building materials. Furthermore, it is subjective in its approach and require further development to be implemented easily.
3	Longevity indicator (Corona et al., 2019; de Pascale et al., 2021; Franklin-Johnson et al., 2016)	Initial Lifetime, Refurbished Lifetime, Recycled Lifetime, and corresponding weight of Product in loop.	Longevity seeks to determine the degree to which a system is circular, or the extent to which materials contained in products remain within that system for as long as possible. **Limitations:** This indicator focuses on measuring circularity of a supply chain based on the time a product stays in the closed loop. Hence it is a relevant indicator for circularity. However, it won't amount to much when easing decision making of sellers or buyers in a CPP. The fundamental principle however can be relevant for the entire process as award criteria based on retention can be used to favor one product over the other while comparing similar products on sale.
4	Circular Economic Value	Recovered EOL Material, Material	The CEV represents the circularity of the system by accounting for reduced use of virgin materials, reduced output of waste,

	(Corona et al., 2019; Fogarassy et al., 2017)	Demand, Energy required to recover material, Energy required to produce virgin material	increased use of renewable energies and increased energy output during the end of life. **Limitation:** The CEV is not based on products but materials, and therefore does not specify how to deal with the allocation problem for repurposed content that arises in the case of whether a product is being recycled or recycled material is being used in the product. However, it can still give the repurposing agencies a matrix to quantify the circularity of their process when they need to upscale a product in terms of the amount and type of material and energy used.
5	LCA - Circular Economy Performance Indicator (Corona et al., 2019; de Pascale et al., 2021; Huysman et al., 2017)	The amount of primary and secondary raw materials used for the manufacturing of the product and remaining after product use, Amount of renewable and non-renewable energy resources used.	It is the ratio of the actual obtained environmental benefit (of the currently applied resource recovery option over the ideal environmental benefit according to quality, the latter being the benefit of the resource recovery option to which the resource stream should be directed according to its composition/quality with a minimal required effort, assuming option of closed loop recycling is better, and option of incineration is less preferable. There are two other possible resource recovery options available. They are semi-closed loop recycling and open-loop recycling. **Limitations:** This focuses on plastic recovery and uses vague quality indicators to justify actual benefit. Furthermore, the focus is on recycling processes and can be used only when clear waste streams are present with sufficient database. The calculation relies on predefined quality factors for the analyzed materials (e.g., High quality for recycled materials that can substitute virgin materials).
6	Circular Economy Benefit Indicators (de Oliveira et al., 2021; Huysveld et al., 2019)	The environmental benefits are expressed in terms of natural resource consumption, which is calculated by Life Cycle Assessment, for example by using the CEENE method as lifecycle impact assessment.	Recyclability Benefit Rate (RBR) indicator equals the ratio of the net environmental savings that can be obtained from recycling a product, over the net environmental burdens related to virgin material production and disposal. Recycled Content Benefit Rate (RCBR) equals the ratio of the net environmental savings that can be obtained from introducing recycled material in a product, over the net environmental burdens related to virgin material production, manufacturing, use and disposal. The indicators also take into account (i) the final step (e.g. incineration) in the cascaded use of the material; (ii) accounting for the same basket of products in the denominator as the one in the nominator of the indicator; (iii) eliminating confusion about the calculated result when the denominator is negative; and (iv) introducing a new parameter 'd' to account for the lifetime of the product made from recycled material compared to the product made from virgin material. **Limitations:** The focus is on plastics and recycling specifically. There is a lack of inclusion of bio-based materials in cascading loops. Also, the waste collection and segregation efficiency has not been considered.
7	Circularity of Material Quality (de Oliveira et al., 2021; Steinmann et al., 2019)	Material properties, Cost of repurposing and transporting	It is a material quality indicator based on the energy use of recycled products versus their counterparts produced from primary material inputs only. **Limitations:** The focus is on recycling and quality of recycled materials. The other exit scenario strategies along with environmental impact indicators are not considered. Also, the quality indicator is based on functional use of materials and other quality parameters are not included.

8	Madaster Circularity Indices (Heisel & Rau-Oberhuber, 2020)	Bill of Materials, BIM Model	It's the process of documenting materials and products (used in the Urban Mining and Recycling unit) on Madaster platform using Circularity Indicators and Material Passports. Circularity indicators cover construction, use, and disposal of building. NL/Sfb categorization and external sources like NMD and NIBE guide disassembly calculations. Indicators show the amount of secondary materials used in a design or construction and their reusability. The end-of-life indication is the most important for the CPP, but the other indicators may influence taxation and award decisions, if used, for an online platform. **Limitations:** Not included are the embedded energy of materials and goods, the building's energy consumption, and the water needed for manufacturing and operation across a building's whole life cycle. Recycling and incineration are the only processes of the R framework. Carbon dioxide emissions are not included in the calculation. For actual decision points and CPP development, the enhanced BIM model should be a digital twin.

Most of the indicators and tools from Table 13 either are about the whole process of CPP or can help examine and guide the recollection facilities in the market as shown in the Figure 30

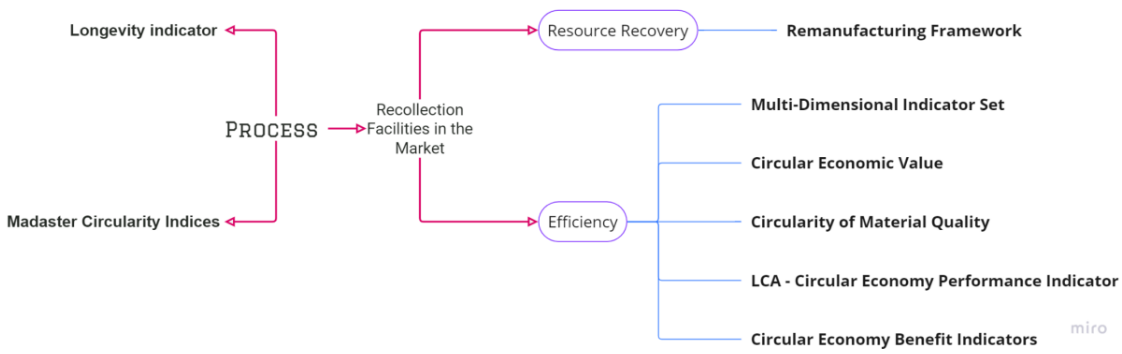


FIGURE 30 CPP INDICATORS MAPPED AGAINST CPP ELEMENTS FOR A PROCESS

Medium: The medium is the platform where trading occurs. Hence, the CPP elements are divided into Stakeholder's characteristics, product characteristics and financial parameters. Stakeholder characteristics have trade-based elements such as dialogue between buyer and supplier, market demand of secondhand products, product ownership, brand reliability and delivery time apart from customer reviews for buyers and seller reliability concerning sellers trade rating. Product characteristics include technical parameters such as risks associated with products, product quality and the relationship between product price and quality apart from environmental parameters such as LCA. The financial parameters of a CPP relevant for a medium include customer service cost, platform management cost, risk insurances and shipping costs for products as shown in Figure 28. Table 14 lists indicators that can guide in providing answers regarding CPP elements relevant for the medium.

TABLE 14 INDICATORS, ASSESSMENTS, METHODOLOGIES AND TOOLS FOR MEASURING CIRCULARITY (AND ITS SUBSIDIARY CONCEPTS) RELEVANT FOR CPP MEDIUM

S. NO	TERM	INPUT	DESCRIPTION
1	Material Price Variance (Boyd, 2013; J. Verberne, 2016)	Standard Price of Material, Actual Price of Material,	It indicates the annual fluctuation in material prices for a specific product at a specific time. Material purchasers in a CPP can utilize the standard deviation from the mean yearly price and the annual price range to illustrate the volatility. It is determined by multiplying the actual quantity of material used by the difference

		Quantity of Material used	between the standard price and the real price per unit of material. In a CPP, the government or other relevant authorities might set this standard price for material derived from used products to encourage procurers to obtain material from used products. **Limitations:** The change in demand and supply of any product eventually affects the price. Hence, it can be seen as limitation if the backend database used to monitor this is not updated. However, this change can also be used as indication of market variation of a product's supply and demand. Furthermore, it is also important to update the standard price to calculate the correct variance.
2	EU Ecolabel (Baldo et al., 2014; Sönnichsen & Clement, 2020)	Material Information such as environmental impact	The EU Ecolabel is an evaluation/communication instrument developed by the European Commission during the last 20 years to support 'business to consumers' environmental initiatives as set out in the latest revised Regulation (EC) No. 66/2010 of the European Parliament and of the Council of 25 November 2009. The EU Ecolabel is a 'Type I' environmental label, according to the ISO 14020 classification (ISO 2000) and is intended to be a voluntary market tool for promoting environmental excellence in products and services in a rigorous and standardized way. The focus is usually on textiles, paintings and furniture and other consumer product. **Limitations:** Products like steel and concrete are usually not included that are up for trade after second use.
3	Circular Economy Index (de Pascale et al., 2021; di Maio & Rem, 2015)	Material Composition of a Product, Financial reports indicating value of material to be recycled and cost to (re)produce the material.	It measures circularity in terms of the ratio of recycled material value from end-of-life products compared to total material value in recycling processes needed to produce new versions of the same product. **Limitations:** Measures recycling rates, excluding all other circular economy effects and loops. Only applicable to recyclers with same assortment.
4	Material Supply Chain Risk (McKinsey, 2020; J. Verberne, 2016)	Market Demand and Supply of Raw Material	Material supply chain risks reflect the product's availability, industry demand, competitiveness and synergy, legal extraction limit, economic and political dangers. It can be a tool for evaluating a trading platform's material availability and scarcity. **Limitations:** This is a broad assessment methodology that comprises of understanding the risks of operational, structural, financial, regulatory, and reputational nature associated with supply chain of a product and pertaining to data security.
5	Material Flow Analysis (Arko van Ekeren, 2018; Brunner & Rechberger, 2016)	Information of raw material mined from nature in the system, Energy consumed during a process	Material flow analysis (MFA) assesses the status and changes of material flows (input and output) and stocks (geogenic and anthropogenic reservoir that can be fixed or changing) in a specified spatial and temporal system (physical boundary like country, organization, building or any virtual boundary). MFA connects the sources, routes, intermediate, and final sinks of a substance. A mass balance can be used to control the outcomes of an MFA due to the law of conservation of matter. This makes MFA a useful tool for resource management, waste management, environmental management, and policy evaluation. In a spatially defined system, an MFA collects data on all flows and stocks of a certain material over time. By balancing

			inputs and outputs, it is possible to identify waste and load flows. Early detection of stockpile accumulation or depletion enables countermeasures or future stockpiling and use (such as for urban mining). If MFAs are conducted over longer periods of time, subtle changes that are too small to assess on short time scales but may contribute to long-term harm become apparent. This can be used to navigate prices of listed goods on the trading platform based on supply and demand of a product. **Limitations:** MFAs have a higher chance of being subjective in nature. Incompleteness of flowcharts, limited data quality, and model assumptions reduce the reliability of MFAs.
6	Product Level Circularity Metric (de Pascale et al., 2021; Linder et al., 2017)	Price of Product	It is ratio of recirculated economic value to total product value as a circularity metric, using value chain costs as an estimator for circularity. **Limitations:** It does not include issues such as toxicity, and environmental impacts. It does not consider total cost of a parts of products if they are leased as the economic value parameter for leased product due to ongoing cost is unknown. Indirect costs used in production processes such as machinery used is not included in the metric. It states to be designed for keeping data confidentiality. However, the data from raw material suppliers before and during first use is still required by suppliers who intend to use it again. It considers two products with different lifespans as equals if they are obtained from the same fraction of recirculated material.
7	Global Resource Indicator (Adibi et al., 2017; de Pascale et al., 2021; Moraga et al., 2019)	LCIA	GRI incorporates various aspects of resource appraisal to enhance resource characteristics. Various attributes related to accessibility, involving both geopolitical availability and recyclability of resources, constitute the multi-criteria indicator to complement the resources deficiency. **Limitations:** Although this is not directly beneficial for the CPP but a localized scope of this can be used on the trading platform to allocate benefits to one trading transaction over the other and provide a dynamic way of growth
8	LCA- Eco-efficiency index (Corona et al., 2019; Laso et al., 2018)	LCA, LCC, Ecolabel	Using linear programming (LP), LCIA and LCC methods are combined to reach an eco-efficiency index (EEI) that attempts to quantify circular economy. **Limitations:** The focus is on fishing industry. The methodology to use LCA and LCC along with Ecolabel can be way to choose between similar options but is quite cumbersome and time consuming.
9	Linear Flow Index for Product Families (de Pascale et al., 2021; Ellen MacArthur Foundation & ANSYS Granta, 2019; Mesa et al., 2018)	Material data from producer and during use, Bill of Material	It measures the proportion of material flowing linearly, that is, from virgin materials and up to unrecoverable waste. It is calculated as the sum of the relation obtained by dividing the amount of the product family material flowing in a linear fashion by the sum of amounts of product family material flowing in a linear and a restorative fashion. This index is an adaptation of the Linear Flow Index proposed by (Ellen McArthur Foundation, 2010). **Limitations:** The complexity of this calculation depends on the number of components or modules and the number of different manufacturing materials; hence it can vary as the products become more composite.
10	Retained Environment Value	LCA of materials in the product	Retained environmental value (REV) measures the share of the environmental impact (EI) from the production of a material or product that is retained in products and materials recovered

	(Haupt & Hellweg, 2019)		from reuse, remanufacturing, or recycling, quantifies the share of the original environmental impact that can be retained in the Technosphere through value retention processes. **Limitations:** Since the indicator is based on LCA, it is essential to understand the limitation that come with it. Furthermore, social, and economic impact indicators must be used to compliment this indicator.
11	Circularity Check (de Oliveira et al., 2021; Ecopreneur, 2019)	60 questions with proof of answer	It focusses on complete strategic scan at product level. It focuses on five indicators: design procurement and production, recovery, delivery, use and sustainability and has about 60 questions. It is a web-based tool and ask for evidence against every question answered. The result is percentage of circularity. **Limitations:** It is combination of qualitative monitoring and uses C2C framework as guidelines. There is no weighting of the indicator and is prone to a bit more subjectivity.
12	Platform CB23 Guide (Platform CB'23, 2020)	LCA, Material Inventory and Value data from NMD, Ecoinvent 44, Product Environmental Footprint Pilot Guidance, Annex V of SBK Determination Method, Oekobaudat.de,	The guide provides methodology to determine the amount of different input and output material along with their end-of-life scenarios, impact on the environment, and technical and socio-economic value of a product. **Limitations:** Materials that are consumed but do not end up in the object or sub-object and are not production waste, do not yet have to be counted as used material stock. Environmental Impact caused by users, but not directly related to the object or sub-object, is not included. Value based indicators of this methodology are still not defined.
13	C2C Circular Product (Cradle to cradle products innovation institute & MBDC, 2021)	Bill of Materials	It gives circularity assessment rating based on the actions taken by the product owner or manufacturer. The rating is done bronze, silver, gold, and platinum for categories such as intended further use, product's technical and biological cycle, incorporation of cycled and/or renewable content, material value retention, presence of circularity data and cycling instructions and availability of various end of life cycling opportunities. **Limitations:** This is a part of C2C certification framework and focuses on circular intention only. The required data on Bill of Materials is usually difficult to acquire due to confidentiality issues. Hence, generic product thresholds are used to map circularity at product level. Furthermore, there is a slight chance of subjectivity while assigning the rating.
14	C2C Clean Air and Climate Protection (Cradle to cradle products innovation institute & MBDC, 2021)	Bill of Materials	"This assessment assigns rating based on whether product's manufacturing results in a positive impact on air quality, the renewable energy supply, and the balance of climate changing greenhouse gases. The ratings are given on categories such as Air Emissions Compliance, Quantifying Electricity Use and Greenhouse Gas Emissions, Clean Air & Climate Protection Strategy, Using Renewable Electricity and Addressing Greenhouse Gas Emissions in Final Manufacturing, Energy Efficiency During Product Use, Transparency, Using Blowing Agents with Low or No Global Warming Potential and Addressing Embodied Greenhouse Gas Emissions. **Limitations:** This is a part of C2C certification framework and focuses on air quality and climate. The required data on Bill of Materials is usually difficult to acquire due to confidentiality

			issues. Hence, generic product thresholds can be used to map effect on air quality and climate."
15	C2C Material Health Assessment Methodology (Cradle to cradle products innovation institute & MBDC, 2021)	Bill of Materials	"It gives the material assessment rating based on those hazards and relative routes of exposure **Limitations:** This is a part of C2C certification framework and focuses on material health only. The required data on Bill of Materials is usually difficult to acquire due to confidentiality issues. Hence, generic product thresholds are used to map toxicity of materials"
Remanufacturing metrics, Lifecycle Assessment and Madaster Circularity Indicator are also relevant for this category.			

The indicators and tools from Table 14 are about the product's quality or risks associated with them and about stakeholder relevant elements such as market demand, product comparison for buyers and seller's reliability based on product's circularity as shown in Figure 31.

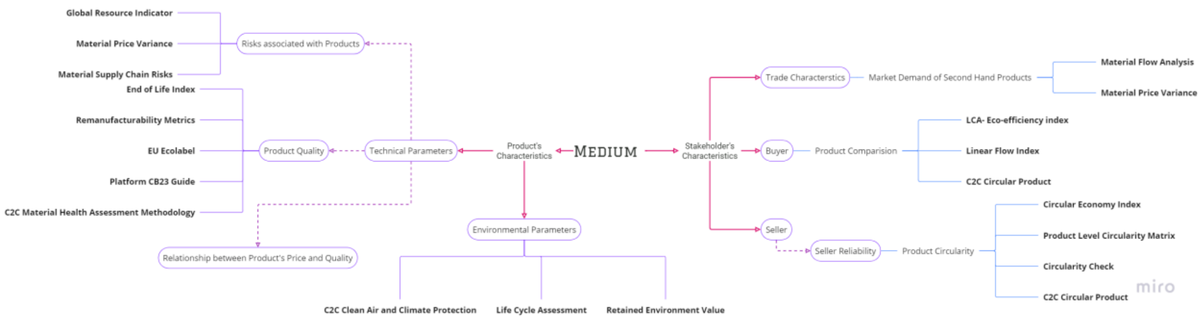


FIGURE 31 CPP INDICATORS MAPPED AGAINST CPP ELEMENTS FOR A MEDIUM

Buyer: A buyer is the one who trades a product for money and uses it or upscales it and sells it further and gains ownership for a period under some trade agreement. The CPP elements associated with buyers are stakeholder-based characteristics like technical and economic capability of buyers and the urgency to procure material; financial characteristics such as cost when trade agreements are not followed, price of the product and grants and subsidies associated with procuring second hand products; and product-based technical elements such as product durability, product adaptability, ease of renewability, material passports, product quality, product impact history, disassembly and renewability parameters and product based environmental elements. Table 15 lists indicators that can guide in providing answers regarding CPP elements relevant for the buyer.

TABLE 15 INDICATORS, ASSESSMENTS, METHODOLOGIES AND TOOLS FOR MEASURING CIRCULARITY (AND ITS SUBSIDIARY CONCEPTS) RELEVANT FOR CPP BUYER

S. NO	TERM	INPUT	DESCRIPTION
Buyer			
1	Remanufacturing Product Profiles (de Pascale et al., 2021; Gehin et al., 2008; Zwolinski et al., 2006)	Available Material Processing Options and Bill of Materials	This tool gives designers relevant information to reach a successful remanufacturing situation. This information includes 15 variables such as ratio of cost of recycled to virgin materials, useful life between remanufacturing cycles, first and second lifetime, redesign level, reason intervals between redesigns, market competitor and more. For its use, about 30 remanufactured products were tested and the essential criteria for the success of remanufacturing procedures were identified. **Limitations:** It is only limited to remanufacturing rates. Also, the

			tool does not measure actual remanufacturing rates, focusing instead on criteria that are likely to improve remanufacturing rates. The tool is assumed to be economically profitable and eco-friendly with no criteria given. Hence it can only be used with other parameters.
2	Material Circularity Indicator (Ellen MacArthur Foundation & ANSYS Granta, 2019; Gupta, 2019; Jiang, 2020; Saidani et al., 2017; van Vliet, 2018; J. Verberne, 2016)	Bill of Materials	This indicates the material circularity of a product without considering the external assemblies. Hence it is a theoretical index. Disassembly of a material needs to be considered alongside MCI to make better decisions regarding selection of product by a buyer. **Limitations:** Linear flow index (essential for MCI) is contained within MFA. When considering mass flow, numerous materials and components are combined. This makes including remanufacturing in the metric challenging. The utility factor is derived from estimated average product lifetimes. This is a judgment call that invites estimates of circularity that contradict clear methodological principles. Ex ante assumptions regarding the destination of a product after use and its recycling efficiency are required. Generally, required information (such as the bill of materials for each component) is regarded as confidential. Verification by a third party is difficult (Linder et al., 2017). The MCI assumes that neither the quality nor the quantity of a product degrades during use. The reclaimed item is as good as new(Jiang, 2020).
3	Eco-Cost Value Ratio (Klaassen et al., 2020; Scheepens et al., 2016)	LCA	The Eco-Cost Value Ratio model assesses sustainability through three dimensions: costs, market value, and “eco-costs” (i.e., externalities). A product or service is “clean” when eco-costs are below a certain threshold. This means that products and services can be improved by either lowering externalities or by increasing a product’s market value to prevent rebound effects. **Limitations:** Whereas increasing circularity may be a means to reduce externalities, this metric does not specifically address circularity. A thorough LCA that follows strict guidelines (International Organization for Standardization [ISO] 14044) often requires a year to complete and is challenging when introducing new products. Measures environmental impacts per euro spent, not necessarily focusing on closed material loops, but implicitly considering circular economy effects as sharing, reusing and renewable energy. Environmental impacts during usage included although uncertain: depends on the condition of use. Verifying eco-cost of a product might be difficult because of confidentiality.
4	Environmental Product Declarations (EPD, 2021)	Environmental impact and inventory indicators, and impact assessment methods like GWP, Acidification Potential and others	It is a report that includes information about the use of resources, potential environmental impacts, waste production and other environmental indicators, divided into different life cycle stages and given per functional (or declared) unit. **Limitations:** EPDs can be used to compare different materials while making decisions to buy one over the other. However, it is essential to understand that the products should be very similar to avoid traps like more replacement, operation energy during building lifecycle for a product with lower manufacturing energy. Otherwise, it becomes important to compare EPDs at building level. Furthermore, EPDs are not equally good. Hence, due diligence is required while using EPDs.

Indicators in Table 15 and under the category medium, process and seller that are relevant for this category are given in Figure 32.

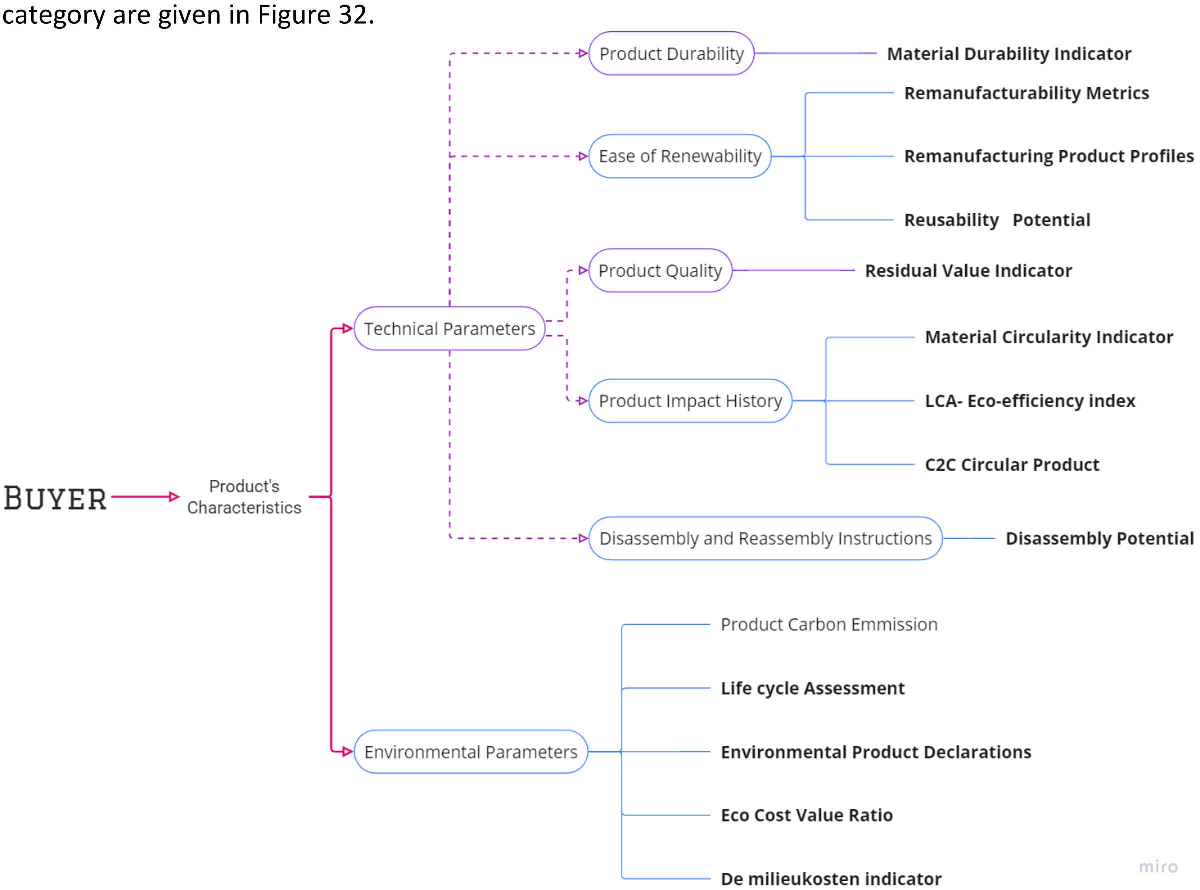


FIGURE 32 CPP INDICATORS MAPPED AGAINST CPP ELEMENTS FOR A BUYER

A product's exit scenario, life cycle (cost, environmental impact, etc.), quality and residual value, and market demand projection, which also comprise some of the significant barriers as indicated in section 3.4.1, are all themes that recur when looking at the key CPP features and indicators. The key elements necessity and fundamentals are summarized below.

Exit Scenario of a Product: The exit scenario of a product determines the second life of the product and/or its elements. This prediction is needed to sustain a circular loop and optimize resources. It has been discussed in section 3.4.3. A product might be part of a system or utilized alone and segregated. It is safe to say that a group of units (system, product, etc.) can be broken down into units (products or components or other). Groups of units can include renewable bio-based units and non-renewable finite units.

- The renewable group may be cascaded to make a unit survive several lifetimes in distinct value streams; transformed to high-value biochemical feedstock when broken down; or composted and anaerobically digested to produce manure and fertilizers before returning to the atmosphere's biological cycles.
- The non-renewable group of units can go through the R framework as showcased in Figure 12. It involves methods to maximize a group or unit's usefulness by rejecting the use of virgin materials, rethinking utilization by sharing resources, and limiting waste. Additionally, product lifespan can be prolonged by reusing groups of discarded units, repairing, and maintaining units and restoring the group, remanufacturing the units to form the same group or repurposing the units to form a different group. Alternative options for creating a (semi) closed circular loop include recycling the units or recovering the energy by incinerating the units.

Product Quality and Residual Value: In CPP, product quality is essential for trading. As buildings age, so does their components and their functional utility decreases as time passes by. This aging is caused by physical deterioration. Based on the quality of a product, one can plan for deconstruction by prioritizing high quality assets over others. The utility of a product influences the evaluation of its quality. It is comprised of three essential elements: Quality Threshold, Residual Value, and Quality Gap.

Quality Threshold is essential to evaluate the quality of a product based on the context in which it will be utilized. After a product's next use has been determined, it is simpler to identify all the necessary attributes that will render it useful. This is the quality threshold of the product.

Manganelli (2013) states that physical deterioration of the building over time can be expressed as the decrease in the length of the life cycle and therefore the equivalent loss of value, measurable during buildings' useful life. The quality of a product at the time of demolition or deconstruction is its residual value. Using the product's quality at the beginning of the construction process as a benchmark and a depreciation rate to determine how much it has depreciated over time, this value may be documented. According to Sanchez et al (2019), it is essential to measure and maximize the residual utility of existing assets to assess its quality for a prospective buyer. Hence, it is essential to measure the residual value of a product. This value can be verified by a site inspection and photographs for more precise findings.

The difference between the threshold value and the residual value is the quality gap. This discrepancy is essential for determining the intended strategy to upscale the product (or its components). Once this is determined, the transition cost to restore a product (or its components) to its maximum utilization can be computed.

Lifecycle Sustainability Assessment (LCSA): The idea of LCSA builds on the "three pillars" understanding of sustainability, which consists of an environmental (LCA), social (Social Lifecycle Assessments), and economic component (Lifecycle Cost). Economic assessments and environmental implications are the focus of this research. This research doesn't address societal impacts.

Environmental Implications: LCA based environmental products and labels appeal more to environmental savvy clients. According to Hauschild et al. (2018), an LCA begins with a concise description of its purpose. Specifying a function unit and defining the scope of a product system specifies which processes and activities are associated with a system. Additionally, geographical, and temporal bounds are chosen in conjunction with applicable research and technology. Then, it is determined whether the LCA will compare choices or evaluate process implications. The inventory is then inspected. The examination of the inventory yields a life cycle inventory, which is a collection of quantifiable physical elementary flows involved in providing a service or function. Utilizing environmental science information and models, the impact assessment transforms the physical flows and actions of a product system into environmental impacts. In accordance with ISO (2006), the first phase of impact assessment is to select impact categories depending on the criteria of the study. The second stage is to map the inventory analysis's basic flows to impact categories. The third stage analyzes the contribution of elementary fluxes to impact using environmental models. The fourth step is to standardize the effects of numerous categories using a single reference impact. Grouping and weighing combines all weighted impact ratings into a single environmental impact score for the product system. This can be useful when combining LCA results with other condensed information, such as alternative economic costs, to help decision making.

Economic Assessment: LCC calculates a product's total lifetime cost of ownership. It's used for investment decision analysis, planning, resource optimization, hotspot detection, and product life cycle sustainability. LCC can be conducted before and after a process changing it from a decision-making tool to a process assessment tool. According to Hauschild et al. (2018), traditional LCC fundamentals can differ depending on the subject's perspective. For a producer of a product, parameters such as operational and capital expenditures are interesting. A recycling plant prioritizes service revenues and recycling costs. Among the factors required for LCC are costs, or the monetary value that someone must pay for something across its entire lifecycle. LCC can include revenues from the sale of goods or services or other uses of capital or assets, which are considered negative costs, but their calculation should be explicit. Practically, they're often left out when one stakeholder's revenue is another's cost. Furthermore, costs are classified into two categories: internal costs and external costs. Internal costs are those borne by stakeholders inside the study's scope, and external costs are from commercial transactions, which are not included in their pricing, or economic developments. Since LCC expenses accumulate over time, multiple monetary flows must be considered. First, raw material's prices change over time, which is accounted for by inflation rate. Second, certain prices are paid later, which is accounted for by discount rate.

Apart from the traditional economic assessment, LCC can be used for the environmental assessment along with economic assessment and is termed as environmental lifecycle cost (eLCC).

Market Demand and Supply: Demand of a product for a buyer is guided by the marginal value (not taking buyer preferences, marginal utility can also be used as marginal value) it offers per unit. Usually, marginal value can be predicted using the market demand as the reference considering external conditions are not affecting the demand. Once all individual demands are added together, it gives the market demand of the product. The supply of product is influenced by its marginal cost. The market supply of the product is obtained by adding all the produced product at the market price.

If a product provides better marginal value to a buyer, it is likely that the product would be chosen over others. This principle also applies for a choice of second-hand product over the virgin product provided preferences of a buyer are met by both.

- Consider a scenario where a competitive market exists for material procurement for construction supplies as stated in the report by NAHB Research Center Inc. & Upper Marlboro MD (2001) .
- In a competitive market, the supply cost of product produced by an individual seller is equal to the price at which it is sold in the market to keep the seller in business.
- When a product is in demand, the manufacturers' marginal cost to produce a new material increase, leading to the decrease in supply of a virgin product. This decrease in supply leads to increase in demand of secondhand product if the marginal value of alternatives is less.
- Due to limited second-hand stock and increase demand of the product, the price of the product increases, making the deconstructions profitable if the marginal cost to produce virgin product is more than the marginal cost to deconstruct and upscale a second-hand product.

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.

Disassembly of Building and its assets: Section 3.4.1 discusses the hurdles to CPP, two of which are building detachability and a lack of understanding of exit situations. These impediments are related to the concept of disassembly and its absence. Hence, understanding disassembly is an important aspect to further provide clarity on these obstacles.

According to Tingley & Davison, (2011), it is difficult to disassemble a building if products are not designed for disassembly (DfD) and material reuse. However, there are barriers to design a product or a building for disassembly as discussed in Chapter 1 and Chapter 3. These barriers are like those listed in the studies of Addis & Schouten (2004); Chini & Balachandran (2002); Dolan et al (1999); Guy & Ciarimboli (2005); Morgan & Stevenson (2005) and M. D. Webster (2005) apart from the barriers in the design stage of the building such as additional design costs, lack of design standards regarding DfD, type of connections and their accessibility. The strategies to avoid these barriers are the prerequisites for DfD and deconstruction. Some of the strategies are shown in Table 16 below along with the extent on influence (High, Moderate, Low) on the R framework strategies to optimize use (R3), extend product lifespan (R4 to R7) and promote smart use of material (R8,R9) as shown in Figure 12.

TABLE 16 DFD STRATEGIES AND THEIR INFLUENCE ON EXIT SCENARIOS

S.NO	STRATEGIES	R3	R4-R7	R8, R9
1	Ascertain the existence of a complete set of as-built drawings.	High	High	High
2	Design for maximum adaptability to preserve the structural integrity of the entire structure.	High	Low	Low
3	The entire design team, the client, and the contractor must all be on the same page.	High	High	High
4	Establish targets for the structure that can be reused.	High	Mod	Low
5	During the design phase, a deconstruction strategy should be developed.	High	High	High
6	Provide Guidance for Deconstruction	High	High	High
7	Provide contractors with appropriate DfD training.	High	High	Mod
8	Provide additional time for DfD integration.	High	High	High
9	Determine the design life of different components.	Mod	High	Low
10	The structure's components should be stratified according to their expected lifespan.	Mod	High	Low
11	Make geometry straightforward.	High	High	High
12	Utilize a structural grid standard	Low	Low	Low
13	Size components according to the method of handling.	High	High	Low
14	Create reusable, resilient components and connections.	High	Mod	Low
15	Make available all components and connecting points.	High	High	Low
16	Provide component identification information	High	High	High
17	Ensure structural systems are effortlessly demountable	High	High	Low
18	Implement passive rather than active service components whenever possible.	High	Low	Low
19	Utilize connections that can be easily detached.	Low	Mod	Low
20	Avoid using adhesives, resins, and coatings that inhibit reuse.	High	High	Mod
21	Use as few connectors as possible and limit the variety.	High	High	Low
22	Reduce the number of employed materials.	Mod	High	Low
23	Provide an elaborate list of all construction materials and components.	High	High	High
24	Where possible, utilize prefabrication and mass production.	High	High	Low
25	Choose recyclable materials that are simple to sort.	Low	Low	High
26	Avoid composite systems.	Mod	High	Mod
27	Design service routes to be easily maintained and accessible.	High	High	Low
28	Provide adequate assembly and disassembly tolerances	Low	High	Low
29	Produce indivisible assemblies from the same substance.	High	High	High
30	Avoid use of toxic and hazardous materials	High	High	High
Sources: (Addis & Schouten, 2004; Cheshire, 2016; Dolan et al., 1999; Guy & Ciarimboli, 2005; Hurley et al., 2002; Morgan & Stevenson, 2005; Storey & Pedersen, 2003; Tingley & Davison, 2011)				

When dealing with CPP, the transformation capability of a building is crucial. Components of a building with a greater tendency to transform can be disassembled more easily. A building designed with DfD in mind has a greater potential for disassembly. Numerous researchers have proposed disassembly potential factors and weighed them using processes such as the fuzzy logic, analytic hierarchy process (AHP) and similar processes based on DfD strategies of Table 16. Some key researchers that propose and use the disassembly factors are (Arko van Ekeren, 2018; Durmisevic, 2006; van Vliet, 2018) for micro and nano level. The details are briefed in Appendix E (Chapter 12)

At the nanoscale, product disassembly must be effortless. The disassembly time and the sequence to disassemble are key parameters for effortless disassembly. There have been several studies conducted to plan disassembly sequences and compute optimal disassembly time. For example, Vanegas et al., (2018) provides a measure for quantifying the disassembly time so that products can be dismantled for reuse, repair, and remanufacturing by calculating time taken six disassembly tasks: Tool change, identifying connections, product manipulation for accessibility to connections, positioning of tools to disassemble, actual disassembly and removing the unfastened components and putting them. These tasks are modelled using Maynard operation sequence method (Zandin, 2002). Another example is the study by Huang & Huang (2002). According to the study, the effectiveness of disassembly is affected by the stability of the other components after one component has been dismantled. Hence, they proposed a method for generating all the possible disassembly sequences for computer aided disassembly planning. A more recent study computing disassembly sequence and time is by Marconi et al., (2018). It detects the target components from the general product assembly by examining the virtual product model. It further defines the disassembly matrix levels and calculates feasible and the best disassembly sequences using data mining techniques.

Furthermore, concepts like material passport, building information management, photogrammetry and more can help in framing and organizing the elements such as Exit Scenarios, LCSA and market demand of secondhand product in a CPP methodology. When these are combined with external databases and platforms with key impact indicators, a circular procurement ecosystem can exist.

3.6 Conclusion

Circularity a principle that is often employed in conjunction with other concepts. Also, it is frequently confused with or associated with sustainability. In addition, its roots can be traced to earlier theories such as spaceship Earth, steady-state economic models, ecological laws, industrial ecosystems, reverse logistics, and natural capitalism. Additionally, it shares principles with present theories such as the closed supply chain, cradle-to-cradle, performance economy, and doughnut economy. Hence, circularity at its core is the concept of **limited resources and a systemic model that enables an uncompromising, regenerative distribution of resources through time**.

Circularity is a simple concept that **can be applied to any problem or industry**. This implies that the scope of circularity is huge, ranging from a global scale (macro) to a material scale (nano), resulting in varied interpretations, definitions, and methods to measure. Since this project involves the **procurement of building parts and components from an existing structure**, circularity in this context follows the principle that a component must be preserved by various biological and technical tactics to make it a circular product. This activity should be performed while monitoring its present and future effects on the environment and society.

In context of circular ecosystem resource loops, some material flow rules were found. First, for **non-renewable resource types**, the loop can be closed using various R techniques, whilst **biological resources** can be cascaded or returned to the ecological cycles of the surrounding environment via anaerobic digestion, regeneration, farming, or biogas production. Second, while closing the loop, it is essential to incentivize durable and easily recaptured commodities and prevent the devaluation of materials due to systemic leakage in the circular supply chain. Based on the resource flow, some common characteristics of the most prominent circular business models have been identified, such as 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.

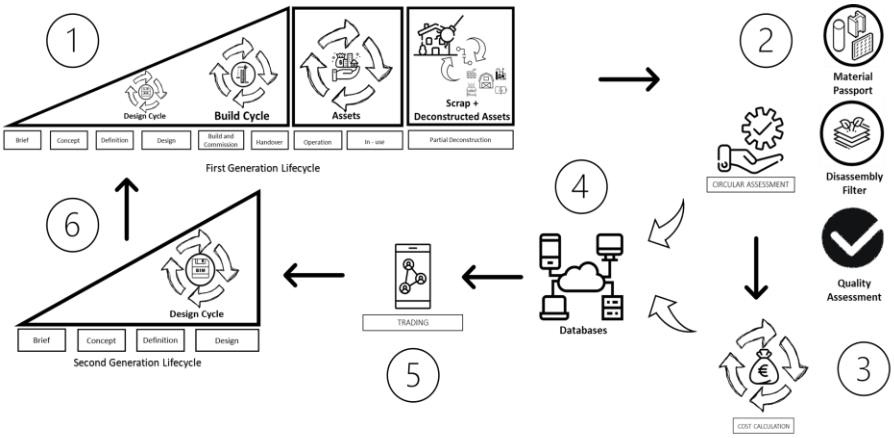


FIGURE 33 CONCEPT DIAGRAM FOR CIRCULAR ECOSYSTEM

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.

Stages of a Building Lifecycle

Design Stage	Construction Stage	Operation and Maintenance Stage	Demolition Stage
❑**Feasibility Study** • Strategic Brief • Site Analysis • Zoning Analysis • Project Scope • Building Program • Project Budgeting • Selection of Project Team ❑**Concept Design** • Outline Specifications • Schedules of Accomodation • Planning Strategy • Cost Plan • Procurement Options • Programing and Phasing Strategy ❑**Detailed Design** • Architectural Detailed Design Model • Structural Detailed Design Model • Services Detailed Design Model ❑**Post Design Phase** • Document Handover • Tendering	❑**Pre Construction** • Site Acquisition • Selection of Project Team • Permissions • Mobilisation ❑**Material Procurement** • Selection of Suppliers • Material Supply ❑**Construction** • Site Clearance • Surveying and Building Layout • Excavation • Foundation • Frame and Roof Construction • Cladding Installation • Fitting out • Landscaping ❑**Monitoring** • Health and Safety • Construction Progress • Inventory • Budget • Waste Disposal ❑**Handover and Closeout** • Preoccupancy Evaluation • Corrective Measures • Payment • Site Handover	❑**Requirements Management** • Requirement Planning • Contracting and Outsourcing ❑**Commissioning** • Planning • Cordination ❑ **Operation** • Asset Operation • Energy Management • Hazardous Waste Management • Recycling • Indoor Air Quality • Inventory Management • Communication Management • Alteration Management • Relocation • Disaster and Prevention Recovery ❑**Maintenance** • Planned Maintenance • Preventive Maintenance • Corrective maintenance • Front-line maintenance • Predictive maintenance • Reliability Centered maintenance ❑**Post Occupancy Evaluation** • Occupant and owner specific evaluation • Monitoring of building's environment strategies • Assessment of design quality of building	❑**Pre Demolition** • Pre Demolition Assessment • Cost Estimation • Planning • Inventory Managemen and inspections ❑**Demolition** • Site Preparation • Utility Processing • Asbestos Removal • Soft Strip • Superstructure Processing • Slab and Foundation Demolition • Site Finishes ❑**Material Disposal** • Waste Management Plan • Waste Seggregation • Waste Disposal

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.

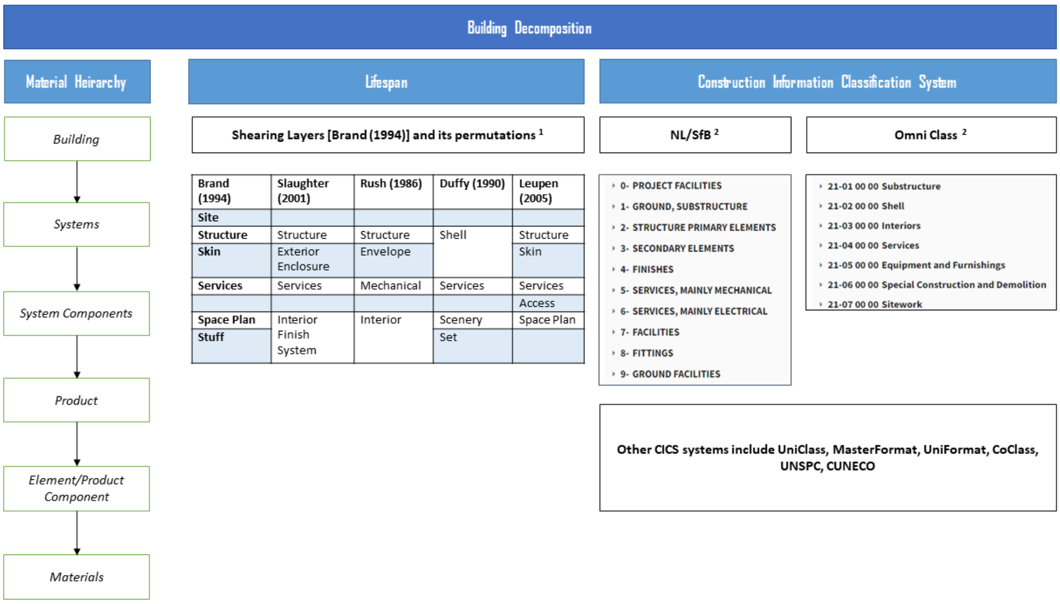


FIGURE 35 MATERIAL HIERARCHY, SYSTEM DECOMPOSITION, ABSTRACTION (J. VERBERNE, 2016), 1: (SCHMIDT III ET AL., 2011B), 2:(MADASTER, 2020)

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).

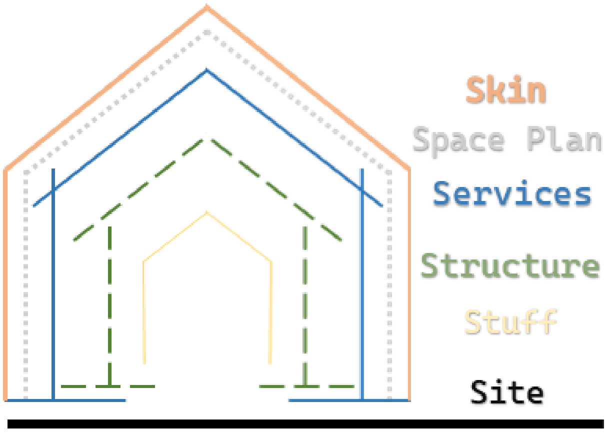


FIGURE 36 SHEARING LAYER

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.

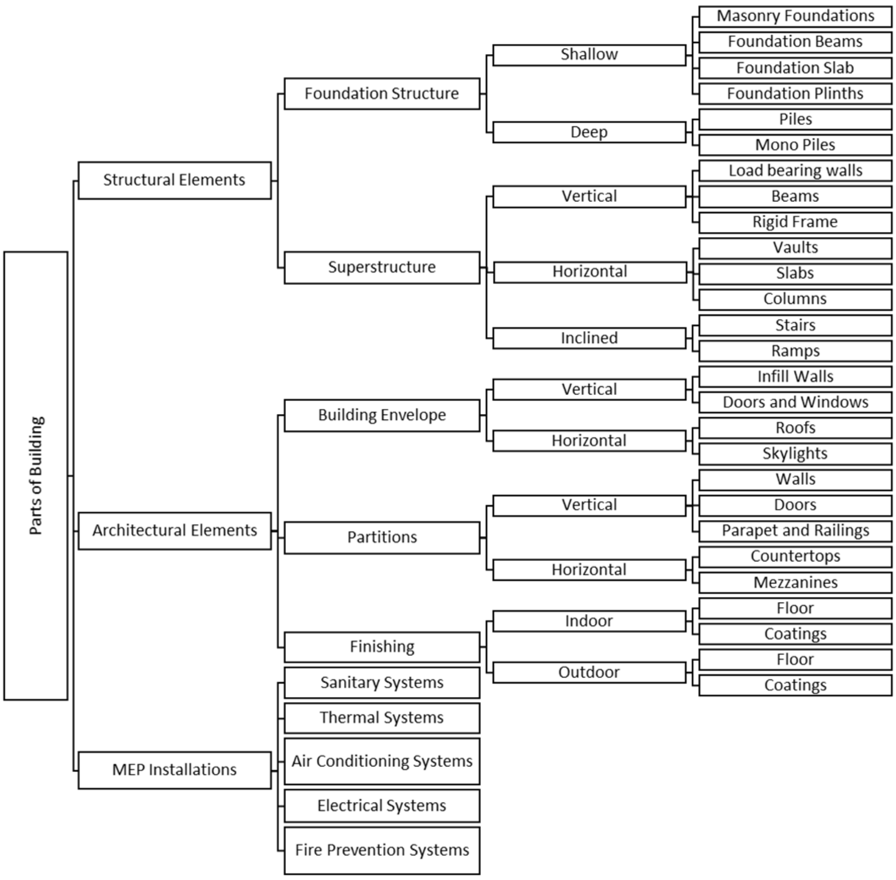


FIGURE 37 DECOMPOSITION BASED ON MATERIAL HIERARCHY

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.

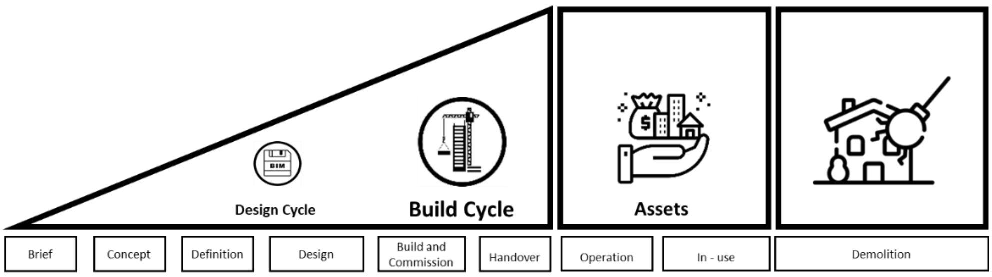


FIGURE 38 BUILDING LIFECYCLE IN A LINEAR ECOSYSTEM

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.

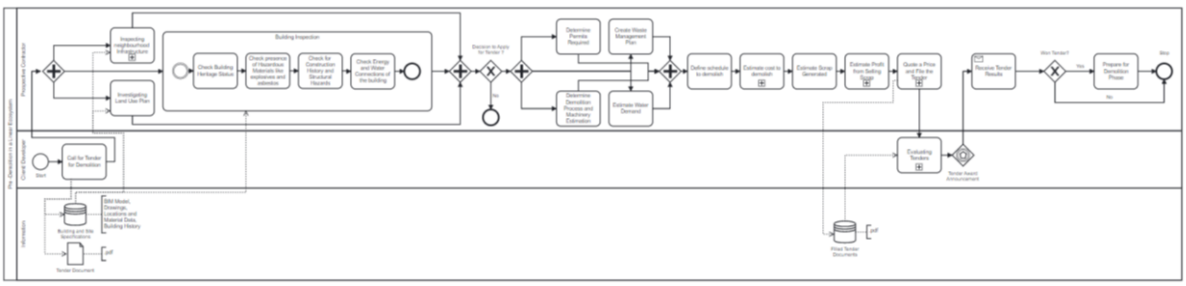


FIGURE 39 PRE-DEMOLITION PHASE IN LINEAR ECOSYSTEM

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.

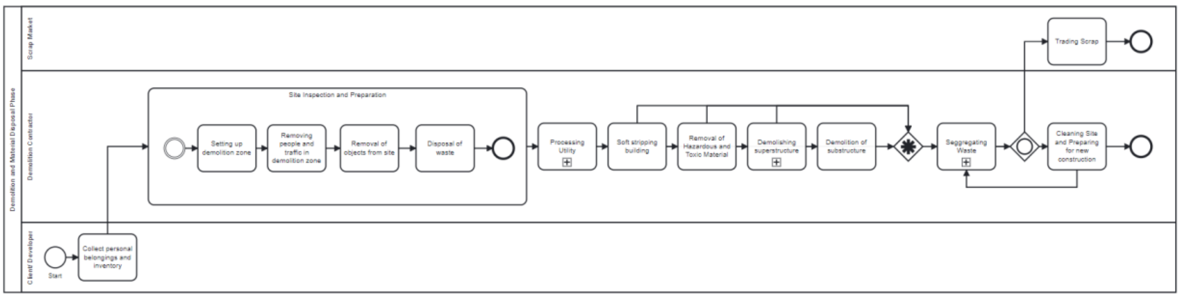


FIGURE 40 DEMOLITION AND MATERIAL DISPOSAL IN LINEAR ECOSYSTEM

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.

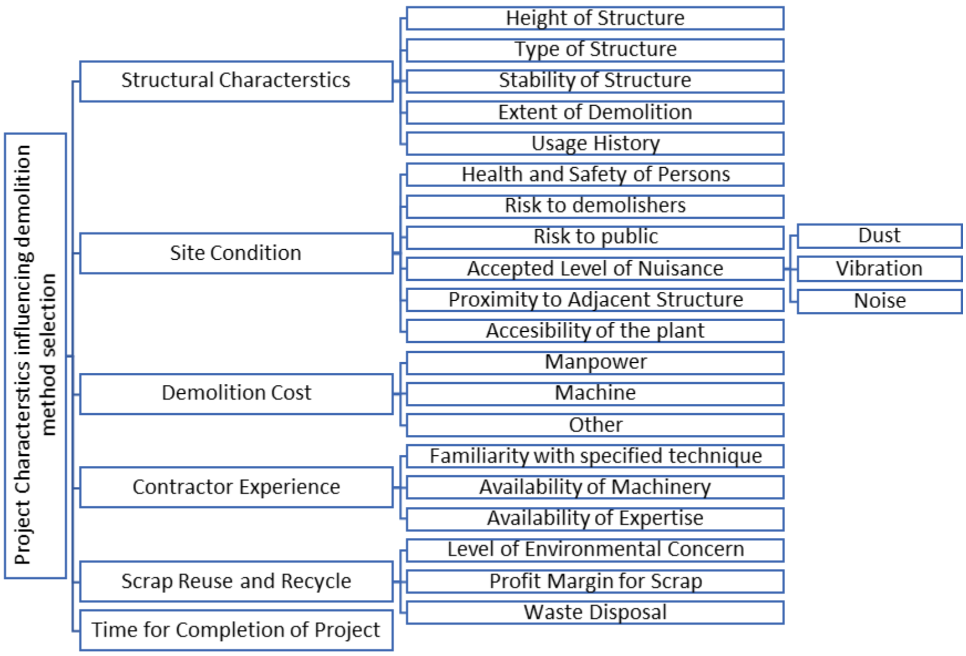


FIGURE 41 PROJECT CHARACTERISTICS THAT INFLUENCE DEMOLITION PROCEDURE SELECTION (ABDULLAH ET AL., 2002)

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.

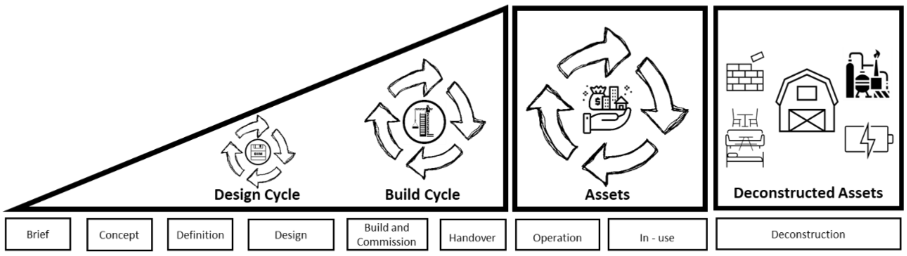


FIGURE 42 BUILDING LIFECYCLE IN A CIRCULAR ECOSYSTEM

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.

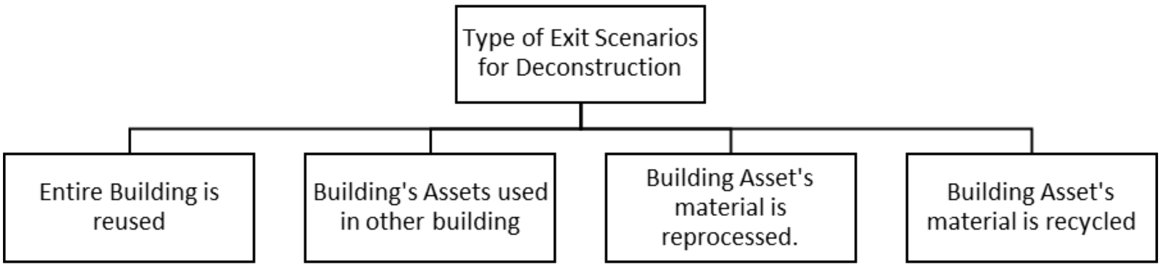


FIGURE 44 CATEGORIES OF EXIT SCENARIOS FOR DECONSTRUCTION (BERTINO ET AL., 2021)

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

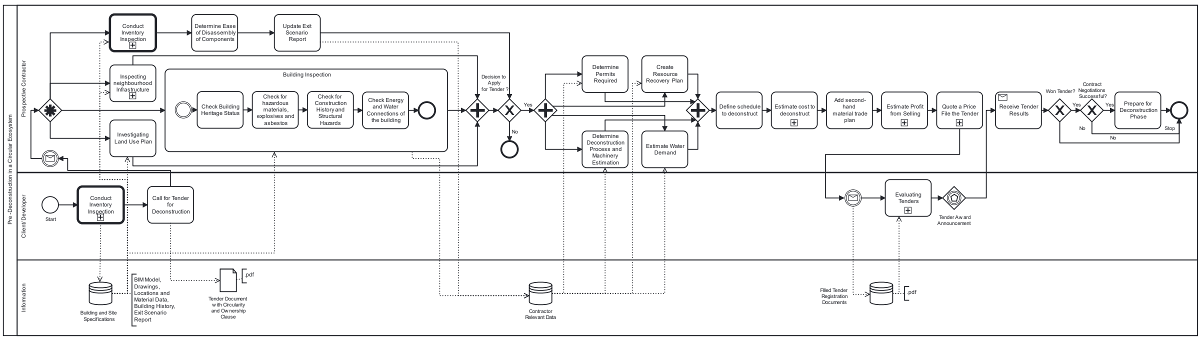


FIGURE 45 PRE-DECONSTRUCTION PHASE IN A CIRCULAR ECOSYSTEM

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.

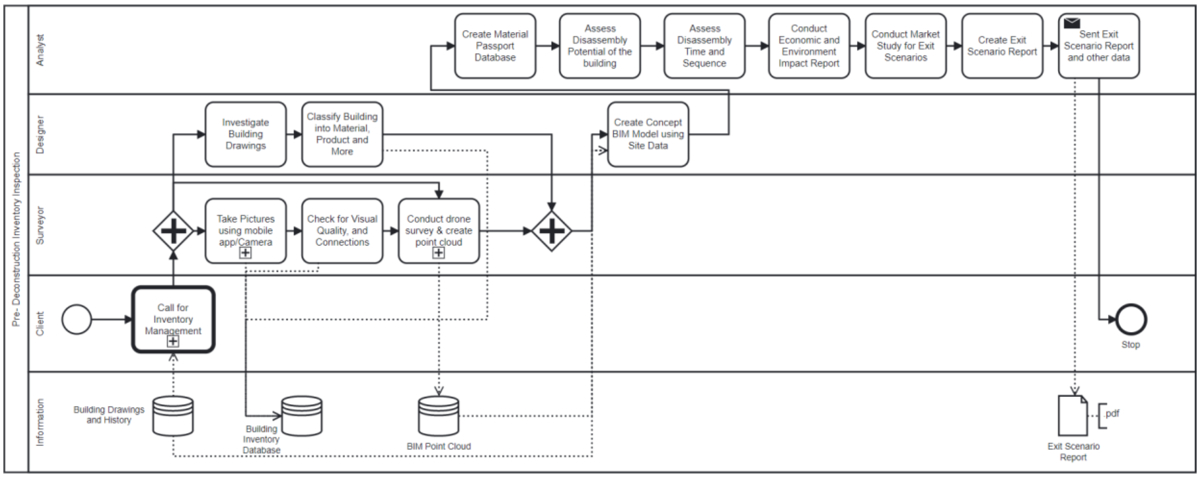


FIGURE 46 PRE-DECONSTRUCTION INVENTORY INSPECTION

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.

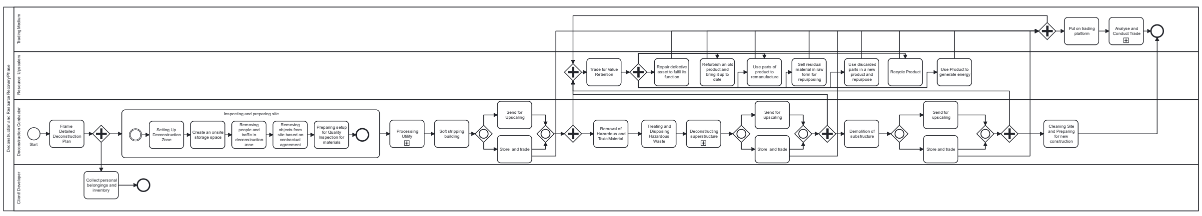


FIGURE 47 DECONSTRUCTION AND RESOURCE RECOVERY PHASE

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.

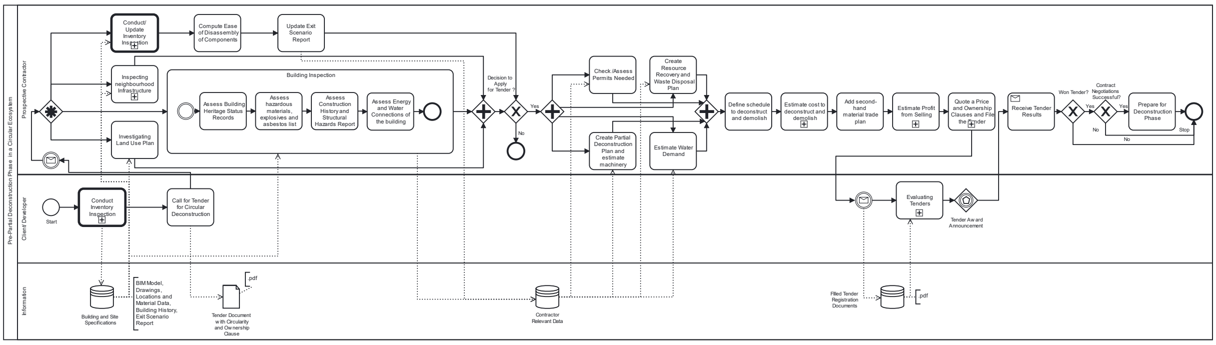


FIGURE 48 PRE-PARTIAL DECONSTRUCTION PHASE IN A CIRCULAR ECOSYSTEM

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.

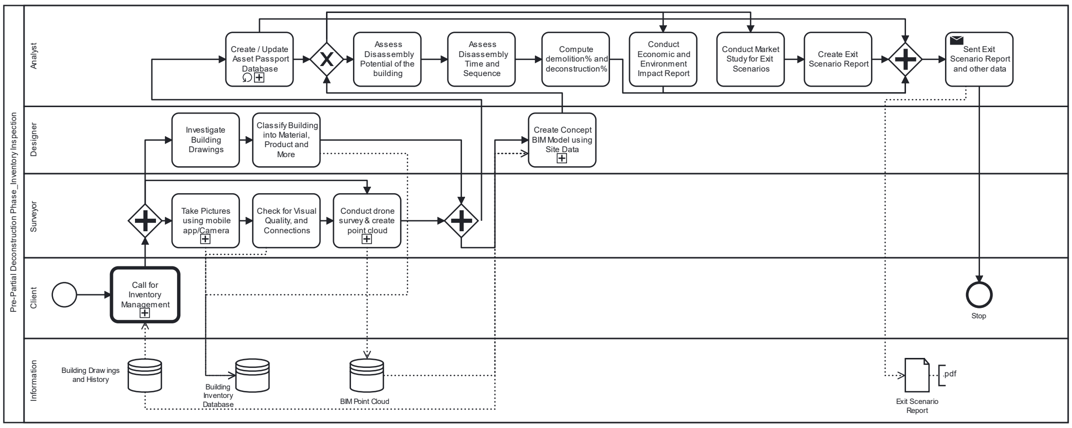


FIGURE 49 PRE-PARTIAL DECONSTRUCTION PHASE - INVENTORY INSPECTION

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.

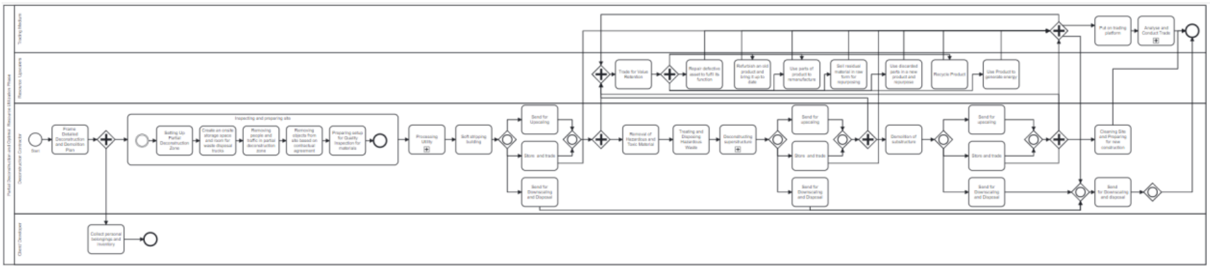


FIGURE 50 PARTIAL DECONSTRUCTION AND OPTIMAL RESOURCE UTILIZATION PHASE

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.

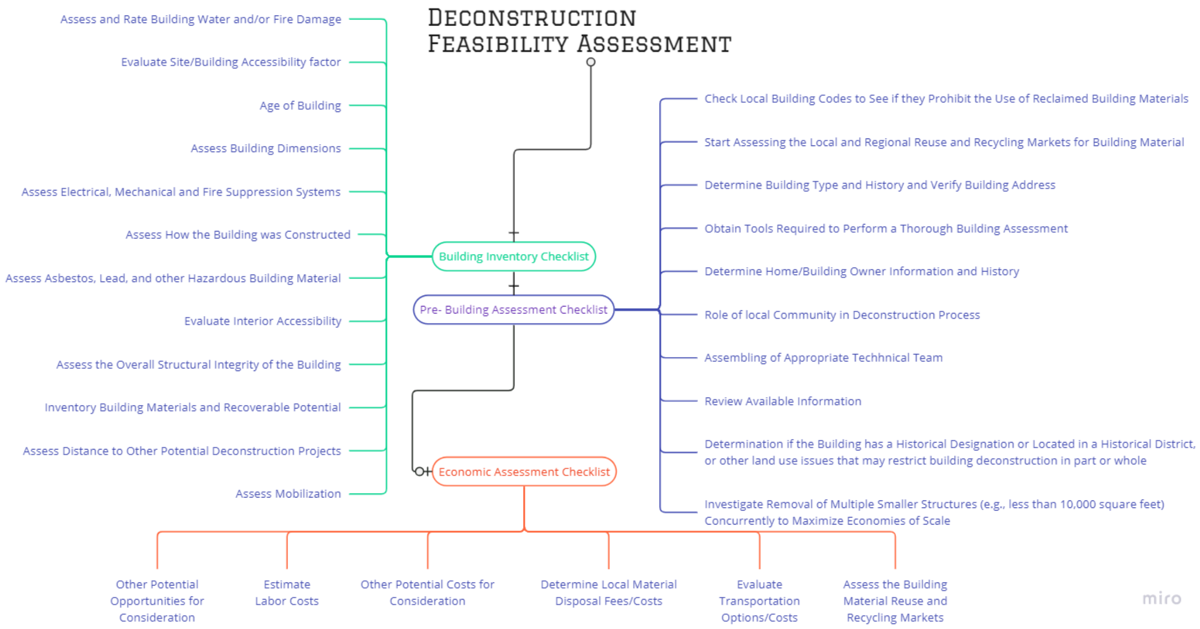


FIGURE 52 DECONSTRUCTION FEASIBILITY ASSESSMENT (ENVIRONMENTAL PROTECTION AGENCY, 2012)

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.

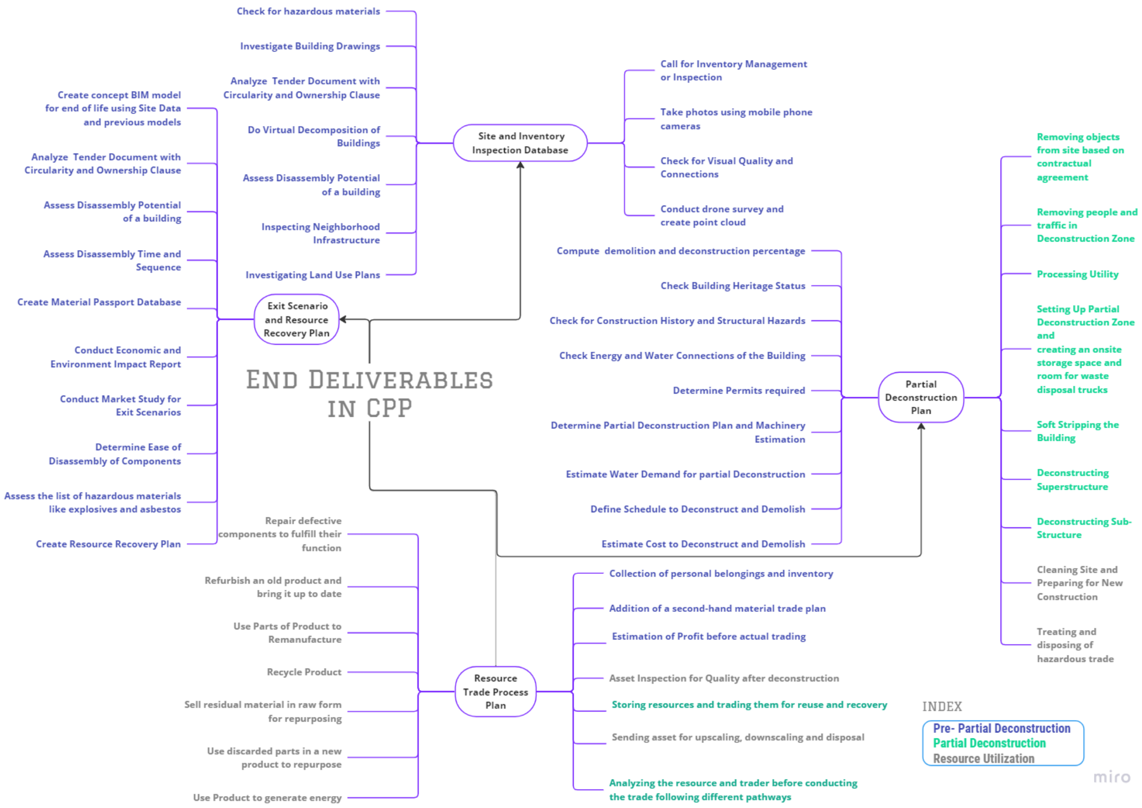


FIGURE 53 PROPOSED FRAMEWORK'S PROCESS DISTRIBUTION BASED ON PURPOSE

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.

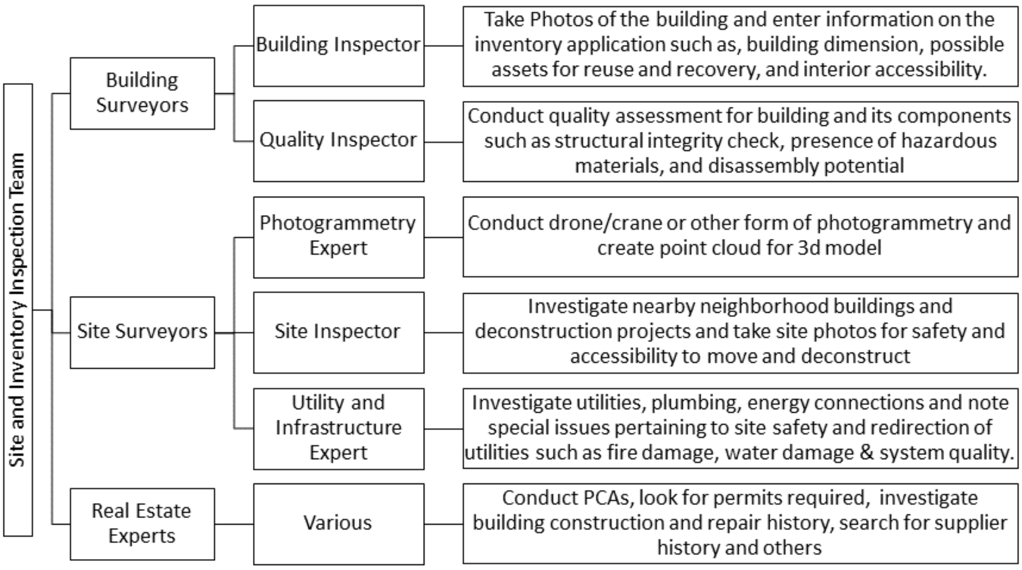


FIGURE 54 SITE AND INVENTORY INSPECTION TEAM COMPOSITION BASED ON FUNCTION

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.

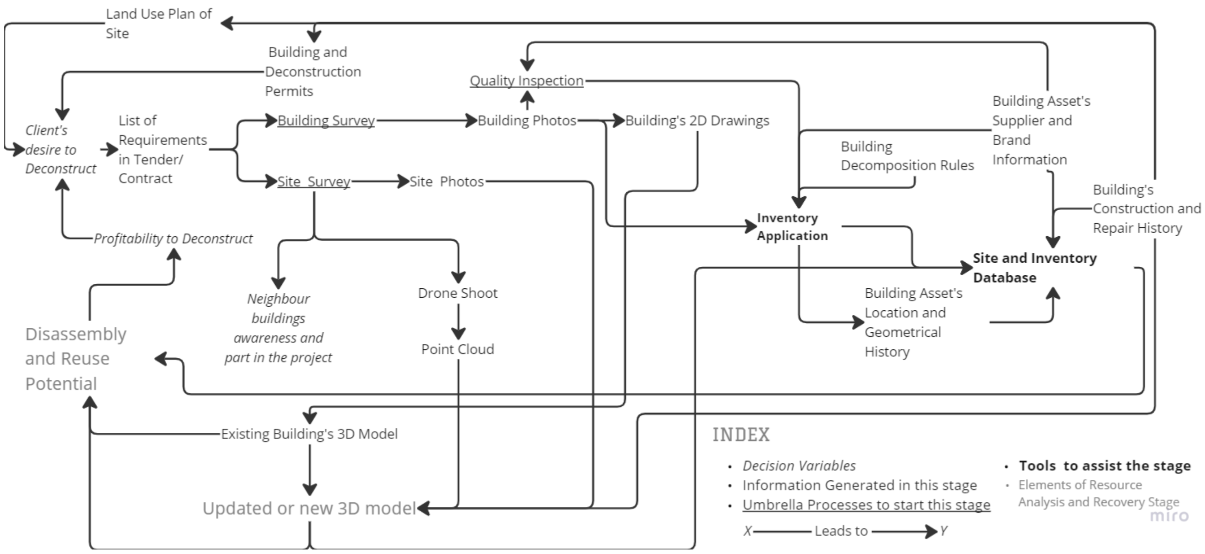


FIGURE 55 POSSIBLE RELATIONSHIPS BETWEEN ELEMENTS OF SITE AND INVENTORY INSPECTION

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.

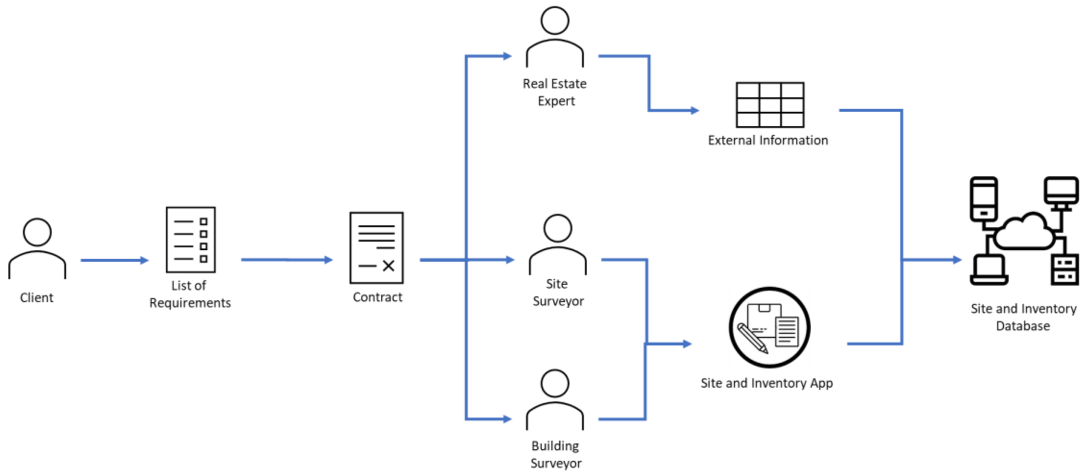


FIGURE 56 OUTLINE OF A PROCESS FOR SITE INVENTORY AND INSPECTION

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.

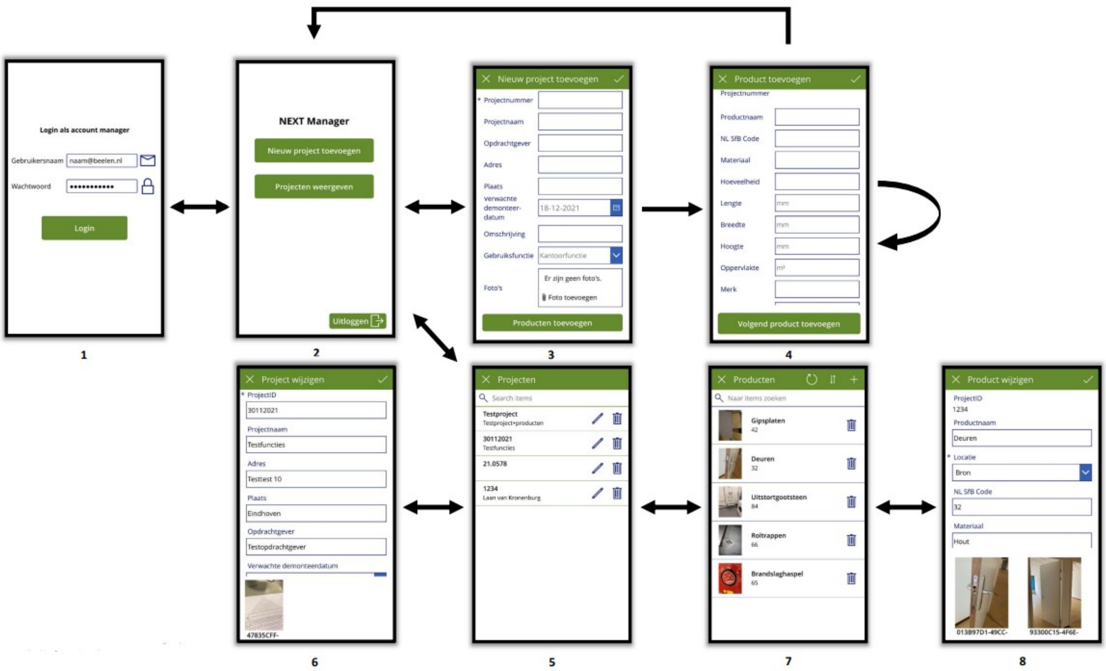


FIGURE 57 EXAMPLE OF AN SITE AND INVENTORY MOBILE APPLICATION (BRETELER, 2022)

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.

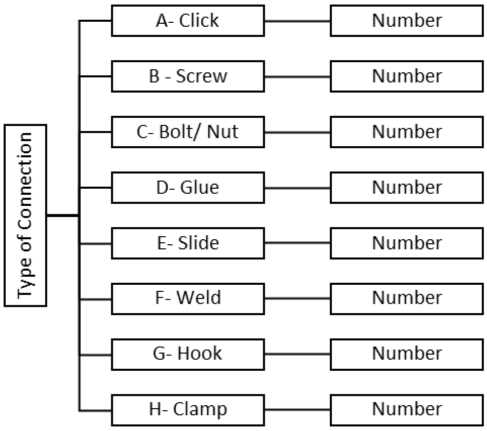


FIGURE 58 REQUIREMENT FOR DISASSEMBLY POTENTIAL ASSESSMENT DURING SITE INSPECTION BY (BRETELER, 2022)

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.

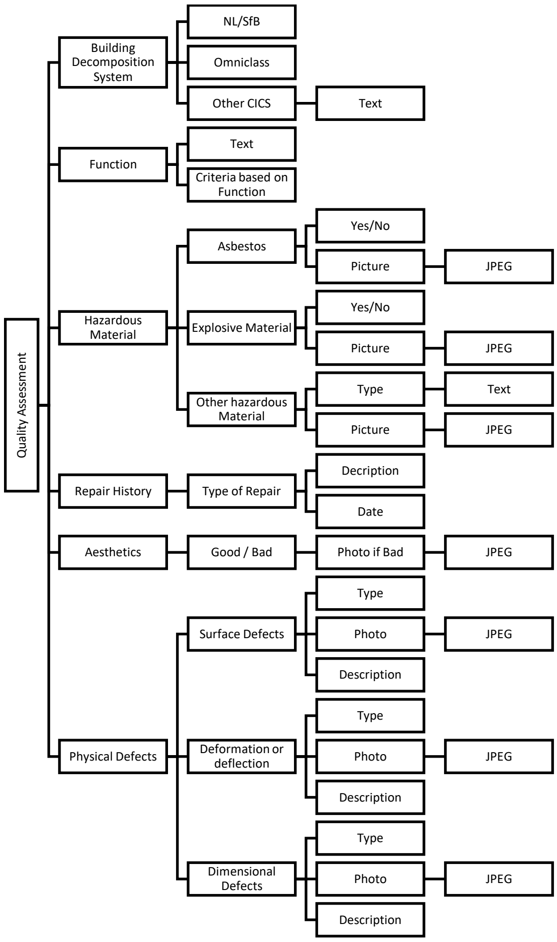


FIGURE 59 EXAMPLE OF A VISUAL QUALITY ASSESSMENT CRITERIA

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

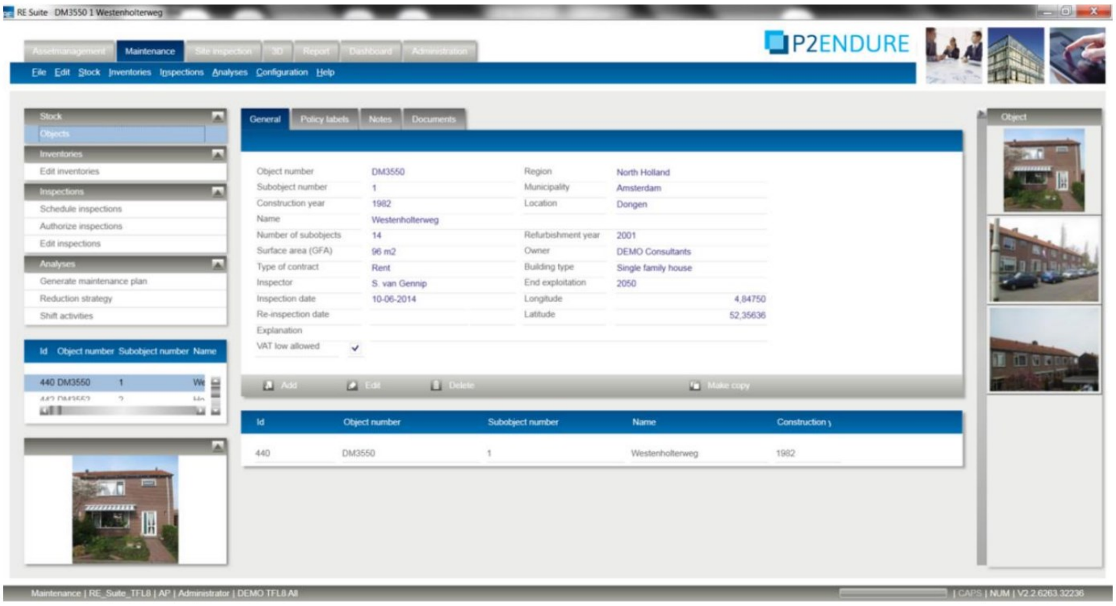


FIGURE 60 P2 ENDURE SITE INSPECTION TOOL SHOWCASING GENERAL PRODUCT INFORMATION UNDER MAINTENANCE (GRALKA & VAN DELFT,2017)

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.

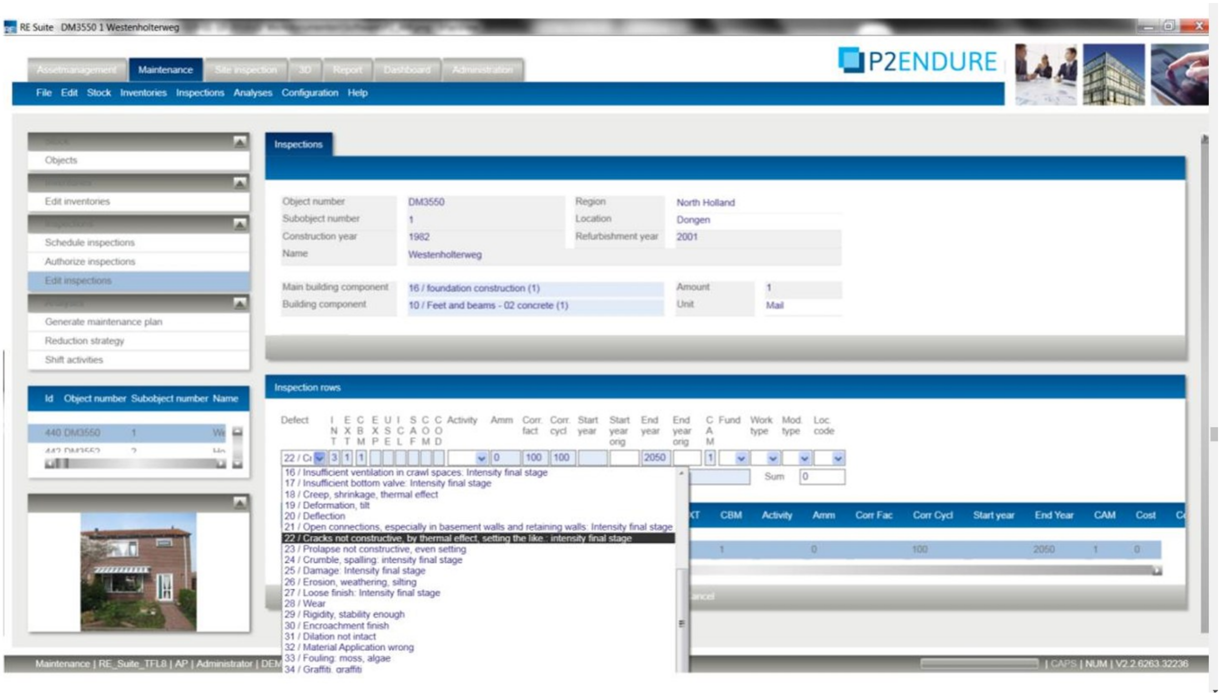


FIGURE 61 P2 ENDURE SITE INSPECTION TOOL SHOWCASING GENERAL PRODUCT INFORMATION UNDER MAINTENANCE (GRALKA & VAN DELFT,2017)

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.

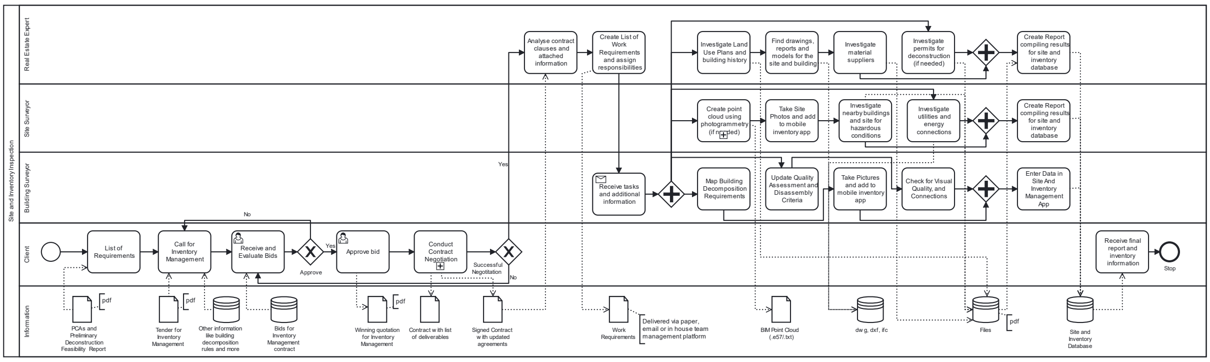


FIGURE 62 SITE AND INVENTORY INSPECTION INFORMATION EXCHANGE

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.

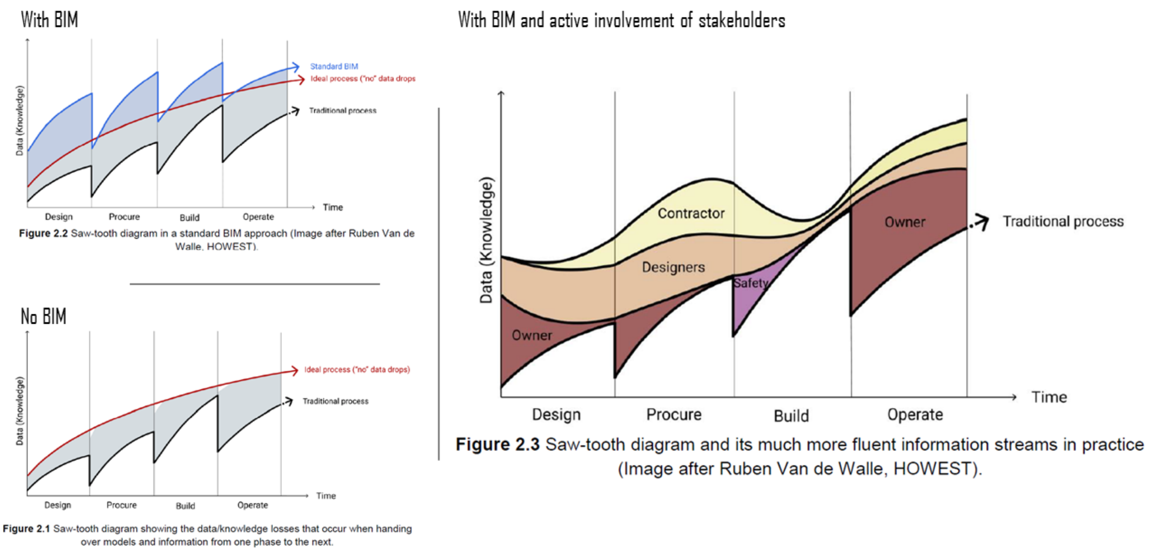


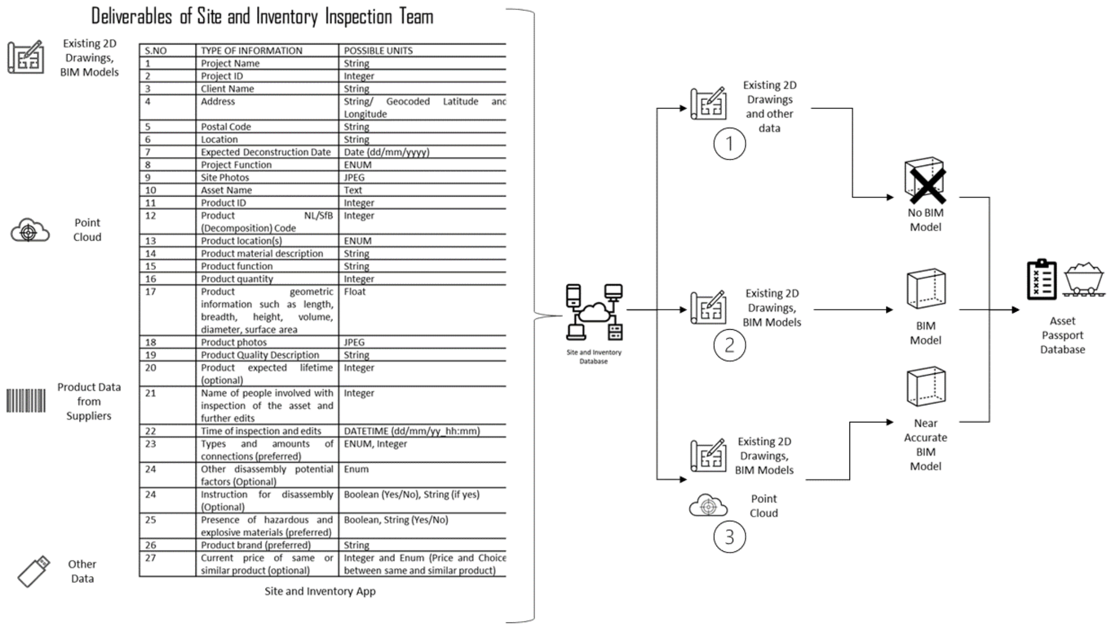
FIGURE 63 INFLUENCE OF BIM AND STAKEHOLDERS ON INFORMATION DROP DURING HANDOVER PHASE (PAUWELS & PETROVA, 2020)

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.



S.NO	TYPE OF INFORMATION	POSSIBLE UNITS
1	Project Name	String
2	Project ID	Integer
3	Client Name	String
4	Address	String/ Geocoded Latitude anc 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	Integer
13	Product location(s)	ENUM
14	Product material description	String
15	Product function	String
16	Product quantity	Integer
17	Product geometric information such as length, breadth, height, volume, diameter, surface area	Float
18	Product photos	JPEG
19	Product Quality Description	String
20	Product expected lifetime (optional)	Integer
21	Name of people involved with inspection of the asset and further edits	Integer
22	Time of inspection and edits	DATETIME (dd/mm/yy_hh:mm)
23	Types and amounts of connections (preferred)	ENUM, Integer
24	Other disassembly potential factors (Optional)	Enum
24	Instruction for disassembly (Optional)	Boolean (Yes/No), String (if yes)
25	Presence of hazardous and explosive materials (preferred)	Boolean, String (Yes/No)
26	Product brand (preferred)	String
27	Current price of same or similar product (optional)	Integer and Enum (Price and Choice between same and similar product)

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.

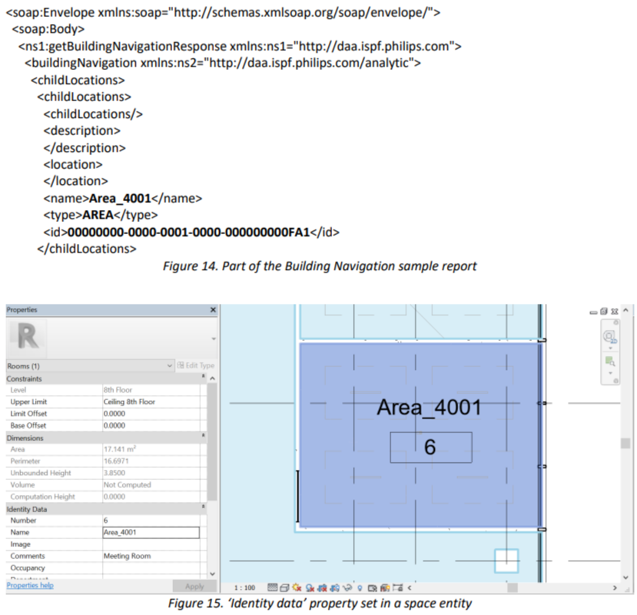


FIGURE 65 DEFINING PROPERTY SET IN THE MODELLING SOFTWARE (DE BARROS LIMA, 2020)

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.

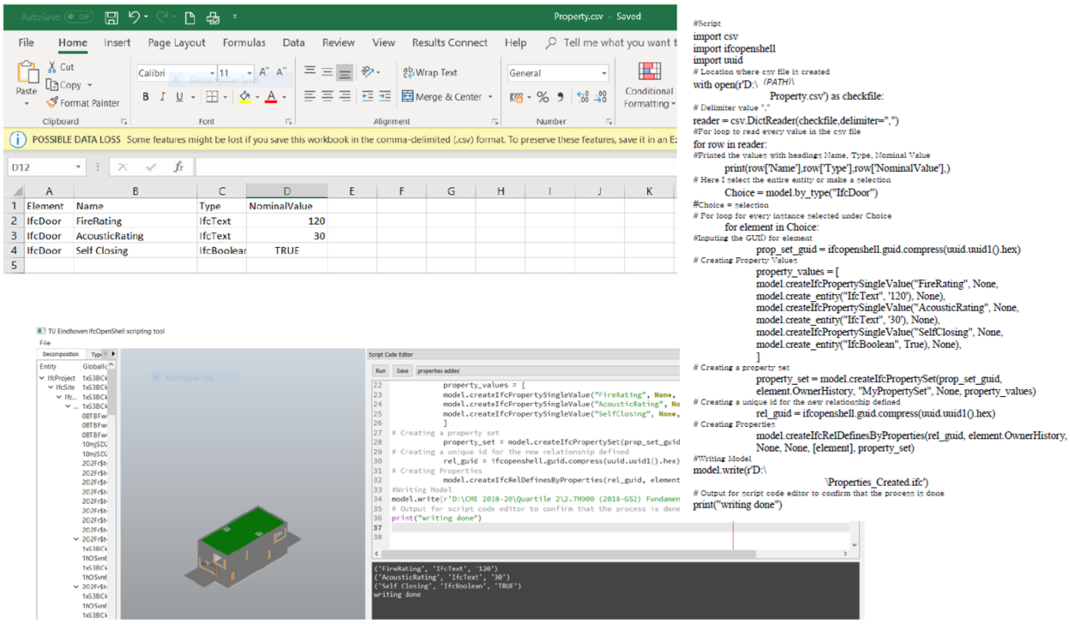


FIGURE 66 ASSET PASSPORT PROPERTY ADDED USING IFC OPEN SHELL

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.

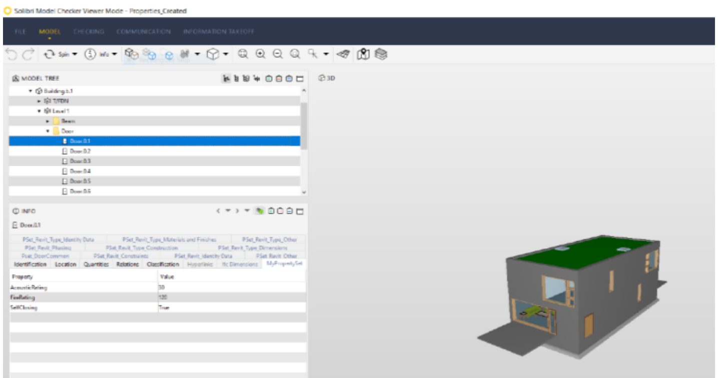


FIGURE 67 NEW PROPERTIES FOR ASSET PASSPORT VIEWED IN SOLIBRI

[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.

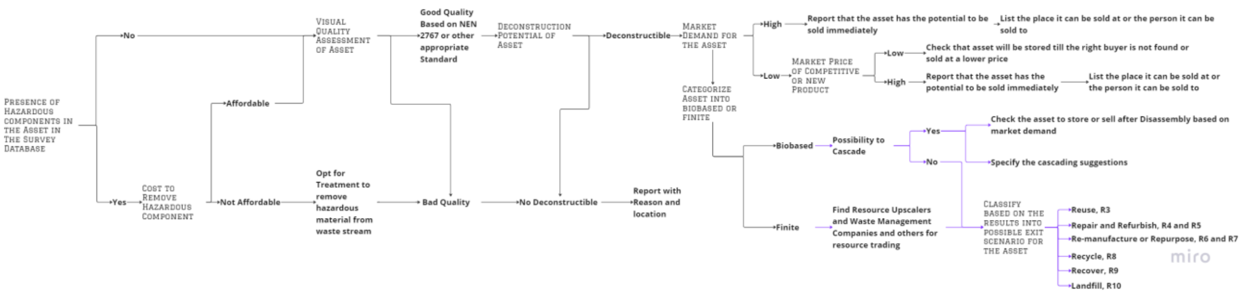


FIGURE 68 SEQUENCE FOR RESOURCE RECOVERY ANALYSIS

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.

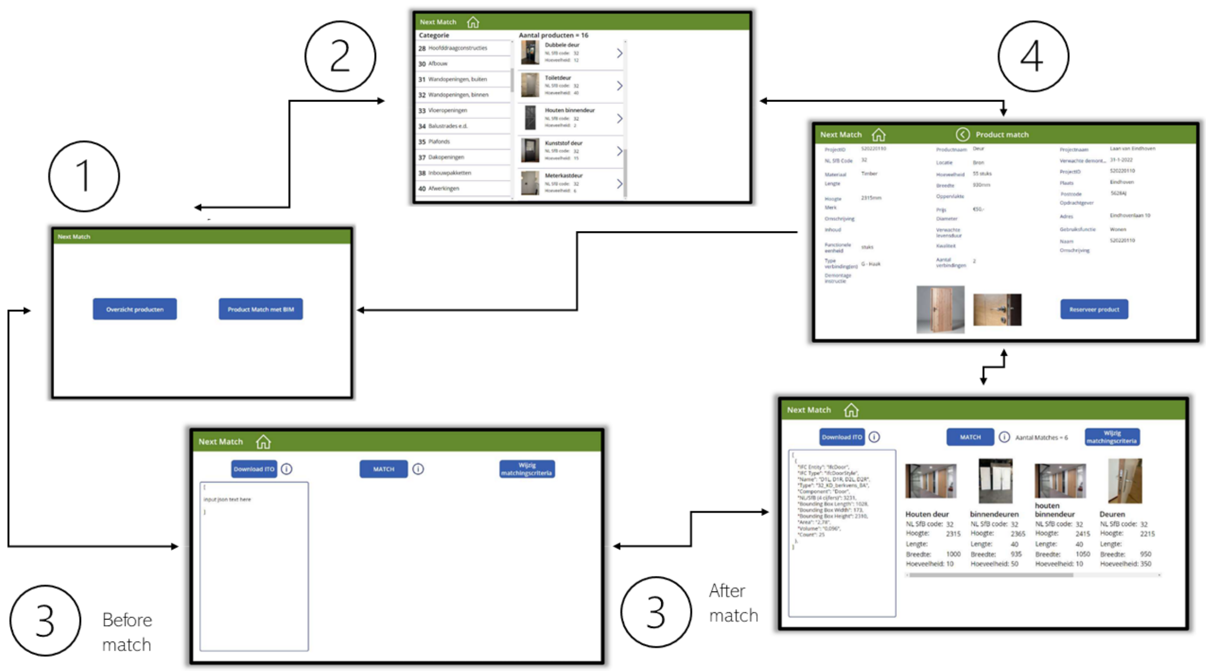


FIGURE 69 EXAMPLE OF MARKET SEARCH FOR SIMILAR PRODUCTS BRETELER (2022)

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.

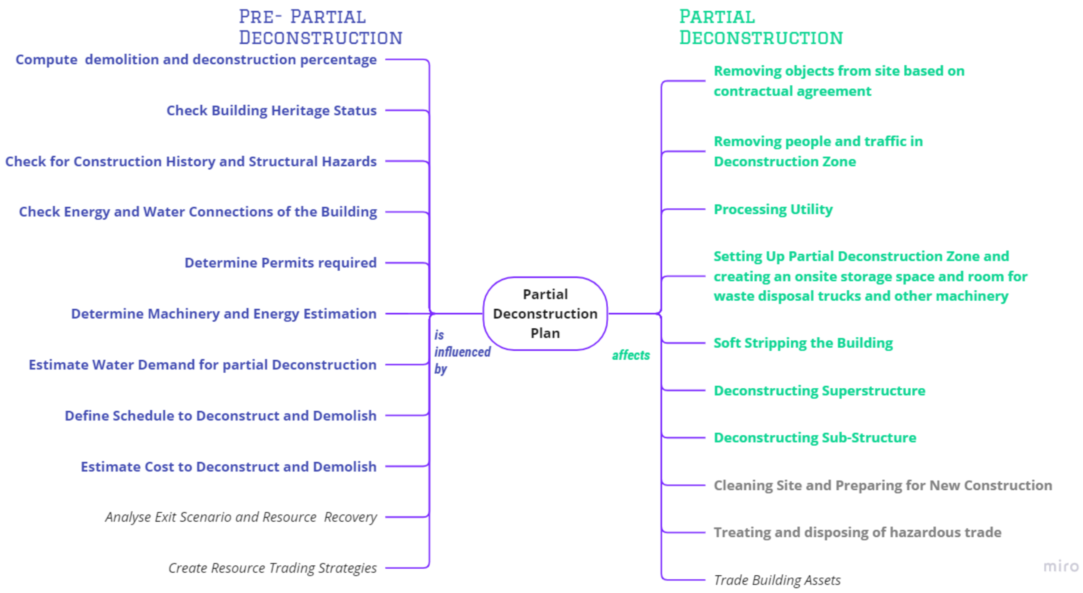


FIGURE 70 PROCESSES ON FOCUS IN PARTIAL DECONSTRUCTION PLAN

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.

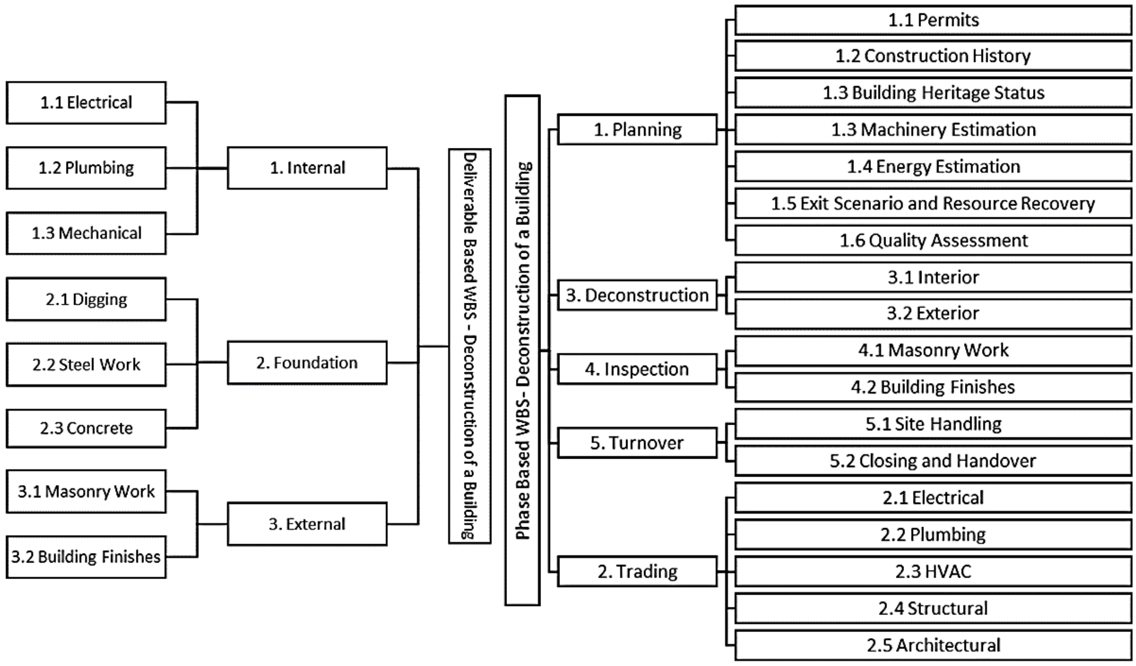


FIGURE 71 TYPES OF WBS FOR DECONSTRUCTION OF BUILDING

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].

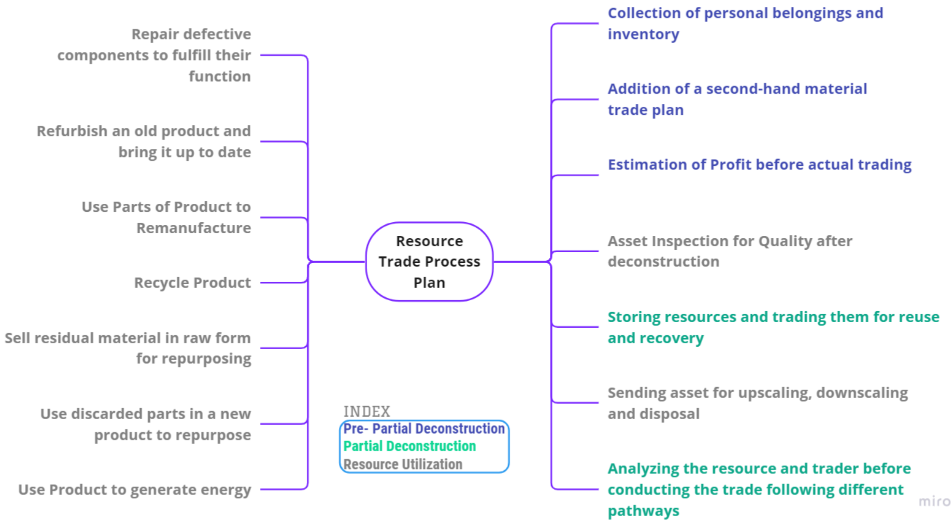


FIGURE 72 PROCESSES THAT CAN INFLUENCE RESOURCE TRADING

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.

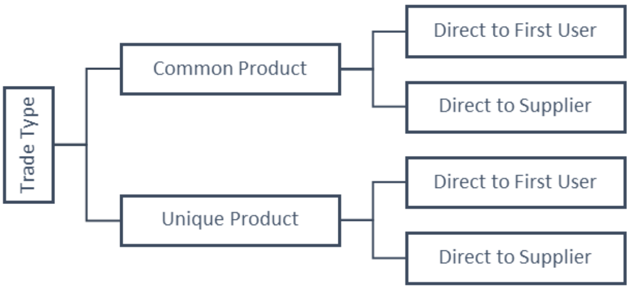


FIGURE 73 TRADE TYPES IN SECOND-HAND MARKET

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.

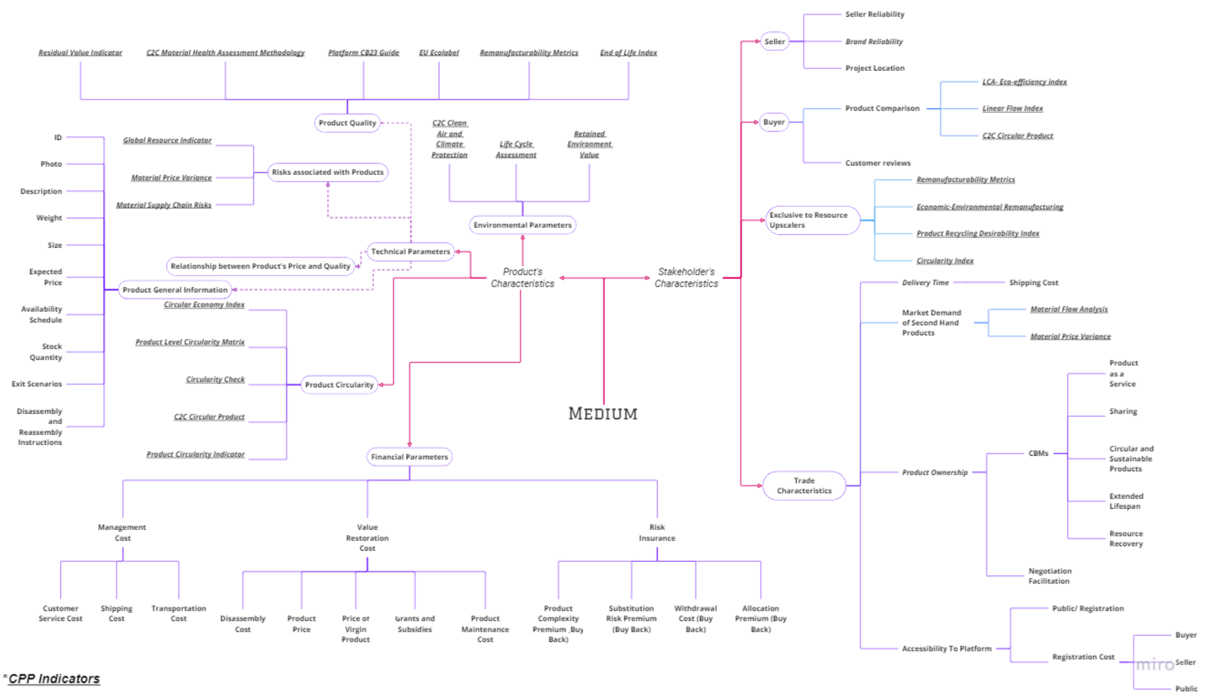


FIGURE 74 CPP ELEMENTS THAT CAN INFLUENCE THE ONLINE MARKET PLACE

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.

Based on the above elements, a price of a secondhand product is set, and the taxes, subsidies and discounts are added to it which makes the minimum retail price of that product to be sold.

There are some misconceptions while setting the price of a second-hand product such as product's original price can determine the new price. According to Kwak et al (2012), the original price cannot be expected to have a significant correlation to the resale value or to provide a reliable measure of the resale price. Another misconception is the older the product, the lesser its resale value. However, the age of a product alone does not determine the price on resale. A product that facilitates upgrading can be priced higher than a similar product without the option to upgrade. Hence, products designed for upscaling, durability and disassembly can be priced higher. Frota Neto et al. (2016) state that another interesting pricing strategy that can be used is to price remanufactured and repurposed products higher than products marked used because buyers are thought to be more willing to trade with them than with used products, if a product is labelled remanufactured or repurposed. However, the price should still be lower than the new product. Furthermore, the price difference among remanufactured products with similar functions should be less. However, the case of products marked used can have varied prices based on other significant factors as presented by seller.

10. **Subsidies and Incentives based on Certifications, Product and Brand Assessment** – Using subsidies[46] and certifications that are available in the region for a particular product, can result in buyers calculating direct benefits for investing in that product. Hence, sellers can provide information on the subsidies that one can get while using their listed products. The information required for the subsidy or certifications alongside that subsidy or certificate can either be provided by the seller or a list of common available subsidies that can be listed on the platform and based on a checklist, it can be verified if a product can be eligible for that subsidy or a certificate during product registration by seller. Common subsidies for circular businesses in the Netherlands are MilieuInvesteringsaftrek (MIA) or the Environmental Investment Deduction, Energy Investment Allowance (EIA) and Willekeurige afschrijving milieu-investeringen (VAMIL). Quality Certifications such as LEEDS, BREEAM, Ecolabels, Cradle2Cradle can be used to verify product quality by listing certain checklists. Based on the checklists against such subsidies and certification, and subsidy/ certification eligibility mark can be assigned to the product. Furthermore, incentives for a product can be provided based on its most salient features such as quality, lifespan, environmental impact, circularity score and least LFI. These can be calculated using the product passport made using information provided by the seller during product registration.

An example of such a situation is Madaster Platform. The processes such as used by (Heisel & Rau-Oberhuber, 2020) and Madaster to calculate circularity of an asset can be used by the online platform while product registration to calculate the circularity score to sort the products based on circularity score and providing some discounts based on that criterion to the seller to motivate to sell using the platform.

According to Gupta (2019), the objective of MADASTER's material passport is to salvage as much material as possible during the demolition phase. This can be used by the online platform to provide monetary compensations to buyers and sellers based on the circularity score in this case. The process to accomplish that starts with collecting information. To begin establishing a material passport using MADASTER's platform, the BIM is needed since it is crucial to the Madaster platform, and IFC format is required for building data entry. All products must have their material composition used to categorize the types of materials and the proportion of their amount compared to the total weight for each category. To categorize diverse materials such as door, window, skylight, etc., a four-digit NL/Sfb code is required. Material quantities are needed in volume (m^3).

[46] Social Enterprise Finance Tool – It gives a list of different finance mechanisms for entrepreneurs and innovators ranging from loans to subsidies and grants.

The MADASTER platform contains four essential details regarding the material as shown in Figure 75. First, the materials are classified according to the building layer to which they belong as stated above based on the type as shown in Figure 76. Then the volume of material in different phases of building process can be tracked as shown in Figure 77.

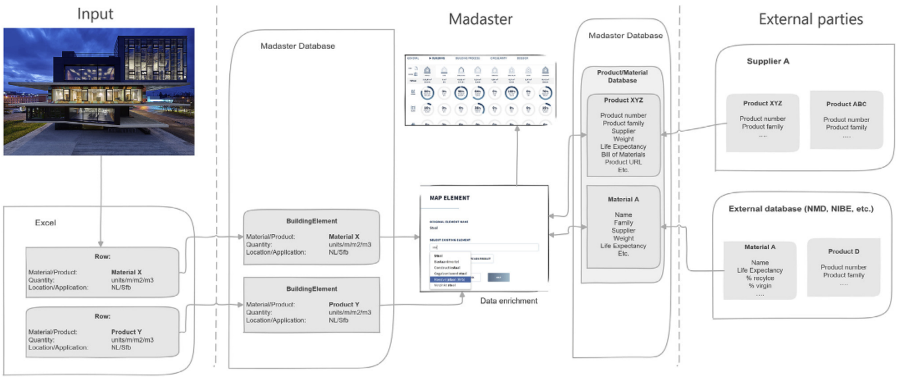


FIGURE 75 MADASTER PLATFORM INFORMATION MANAGEMENT OVERVIEW (HEISEL & RAU-OBERHUBER, 2020)

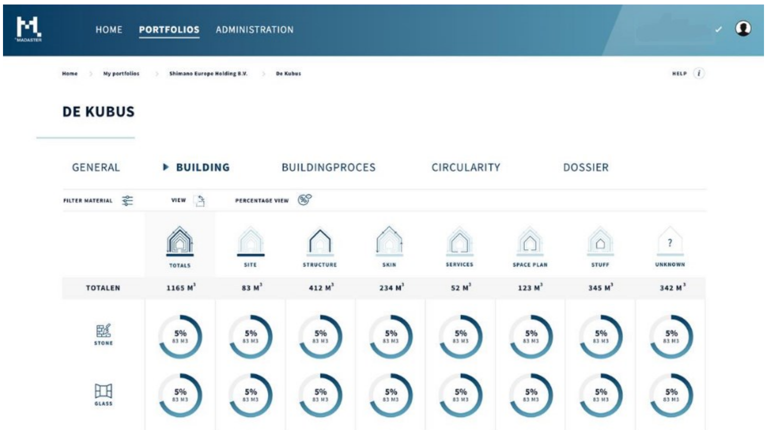


FIGURE 76 BUILDING MATERIAL CATEGORIZED BASED ON BUILDING LAYER(GUPTA, 2019)

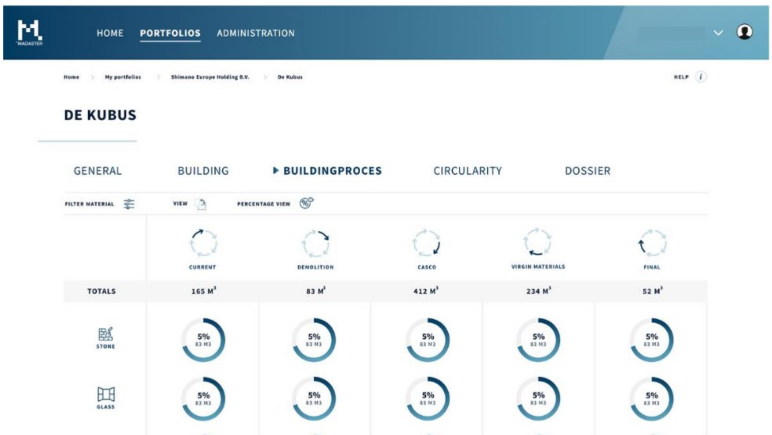


FIGURE 77 TRACKING OF MATERIAL VOLUMES IN DIFFERENT PHASES OF PROJECT IN MADASTER (GUPTA, 2019)

It further gives the circularity value of the different layers alongside the amount of virgin materials in each layer and the whole building. According to Heisel & Rau-Oberhuber (2020), circularity score for construction phase represents the ratio of virgin material to recycled, reused or rapidly renewable material and is equal to sum of recycled, rapidly renewable, and reused material divided by the total mass and multiplied by 100. The recycling efficiency of the recycling centre is also considered. The circularity score of the use phase is calculated by dividing expected lifespan of utilized product to the average lifespan of the status quo product in the same application. The circularity score of the demolition phase is the ratio between waste materials and the reusable or recyclable materials generated when a building is demolished or refurbished. It is obtained by multiplying circularity score during construction and the recycling efficiency and adding the circularity score of use phase to it. It also gives the net present value of the various materials and allows for exporting material information in IFC format.

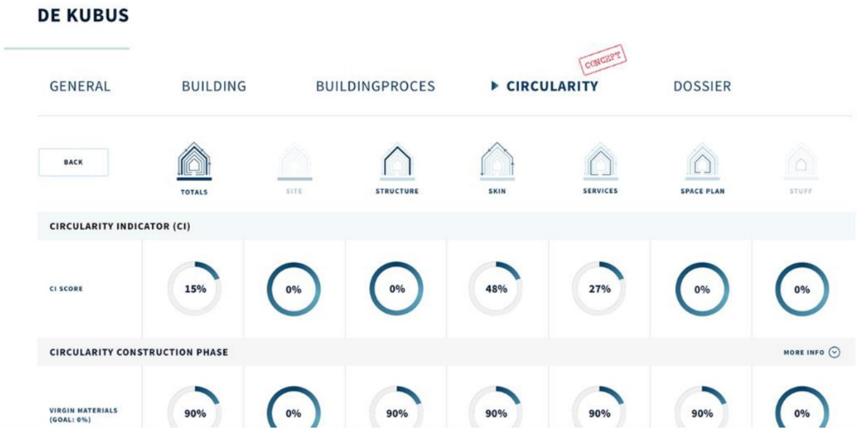


FIGURE 78 CIRCULARITY SCORE PER LAYER, MADASTER(GUPTA, 2019)

Another way to provide incentives is based on the brand reliability. As stated in sub section 5.6.2 that products that are durable, circular, and adaptable can be sold faster than others. Hence, companies which produce circular products can be promoted more to infuse circular practices in the market share of the resource trading platform. For Instance, Polyplank, a manufacturing company, that developed a process to convert plastic waste and wood fibers into a moisture-resistant, recyclable composite material (PolyPlank substance) that is used to produce building planks. According to Nußholz et al (2019), PolyPlank employs circular strategies such as product lifetime and recyclability to reduce environmental impact and life cycle costs. Public housing associations are the primary clients. Creating and delivering value requires a closed-loop, proprietary process, sales channels, and sufficient quantities and qualities of secondary materials. Utilizing secondary materials, manufacturing processes, and labor, value is captured. Product sales produce money. Now providing incentives to the company and its products not only creates incentive for the company but also captures new buyers such as public housing associations towards the platform.

11. **Sales Negotiation** – Usually when an online trading is done, the seller's contact information is removed to avoid backend deals. This lends exclusivity to the online trade platform. Hence, a chance to negotiate which is the most important aspect when a buyer and a seller can meet should be provided by the online platform. This is usually possible using a in-app video conference when trading online. Hence for buyers to reach at the stage where they can negotiate some relevant product information must be provided. Furthermore, the provision of online calls and chance of meeting face to face can facilitate the sales negotiations if the parties opt for it along with product sampling. In case that is not necessary, the buyers should be given enough information to make a trade for negotiating with the sales representative on the online platform to understand the quality of the product that they are interested in buying. This service if done free of charge provides a way to keep the parties on board and the value gained by the online platform is in form of customer retention. Another added value to keep negotiations through online platform and charging the trade parties for it can be based on moderating the legal formalities between the buyer and seller. It must be provided based on the type of circular business model that they opt for such as resource sharing, buy back agreement or a normal trade agreement with transfer of ownership rights. An easy way through that is provision of templates

for relevant trade agreement along with the presence of legal trade moderator who can navigate the questions and facilitate the trade.

12. **Push for Circularity through ads and conversations** – A study by behavioural Insights team [47] in 2021 showcased that when encouraged through use of cost benefit, environmental contribution, ill effects of waste or user specific humour with a sustainability quote and usage of terms such as second-hand, pre-owned and others impact the tendency of buyer to choose the second- hand products. It is also essential to go circular to resolve barriers of use such as costs and quality concerns. According to Frota Neto et al (2016), relevant and effective quality cues affect customer behaviour more for products marked used than remanufactured or new products. So, with the addition of reliability for a product alongside positive message to consume circular is a necessity for online marketplace. In the analysis of all the marketplaces that are existing as shown in Table 25, no such ads were included. Hence, it seems necessary to create such an impact using the price elements as listed in Table 27 and circular indicators in section 3.5 and Figure 72.

13. **Reviews and Feedback** – These are provided after a trade agreement is reached and a handover has happened. The more reliable and higher rated a trader is on a platform, the more likely their products appear online. These can be a score out of 5 or 10 or a star system and a comment box letting the buyers and the sellers to not only review each other but the product and the platform in question. The reviews and feedback are necessary because on trading platforms unsubstantiated quality cues by sellers that cost them no extra money in advertising or with lack of legally binding warranties can harm buyers. Frota Neto et al (2016) state that buyers can report sellers who abuse these cues, which raises negative feedback and decreases future cash flows. This reduces the likelihood of sellers lying about their products.

14. **Special Trade Settings –** An online marketplace much like the traditional marketplace can held auctions for special items that are high in demand. After listing an auction catalogue, bids can be made during or before the auction for items that have been valued before by a professional. The sellers can apply for choice to auction the item and the dates can be given for possible auctions. The only difference is the online platform where the bidding happens. It can also be a place to put the products from the void buy back agreement to compensate for the loses of the parties involved.

Hence, key aspects such as seller registration, buyer registration, their types, along with product specific aspects such as product registration, product passport, classification of product catalogue, along with features such as similar product suggestion, product filtering and sorting can help in creating a buyer friendly interface. Furthermore, pricing strategies favoring seller and subsidies and cortication's used to incentivize product price for buyers can strike a perfect balance for resource trade. On top of that well-suited negotiation platform coupled with a mediator, a quality check and templates for necessary trade documents, along with proper advertisements pushing circular purchase can make buyers well informed to go circular. In conclusion, these elements can facilitate the online marketplace to not only promote circular practices but also establish them in a way that they can become industry standard as these can be monitored well. Based on the twelve key aspects stated above the information in a standard product passport generated for an online marketplace can be seen in Table 28. Some information can be visible to the buyer and other attached with the product is used by the online medium to run analysis. This passport also is adapted based on the analysis that the medium representative chooses to offer a seller to inspect analysis.

[47] Source - A blog by Behavior Insights Team dated 20 Dec 2021

TABLE 28 INFORMATION CONTAINED IN A PRODUCT PASSPORT GENERATED FOR AN ONLINE MARKET PLACE

S.NO	PURPOSE	PRODUCT PASSPORT ENTITIES	TYPE	PROVIDED/ GENERATED BY	INDICATORS FOR ANALYSIS
1.	Mapping and referencing	Product ID	NL/Sfb Code	Platform	-
2.	Visual Reference	Product Photo(s)	JPEG	Seller	-
3	Website Use	Principal Photo for Display	JPEG	Seller	-
4.	For Pricing	Amount	Number of Pieces/ Kg	Seller	-
5.	For Reference	Title	Text	Seller	-
6.	USP of Product	Product Description	Text	Seller/ Online Platform	-
7.	For buyers to make sale	Final Date for Product Availability	Date Time	Seller	-
8.	For reference	Date of Upload	Date Time	Online Platform	-
9	For reference and further analysis	Product Measurements (Length, Breadth, Width, …)	Number	Seller	-
10.	For reference and further analysis	Product's Material Composition	Text	Seller	-
11	For Authentication Purposes	Verified Seller	Yes/No	Platform	-
12.	For Buyers to Judge Seller Conduct and Product Quality	Reviews for Products from Seller	Text and Date Time	Other buyers	-
13.	For Seller Reliability	Trust Score	Number from 1 to 10	Platform	-
14.	For Seller Verification	Supplier Information	List with basic seller contact information	Seller	-
15.	For promoting circular product use	Product Brand	Text	Seller	-
16.	For product filter and assessment	Environmental Impact	Scores	Online Platform	LCA, MKI, C2C Clean Air and Climate Protection, Retained Environment Value
17.	For product filter and assessment	Circularity Score	Scores	Online Platform	LCA – Eco Efficiency Index, C2C Circular Product, Product Circularity Indicator, System Circularity Indicator
19.	For product filter and assessment	Amount of virgin materials	Scores	Online Platform	Linear Flow Index
20.	For product filter and assessment	Visual Quality Assessment	NEN 2767 grade with proof	Online Platform/ Seller	-
21.	For product filter and assessment	Residual Value	Scores	Online Platform/ Seller	Residual Value Indicator, C2C

					Material Health Assessment Methodology
22.	For product filter and assessment	Functional Lifespan	Years	Seller, verified by online platform for a price	Longevity Indicator
23.	For product filter and assessment	Exit Scenario(s) for next use	R3 to R9 from R framework	Seller, verified by online platform for a price	End of Life Index, Circular Pathfinder
24.	For Buyer's Ease of Assessment	Certifications	Documents	Seller and by provided by online platform for a price with the help of an external party	EU Ecolabel, Platform CB23 Guide
25.	For Buyer's Ease of Assessment	Subsidy Eligibility	Yes/No	Seller or by provided by online platform for a price with the help of an external party	-
26.	For Seller's Performance and prospective buyer's ease of assessment	Product Reviews	Text and TimeStamp	Old Buyers	-
27.	For guiding seller to put the right price on a product	Product Price Range	Range of Numbers with the highest and lowest value	Suggested by online platform based on certain analysis	Material Price Variance
27.	For buyers to know the asking rate	Product Price	Numbers in a currency denomination	Seller	-
28.	For ease of negotiation and trade agreements	Type of Preferred Trade	Sale, Auction, Traditional	Seller	-
29.	For Buyer's Ease of Assessment	Instruction for Use	Text	Seller, Verified by Online Platform for a price	-
30.	For Buyer's Ease of Assessment	Shipping Cost	Numbers in a currency denomination	Online Platform	-
31	For Buyer's Ease of Assessment	Availability for Risk Insurance	Yes/ No	Online Platform if permitted by seller and opted by buyer at checkout	Material Supply Chain Risk, Material Price Variance, Global Resource Indicator
32	For Buyer's Ease of Assessment	Product Source	Location from where product is obtained	Seller during product registration	-
33	For Seller's assessment for market price	Market Price of New Product with similar function	Numbers in a currency denomination	Online Platform through legal web scraping	Material Price Variance

34	For Product Filter and Assessment	Shadow Cost of New Product with similar function	Numbers in a currency denomination	Online Platform, if opted for by seller at product registration	MKI
35	For fair trade practices	Possibility to Negotiate	Yes/No and Way of Contact (if yes)	Seller during product registration	-

6. Chapter 6: Conclusion

6.1 Discussion and Results

6.1.1 Need for a circular trading ecosystem[48]

Mankind has lavished itself with the riches that the earth has supplied. This has resulted in an imbalance, needing caution, due to the high demand for depleting resources. Resource management and its utilization have already been a much-discussed research topic. As stated by Kate Raworth in an interview with Hens (2019), it is essential to redesign institutions and align them with the cycles of the living world to create an economy that regenerates when wealth is distributive rather than concentrated without any compromise. Circularity shares the terms of fair distribution, smart and optimized use and sharing of resources, and sustainable regeneration have been used in most of them.

The construction industry has been resistant to researching and implementing the most efficient resource utilization method. Because of the decentralized and diverse material flows in the construction industry, it is difficult to repurpose resources to meet the needs of a growing population. One solution is to reutilize resources. A circular trading ecosystem is required to improve resource utilization and implement a circular procurement process.

Before adapting to a CPP, stakeholders in material procurement must overcome challenges in implementing the infrastructure and processes required to make it viable for future use of existing resources due to some obvious but overlooked details. One such fact is that the procurement of materials and building elements never ceases and occurs at multiple stages of the project lifecycle. Future planning is hampered by the inability to follow circular business protocols and understand social, and environmental impact due to lack of a transparent procurement procedure. Additionally, as demand and requirements for a building product fluctuate based on its function and price, the situation becomes increasingly difficult. Also, despite multiple efforts and case studies, CPP is not yet an industry standard. In addition to the issues mentioned, there is a lack of awareness of circular procurement concepts and a financial pressure of transforming linear supply chains into circular ones.

Nonetheless, there have been attempts to trade materials both online and offline. Since offline solutions are private and difficult to study, the focus is on online alternatives that are already available. In context of CPP, the resource offerings and pricing mechanisms of online trading platforms differ, as shown in Table 25. Some need a registration fee and are only available to businesses, while others are available to the public. Pricing policy may differ depending on the base price of the product, logistics, market demand, and material quality. The bulk of them do not provide enough information about environmental impact or product quality to entice people to buy pre-owned materials. Online marketplaces that sell products generated from biological resources, for example, may provide information on a product's environmental friendliness or durability. However, it is difficult to find used materials, such as steel and concrete, for sale. Furthermore, product's performance efficiency and value are not defined explicitly between a buyer and a seller prior to the execution of a trade transaction. Problems with the detachability of building materials due to the lack of immediate benefits during the demolition phase of construction, an uncertain demand for used products on the market, and the absence of a circularity clause in contractual agreements between stakeholders all act as roadblocks to the trading of used materials.

It can be concluded that a framework is indeed required, that focuses on the purchase of materials, or services that contribute to the looping of building materials' supply chain. Furthermore, the framework

[48] This section provides answer to Sub Q1.

should ensure that the negative social, economic, and environmental consequences of reusing construction components are kept to a minimum and that no waste is produced.

6.1.2 Framework for valuation of building elements for construction industry in a circular ecosystem[49]

A methodological framework has been proposed in this research and is divided into two broad categories, the first is pre-partial deconstruction phase and the second is partial deconstruction and resource optimization phase as shown in Figure 79.

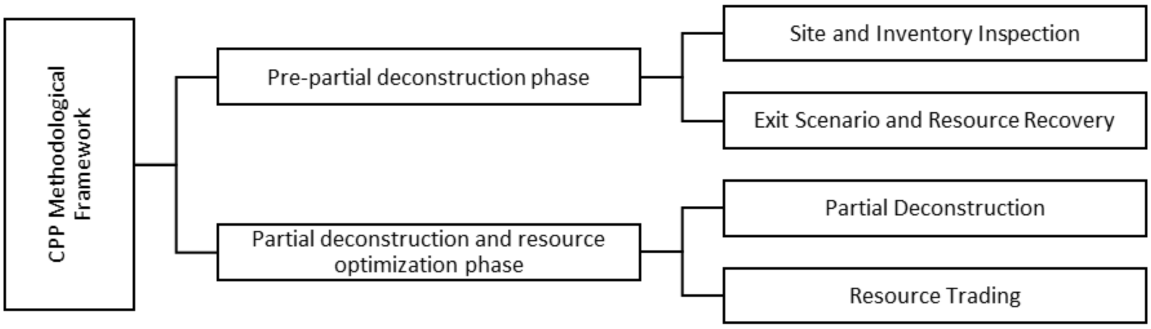


FIGURE 79 BREAKDOWN OF CPP METHODOLOGICAL FRAMEWORK

In the pre-partial deconstruction phase (Figure 48), the client should order an inventory inspection before requesting bids. Inventory inspection should include building and site specifications. BIM model, 2D drawings, material locations, building construction history, and exit scenario report for building assets are included. Bids must specify asset ownership and resource recovery. A prospective contractor can then inspect the building, neighborhood, and land-use plan. The building site inspection examines the building's heritage status, presence of hazardous and explosive materials, construction history, structural hazards, energy and water connections, and any underground infrastructure that must be rerouted. Based on the inspection, the contractor can determine whether to apply for the project or not. If the answer is affirmative, the contractor can determine the approvals required for the operation, plan the partial deconstruction process, and estimate the machinery, water, and manpower required to finish the project. They must also establish a waste disposal plan based on the tender's ownership clause and the client's circularity criteria. This information helps the potential contractor estimate deconstruction and demolition schedule and cost. A cost benefit plan predicts profits from reusing, rehabilitating, recovering, or disposing of building assets. This is sufficient information to quote a price and submit a bid. If the bid is accepted, the contractor and client can negotiate contractual agreements. 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. During the exit scenario and resource recovery planning (Figure 80), designers make use of the information gathered.

[49] This section answers the main research question.

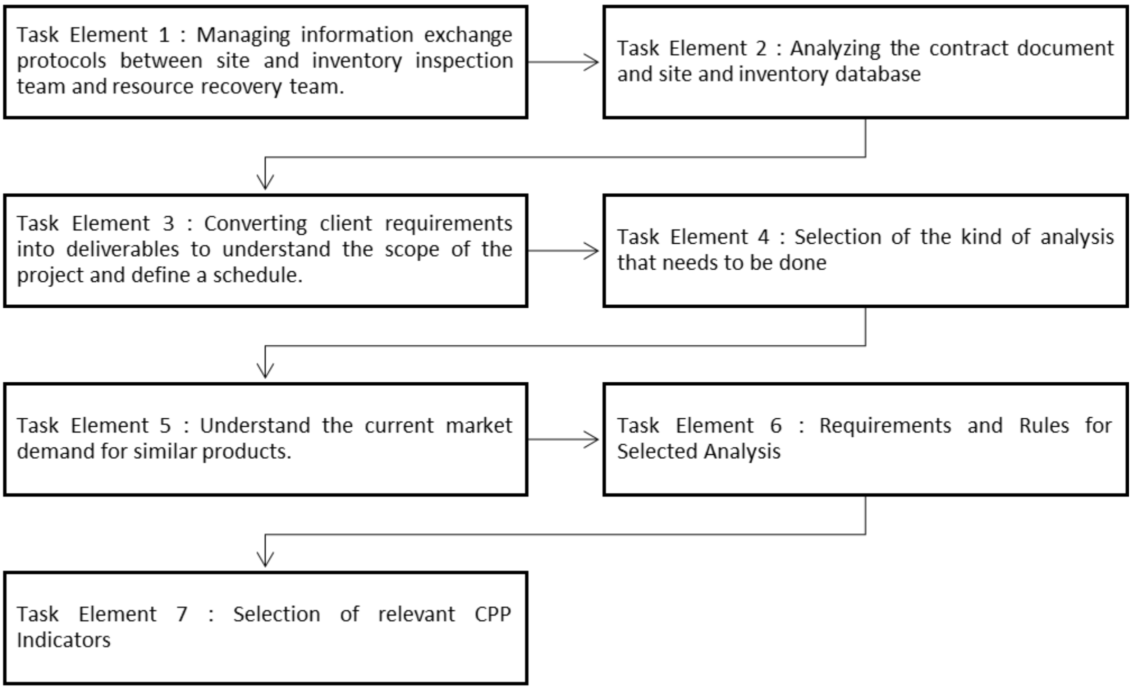


FIGURE 80 TASK ELEMENTS FOR PLANNING OF EXIT SCENARIO AND RESOURCE RECOVERY

They create a BIM model or feed a data processing platform using architectural drawings and other information, such as point clouds. To create a asset passport database, analysts use BIM and/or a data processing program. They investigate the building's disassembly potential and formulate the asset 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 partial deconstruction and resource optimization phase begins with client-specified deconstruction strategy planning. Typically, this entails the development of WBS, OBS, and CBS. Following planning, both the client must recover their belongings. Then the contractor prepares the property for deconstruction. This procedure includes building a partial deconstruction zone, on-site storage, and space for waste disposal vehicles, among other deconstruction obligations stipulated in the contract. Before partial deconstruction, quality inspections are conducted to prevent contract disputes over damaged assets. After undertaking inspections, utility companies disconnect water and power service. Soft stripping of the building then removes dangerous and explosive substances. The superstructure and substructure are removed and partially demolished. After a quality inspection and partial disassembly, assets are traded or sold. Building assets are sold offline or online dependent on the resource trading clauses of the contract.

6.1.3 Circularity Parameters relevant for Procurement in a Circular Ecosystem[50]

Based on literature research, interviews and the survey conducted for the study, there were a few terms that kept repeating as shown in Figure 81. These were the parameters relevant for CPP which were categorized based on the basic components of a CPP that are buyer (section 3.4.5.2), a seller (section 3.4.5.3), a medium and a process.

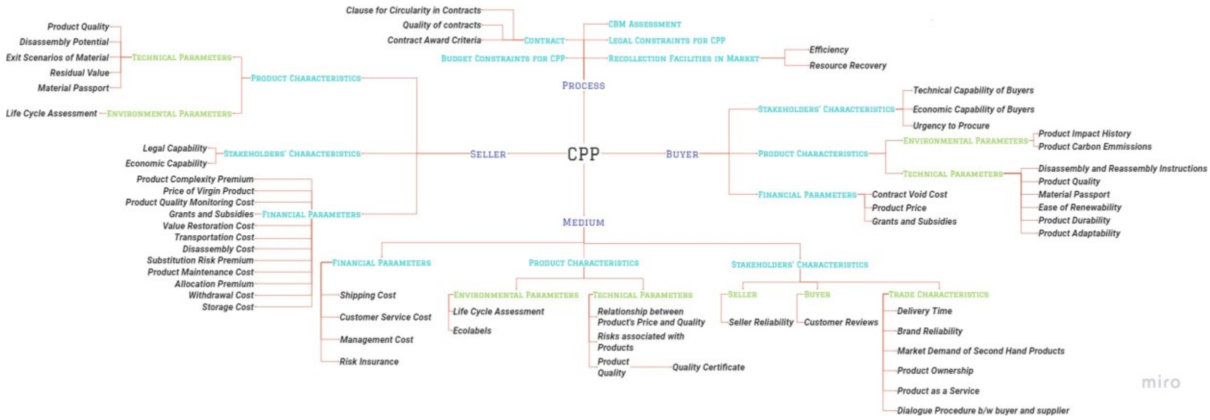


FIGURE 81 PARAMETERS RELEVANT IN CPP

To find ways to measure or investigate the parameters of Figure 81, the research focused on CPP indicators necessary for procurement(section 3.5) and investigated 78 indicators (section 11) that were proposed by various academics and industrial organizations for investigating building and its assets circularity and found 51 useful indicators (section 3.5). These were divided into four categories based on the basic components of a circular procurement system that are sellers, process, medium and buyers as shown in Figure 29, Figure 30, Figure 31 and Figure 32 respectively. It was found that most of the indicators focused on the concepts of deconstruction potential, its ease and time; the lifecycle sustainability assessment with focus on lifecycle analysis and lifecycle cost analysis; market demand; and the quality of the product which provided the relevance to the research objective (section 1.2).

Furthermore, it was found that the indicators used during pre-deconstruction phase focused more on sellers and their intention and insight into circularity along with the behavior of the organization where they belong. Their decision to deconstruct or demolish an asset was based on the type of asset, its exit scenario, the work done by regional restoration companies for restoring the asset or its constituents, asset's quality, the ability to reuse an asset after some restoration, its market demand, or the potential to recover energy from the asset. Hence, the selection of indicators was based on their ability to make these decisions quickly. The types of indicators that can be used during pre- deconstruction stage by the teams hired by owner or real estate developer of the building about to be deconstructed is shown in Table 29.

TABLE 29 USEFUL INDICATORS FOR PRE- PARTIAL DECONSTRUCTION PHASE

S.NO	PURPOSE	INDICATORS
1.	Quality	BIM based Whole – Life Performance Estimator, Material Durability Indicator, Residual Value Indicator, C2C Material Health Assessment Methodology
2.	Exit Scenario	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

[50] This section answers Sub Q2, Sub Q4 and Sub Q5

3.	Disassembly Potential of Asset	Disassembly Potential, Ease of Disassembly Matrix, Effective Disassembly Time
4.	Market Demand	Material Price Variance
5.	Environmental Impact	LCA, De milieukosten indicator, Product Recovery Multi Criteria Decision Tool
6.	Economic Impact	LCCA

It should be noted that some of the exit scenario indicators such as Product Recycling Desirability Index, Circularity Index, Remanufacturability Matrix and Economic Environmental Remanufacturing can also be used by value restoration agents while assessing if the product can be recycled or not. Furthermore, based on the exit scenario, the further analysis and indicators can be seen in the pre-partial deconstruction phase by exit scenario and resource recovery team is shown in Table 30.

TABLE 30 INDICATORS THAT CAN ASSIST EXIT SCENARIO AND RESOURCE RECOVERY TEAM

EXIT SCENARIO	PURPOSE	INDICATOR
Reuse	Residual Value	Residual Value Indicator, BIM-based Whole Performance Estimator
	Durability	Material Durability Indicator
	Environmental Impact on Reuse	LCA- operational and embodied energy
	Environmental Impact of Manufacturing Virgin Product	De milieukosten indicator, Embodied Energy
Repair or refurbish	Cost to repair or refurbish	LCCA of similar product
	Environmental Impact due upscaling	LCA – Operational Energy
	Environmental Impact of Manufacturing Virgin Product	De milieukosten indicator, Embodied Energy
Remanufacture or repurpose	Disassembly Potential of Constituents	Disassembly Potential, Ease of Disassembly Matrix
	Cost to remanufacture or repurpose	LCCA of similar product
	Environmental Impact due upscaling	LCA – Operational Energy
	Environmental Impact of Manufacturing Virgin Product	De milieukosten indicator, Embodied Energy
Recycle	Environmental Impact due to upscaling	LCA – Operational Energy
	Environmental Impact of Manufacturing Virgin Product	De milieukosten indicator, Embodied Energy
	Costs in Recycling	End of Life Indices, Potential Recycle Index

Factors such as ease of indicators' use; their compatibility with the site inspection data that is collected by the site and inventory inspection team; the availability of open-source reliable external databases for analysis during resource recovery phase; the type of analyses done during the resource recovery phase; and the sequence with which these analyses is done affect the selection of the indicators. Hence, the focus to select indicators was to help make the decision to demolish or deconstruct a group of assets quickly.

However, during the post deconstruction phase, the use of indicators was mostly to appeal to the buyer for the second-hand product. However, the control of choosing indicators is mostly influenced by the online marketplace representatives and the CPP elements that influence the online medium as shown in Figure 74. Some indicators were found effective to judge the efficiency of the entire process such as Remanufacturing Framework, Multidimensional Indicator Set, Longevity Indicator, Circular Economic Value, LCA based Circular Economy Performance Indicator, Circular Economy Benefit Indicators, Circularity of Material Quality. And for resource trading on the online platform, the essential indicators can be seen in Table 31.

TABLE 31 INDICATORS ESSENTIAL FOR TRADE ON ONLINE PLATFORMS

S.NO	ANALYSIS	INDICATORS FOR ANALYSIS	PURPOSE
1.	Environmental Impact	LCA, MKI, C2C Clean Air and Climate Protection, Retained Environment Value	For product filter and assessment
2.	Circularity Score	LCA – Eco Efficiency Index, C2C Circular Product, Product Circularity Indicator, System Circularity Indicator	For product filter and assessment
3.	Amount of virgin materials	Linear Flow Index	For product filter and assessment
4.	Residual Value	Residual Value Indicator, C2C Material Health Assessment Methodology	For product filter and assessment
5.	Functional Lifespan	Longevity Indicator	For product filter and assessment
6.	Exit Scenario(s) for next use	End of Life Index, Circular Pathfinder	For product filter and assessment
7.	Shadow Cost of New Product with similar function	MKI	For Product Filter and Assessment
8.	Certifications	EU Ecolabel, Platform CB23 Guide	For Buyer's Ease of Assessment
9.	Product Price Range	Material Price Variance	For guiding seller to put the right price on a product
10.	Availability for Risk Insurance	Material Supply Chain Risk, Material Price Variance, Global Resource Indicator	For Buyer's Ease of Assessment
11.	Market Price of New Product with similar function	Material Price Variance	For Seller's assessment for market price

6.1.4 Valuation of second-hand products in a Circular Ecosystem[51]

The valuation of second-hand products in the linear ecosystem is typically straightforward and simple. However due to the presence of variety of parameters in a CPP ecosystem (Figure 81), valuation becomes complex. The stages where valuation is key is resource trading on an online marketplace. Based on exploratory study, the price of a second-hand product should be adjusted so that its marginal utility is larger than that of a comparable new product. The valuation of a used product must incorporate not only the base price, but also the product's environmental impact as shadow price, the product's utility after first use and depreciation as residual value, and the product's lifecycle cost with an emphasis on the cost to restore value and make it eligible for second use as transition cost. Additionally, there are hazards associated with secondhand things, and selling a product on an online marketplace costs funds. Additionally, selling a product on an online platform necessitates financial resources. The parameters affecting the valuation are explained in detail in Table 27 and can be seen in Figure 82. Based on the elements in Table 27, a price of a secondhand product is set, and the taxes, subsidies and discounts are added to it which makes the minimum retail price of that product to be sold that can be suggested to the seller and they can choose to determine the price based on that.

[51] This section answers Sub Q3.

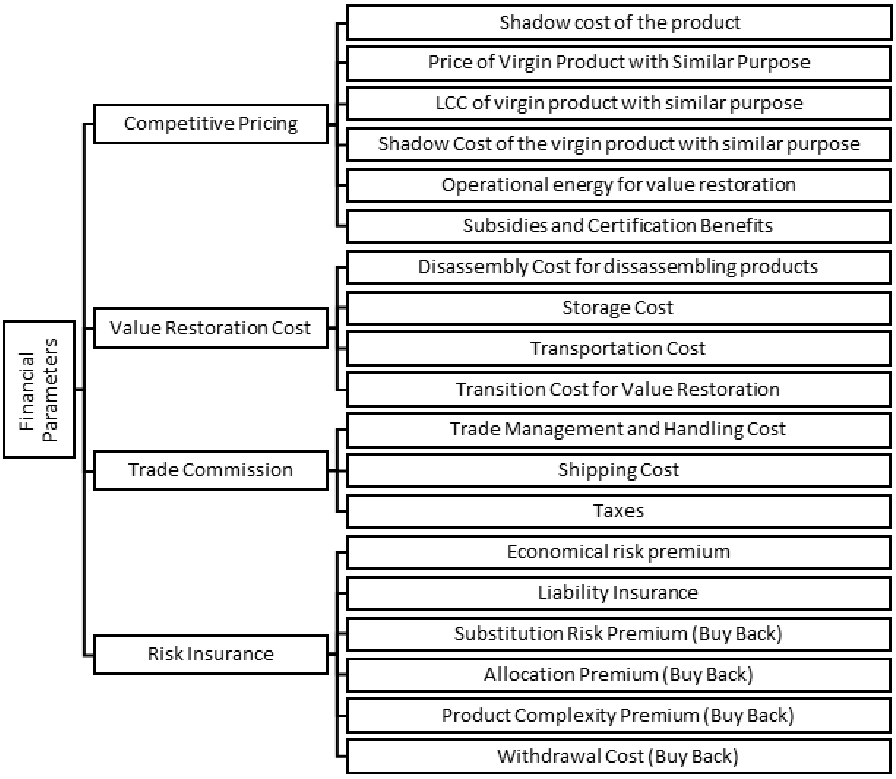


FIGURE 82 FINANCIAL PARAMETERS AFFECTING PRODUCT VALUATION IN CPP

6.1.5 Role of BIM and Essential Data Requirements to enable CPP [52]

To conclude deconstruction and CPP, it is necessary to evaluate whether deconstruction is feasible and what is required to enable CPP after deconstruction. This is the true motive of all information required at the end of a building's or asset's existence. In Figure 79, the four distinct deliverables that make up the proposed ecosystem can be seen. Each deliverable has its own set of goals. These four deliverables are intertwined with the others as one progresses further along the ecosystem's operations till the end goal of a successful resource trade online or offline.

The first deliverable is the site and inventory database. The information needed for the database is in Table 22. Apart from that, data needed during the inspection is listed in Figure 83.

FIGURE 83 SITE AND INVENTORY INSPECTION

The second deliverable is the Exit Scenario and Resource Recovery Plan. It has three stages, Planning; Preparation; and Resource Analysis and Information Delivery. The purpose of the information required at this point is to inspect the deconstruction feasibility of the building and create a resource recovery strategy that can be used by the deconstruction contract down the line and get the maximum return on value while deconstructing the building into profitable assets. It starts with transfer of information from the site and inventory database and use it for further analysis through a mapping process with or

[52] This section answers Sub Q6.

without the use of BIM model to create an asset passport. The assets can be building, a system, a product, or a material based on the scale at which the site and inventory database is formed. The BIM model can be a conceptual model made using exiting 2D drawings and old BIM models which laced with information from site and inventory database can provide the required basis for information take off and analysis. A realistic model can be made by creation of point cloud from the site and building photogrammetry done using drones and lasers when required and update the model to as real state.

BIM tools and software such as Navisworks or Solibri, and Verity are used to help with the process. Once a BIM model is made, the creation of new properties based on the required analysis and data of site and inventory database can be transferred. The analysis process starts with defining the proper order and sequence of analysis as shown in the Figure 84.

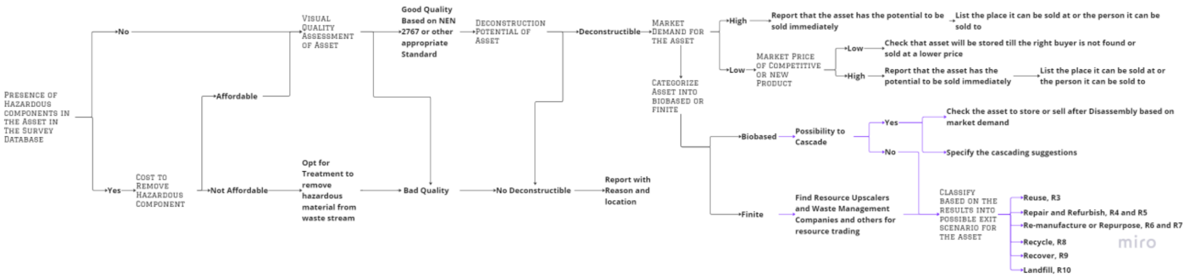


FIGURE 84 SEQUENCE FOR RESOURCE ANALYSIS

The data required for these analysis include site and inventory database (Table 22 and Figure 83) and the information added in the product passport based on the methodology and input (section 3.5) of indicators required (Table 29 and Table 30) for the selected order of analysis to finish the process.The external databases that augment the paucity of information in the resource analysis are another critical element. Information from external databases is necessary for the appropriate analysis based on the planning and tactics chosen. This is heavily impacted by data ownership, and the cost of obtaining appropriate data for the research must also be taken into account. For instance, LCA database information such as NMD and Okobaudat, supplier data acquired after inventory inspection Before doing the real analysis, these external databases must be created when the plan and strategy are complete. Once the analysis is complete, reports may be prepared, and data can be sent to the customer in accordance with the handover rules agreed upon before to the actual deconstruction project's commencement.

The third deliverable is the Partial Deconstruction Plan. Using the information from the exit scenario and resource recovery team, this can be formulated. The plan should include a detailed work breakdown structure (WBS), organizational breakdown structure (OBS), and cost breakdown structure (CBS). Once a structure is decided, cost and schedule plans can be made. BIM's 4D and 5D capabilities can expedite the creation of a cost estimate and project schedule if a BIM model of the building has been generated using existing drawings or point cloud.

The fourth aspect where building data is necessary is Resource Trading. The data presumed necessary by the seller is included in a passport accessed using QR code for inventory management and tracking purposes. The purpose of this information is to make the second-hand product valuable for a potential buyer and eligible for trade on an online medium. The typical product passport that can serve that purpose is shown in Table 32.

TABLE 32 INFORMATION REQUIRED DURING RESOURCE TRADING

S.NO	INFORMATION REQUIRED	TYPE	PROVIDED/ GENERATED BY	PURPOSE
1.	Product ID	NL/Sfb Code	Platform	Mapping and referencing
2.	Product Photo(s)	JPEG	Seller	Visual Reference
3	Principal Photo for Display	JPEG	Seller	Website Use
4.	Amount	Number of Pieces/ Kg	Seller	For Pricing
5.	Title	Text	Seller	For Reference
6.	Product Description	Text	Seller/ Online Platform	USP of Product
7.	Final Date for Product Availability	Date Time	Seller	For buyers to make sale
8.	Date of Upload	Date Time	Online Platform	For reference
9	Product Measurements (Length, Breadth, Width, …)	Number	Seller	For reference and further analysis
10.	Product's Material Composition	Text	Seller	For reference and further analysis
11	Verified Seller	Yes/No	Platform	For Authentication Purposes
12.	Reviews for Products from Seller	Text and Date Time	Other buyers	For Buyers to Judge Seller Conduct and Product Quality
13.	Trust Score	Number from 1 to 10	Platform	For Seller Reliability
14.	Supplier Information	List with basic seller contact information	Seller	For Seller Verification
15.	Product Brand	Text	Seller	For promoting circular product use
16.	Environmental Impact	Scores	Online Platform	For product filter and assessment
17.	Circularity Score	Scores	Online Platform	For product filter and assessment
19.	Amount of virgin materials	Scores	Online Platform	For product filter and assessment
20.	Visual Quality Assessment	NEN 2767 grade with proof	Online Platform/ Seller	For product filter and assessment
21.	Residual Value	Scores	Online Platform/ Seller	For product filter and assessment
22.	Functional Lifespan	Years	Seller, verified by online platform for a price	For product filter and assessment
23.	Exit Scenario(s) for next use	R3 to R9 from R framework	Seller, verified by online platform for a price	For product filter and assessment
24.	Certifications	Documents	Seller and by provided by online platform for a price with the help of an external party	For Buyer's Ease of Assessment
25.	Subsidy Eligibility	Yes/No	Seller or by provided by online platform for a price with the help of an external party	For Buyer's Ease of Assessment

26.	Product Reviews	Text and TimeStamp	Old Buyers	For Seller's Performance and prospective buyer's ease of assessment
27.	Product Price Range	Range of Numbers with the highest and lowest value	Suggested by online platform based on certain analysis	For guiding seller to put the right price on a product
27.	Product Price	Numbers in a currency denomination	Seller	For buyers to know the asking rate
28.	Type of Preferred Trade	Sale, Auction, Traditional	Seller	For ease of negotiation and trade agreements
29.	Instruction for Use	Text	Seller, Verified by Online Platform for a price	For Buyer's Ease of Assessment
30.	Shipping Cost	Numbers in a currency denomination	Online Platform	For Buyer's Ease of Assessment
31	Availability for Risk Insurance	Yes/ No	Online Platform if permitted by seller and opted by buyer at checkout	For Buyer's Ease of Assessment
32	Product Source	Location from where product is obtained	Seller during product registration	For Buyer's Ease of Assessment
33	Market Price of New Product with similar function	Numbers in a currency denomination	Online Platform through legal web scraping	For Seller's assessment for market price
34	Shadow Cost of New Product with similar function	Numbers in a currency denomination	Online Platform, if opted for by seller at product registration	For Product Filter and Assessment
35	Possibility to Negotiate	Yes/No and Way of Contact (if yes)	Seller during product registration	For fair trade practices

6.2 Limitations and Future Scope

The research in this project has an exploratory design and investigates the journey of a building asset from its original use to the next. It bears the inherent limitation of being close to the industrial practices it attempts to investigate and use as the baseline to propose a new connected framework. It also implies that it is a good skeletal structure that can be used to get started with the work for transition to deconstruction in a circular ecosystem.

During several levels of deconstruction, CPP employs the notion of circularity and sustainability. It was found that circularity has notions like a lot of other economic and ecological frameworks alongside sustainability. Hence, the investigation of existing elements and indicators for CPP have a redundant aspect to them. However, the redundancy could prove useful if applied strategically. It is stated clearly that CPP indicators proposed in this research are not same as indicators assessing or quantifying circularity of a process or product. Also, LCA and LCCA methodologies along with disassembly potential and quality assessment, are more important in making the decisions for selecting building asset for deconstruction and, a circularity score like product circularity indicator is used while selling the asset on the online medium. It can be inferred that circularity and sustainability principles when combined with economic assessment parameters over a process can produce more value than the individual principles alone. Further research into essential aspects of CPP indicators such as LCA, LCCA and residual value assessment should be done while designing an application relevant for part of this framework. For instance, aspects of operational and embodied energy while conducting LCA should be carefully decided. Since this research encompasses biobased materials as well, sequestration rates of the materials should also be measured.

The framework spans the whole deconstruction phase of a building including resource trading process and hence it has validated in parts using existing solutions proposed before this research. Some of the key aspects used for validation are the site and inventory inspection application for preparing resource inventory, use of an already proposed matching application for market demand and online marketplace, creating an asset passport using BIM modelling software or IFC open shell. Hence, a case study for the entire framework can be the next step to evaluate it. Due to the broad scope of the proposed solution, specific CPP indicators proposed in this study are recommended rather than selected for the framework and require further updates to better fit the solution. Hence, it does indicate that the framework can be implemented with the help of the available resources and data without proposing new indicators. Also, this study showcases the position where different CPP indicators can be applied along with the necessary BIM tools.

CPP elements form the foundation on which the framework stands. A study into behavioral aspect of different stakeholders has been done and highlighted alongside interviews with industrial actors and surveys for assessing the general opinion. CPP elements highlighted in this study are based on these pillars. This research tries to put the weight equally on each element highlighted in the surveys, interviews, and the behavioral study to create a framework that considers all these subject biases. Hence, a different approach with more structured interviews and surveys can result in influencing the decision-making process based on the weight given to these tools.

The influence of the demolition process in general and deconstruction process in the Netherlands form the skeletal system on which this methodological framework rests. Hence, there is probability that based on different regions and regulations, there can be changes in the elements included in the framework. However, the framework provided is flexible in nature and can be modified based on the regional aspects for which it is adapted.

All four deliverables proposed for this framework have their own unique set of requirements that are showcased in this research. This gives an idea of the requirements needed for the system design of possible applications that can ease the decision-making process for the stakeholders involved. Based on the proposed ecosystem and its breakdown, a presence of application or network of applications is necessary for the pre-partial deconstruction part and a proper system design is required for an online trading platform. Since the applications used during deconstruction process are reflective of the needs of the contractor and can't be estimated as it may vary based on the deconstruction project and its requirements. The future applications for this framework include:

1. A BIM compatible Site Inventory Mobile Application and DBMS with use of No-SQL or Graph Databases with compatibility to the Resource Recovery Web Application.
2. A BIM compatible Resource Recovery Web Application and DBMS with use of No-SQL or Graph Databases
3. Online Platform for Resource Trading that maps data from BIM models for product registration apart from the Resource Recovery Web Application.

Hence, the research proposes the system design of the pre deconstruction and post deconstruction application platforms as the next step to fill the gap and ease into the proposed methodological framework and its subsequent implementation and testing for a particular project by the concerned stakeholder as shown in Figure 85.

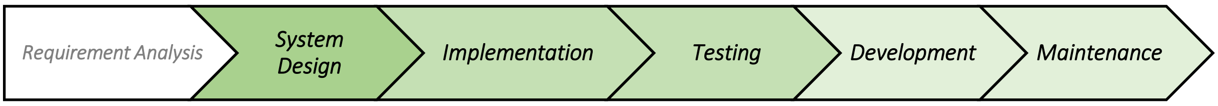


FIGURE 85 NEXT STEPS IN ECOSYSTEM DEVELOPMENT

Furthermore, it should also be understood that the systems should be designed in such a way that are intuitive and the energy spent to use the three systems is done in a sustainable manner and facilitate energy conservation. Another aspect considered while designing the systems is data reliability because the type of information needed for the above three applications has been presented in this research does not mean that it is all that is needed. The second step is the source where this information is coming from. Hence source inspection should be a key point before creation of application to make the information generated reliable and useful for further processes.

Another aspect of this framework is BIM. This research proposed the use of as built models with a recommendation to use real life models with the use of point cloud. It is an expensive affair. Hence, use of BIM models and tools should provide more value to the stakeholder. Use of AI and traditional predictive algorithms in the inventory inspection and resource analysis parts can help provide that. Some examples are use of generative design algorithms to generate accurate concept models from site photos and BIM point cloud, and suggestion of residual quality of a product based on site photos using image evaluation algorithms. This can be used to detect minor cracks, bends and discoloration in visible building components.

The last key part of the ecosystem is the resource trading platform. The research highlights fourteen key design aspects for an ideal online marketplace for used goods. Based on the existing platforms, their characteristics, and the lack of decision-making elements for a buyer form the crux of these proposed aspects. Further research into the business aspect of this is needed to make such a system existing. Use of AI and predictive algorithms can further elevate the value of such a platform. Some of the use cases can be predicting exit scenarios through market data as training dataset for supervised learning. Since the framework proposes calculation of value of second-hand material using some valuation formula and suggests it to sellers. After the seller sets prices as they see fit for the sale, an algorithm can map it and recommend new sellers with similar prices based on the standard prices set. It is like Airbnb.

In conclusion, this framework, with its flaws and limitations, forms the basis of for the vision of the author, with the existence of an online platform in a circular built environment where buildings are listed at their conception, so that the building assets in a building can be sold as futures[53].

[53] *Futures are derivative financial contracts that obligate parties to buy or sell an asset at a predetermined future date and price. The buyer must purchase, or the seller must sell the underlying asset at the set price, regardless of the current market price at the expiration date*.

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7. Chapter 7: References

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8. Appendix A: Interviews with Industry Experts

The interview was conducted with four industry experts and the following questionnaire was sent prior to the interview with the following questions:

- What do you understand by sustainability and circularity in construction industry?
- What do you think about circular economy?
- What is the market trend of reusing construction materials?
- How does the trading of construction and demolition waste work in the industry?
- While doing a construction project, do you look for materials from the industry or buildings yet to be demolished?
- How do you think second-hand material is procured for use in construction projects?
- What can you say about the quality of reused material in construction industry? What sort of assessments are there, if any, to assure the quality of construction material?

8.1 Interview: Pablo van Den Bosch, Madaster

This is an abridged excerpt of the Interview with Pablo van Den Bosch, board member in Madaster, about the transition to a circular economy in the construction industry on 18 December 2019.

Q1. What do you understand by sustainability and circularity in construction industry? How does Madaster play a role in it?

Pablo [00:00:48]: Madaster is an online platform where data on materials and products applied in the built environment can be registered which can be done by uploading either Excel templates or BIM files. So building information models via IFC format and by uploading that information, we can enrich and restructure the data in such a way that we can give you an overview of what materials and products are used in your building or in construction object, what the impact of those materials is on a financial valuation. In this way we can say something about circular characteristics of the construction object and provide a materials passport. If we look at the database, we do have an overview of materials and products used in the environment. Currently, that database is not openly accessible to public. But we are working on it to open the database. So that is what Madaster is.

Coming on how does the construction industry look at the circular economy and what is circularity? First, the industry is very aware of what circularity means. The usage of materials and the reuse of materials is quite common in the construction industry. Construction industry is very old, and every craftsman knows how to reuse their products. When a carpenter uses a timber beam, the carpenter knows how to reuse it, use it again.

The economy, however, is that using new materials and products, very often is cheaper than using existing or reused products and materials. So, the construction industry is aware of the possibilities of reuse, but there is very often not a financial gain to reuse materials. And I'm not talking about the qualitative aspects. What's the quality of the reused material, the guarantee that can be given on the quality? Or the variations in the supply chain so when is it available? But the construction industry is aware. Unfortunate thing is that they are not doing it a lot. They use a lot of materials and throw away and waste a lot of material too. At its best, the construction industry reuses materials as recycled low value products. Like for concrete, they crush and use it as foundation for creating roads. That's not a good way to reuse material. That is what we call downcycling. So, they are aware, but they are slow in starting to realize it. And that is what we are trying to support.

Q2. As you stated that Madaster and other platforms like it exist to support the transition. You said that it is difficult to tap into the financial gains that one can reap while transitioning to circular economy. Could you elaborate on it?

Pablo [00:05:23]: Well, that's a change. And of course, if it was easy, everybody would have done it already. If it's easy to reuse and make money, people will do it. If it's difficult to reuse and not make money, nobody's going to do it. So the challenge that we have as a society is to make sure that we optimally use the materials that our planet has given to us instead of taking and making and wasting materials, which is the concept of a linear economy. What Madaster and also other players try to do is to make it easier for economic actors to reuse materials, make the quality goods, assure that their quality is good, make sure that the availability is there, make sure that the documentation is good, ensure that regulation allows the reuse of materials, factor in the value of materials. When you evaluate a particular object, make sure that the supply chain can easily handle the reuse of materials which means knowing how to construct and deconstruct mounds *{of materials}.* These are all means to ease up the reuse of materials. And Madaster is one of these initiatives.

Q3. As you said previously the construction materials and you specifically said about downcycling of concrete. Are there ways where you can use concrete slabs of prefabricated concrete, which was in the building and you can just use that slab or part of that in a new building? And so basically not down cycling. Is it possible?

Pablo [00:07:44]: Definitely, yes one of the nice examples from that is not been a building, but it's a viaduct. It's like a bridge. It is a concrete bridge over water. One of the examples of such a bridge that is created and constructed by Rijkwaterstraat, the Ministry of Infrastructure within the Netherlands. They've created that bridge from concrete elements that are created in such a way that they can easily be taken apart. So, when they (Rijkwaterstraat) want to reuse these concrete elements they can be just unscrew from the structure and reuse them. They made them in such a size that they can be transported with the use of a normal truck, so it is reusing object elements or products from a technical perspective, there's no issue at all. That's a matter of how do you design it? And do you design with Reuse in mind or do you design to build something that lasts forever? From what we see for instance, with concrete is that we use concrete to create structures on the site that are immovable. But it's possible to create structures that you can demount and remount again in a size so that you can handle it, lift, and transport it. That's doable. But then you must take that into account when you design it. When you build it.

Q4. **So, coming back to the first question again. When you discussed about circularity in the construction industry you also mentioned that there are two ways of doing it. One is to disassemble or demount and then the other one is for durability. So, in the construction sector, in terms of using or reusing materials, what trends have you seen? Do people opt for disassembly or for long term use? How do you think that affects circularity as such?**

Pablo [00:10:34]: Well, it depends a lot, on the circular characteristics of building that we a score to that the so-called circularity index. When you build something, an object that you create to last for at least 50 years, use materials that might last that long. And it's okay if you construct or use them in such a way that difficult to do that amount because 50 years is a long time. Know if you build something for just 5 or 10 years and take it into account that you reuse the material. If you build something that potentially lasts for two hundred and fifty years, use stuff that might require a lot of energy to create now, like big concrete structures. But if you can use it for 250 years, that's a very long time. In the construction industry, the starting point, is very often a decision that we need to build something that is going to last for at least one hundred and fifty years, which is not the case. Look at cities. Cities continuously change. Even if it's a concrete high riser, the chance that the concrete high riser will be there in the city center for the next 50 years is not that big. And sometimes it's even way smarter to build something for a shorter term like logistical buildings. Warehouses are typically something that are built and will be changed within 15 years. So built with design, with reuse or decomposition within 15 years in mind. And there can be a possibility that we use materials that lasts shorter or materials that are stronger and better, but it can have two or three functional applications in the longer lifespan. The technique is not a problem. The problem is defining what do you want to do and what do you have in mind about using that material now and in the future. So, it is all about thinking ahead with the design and the construction and do not expect that the structure will be there for eternity because history has shown us that's not the case.

Q5. So far in the discussion about circular economy, we talked about how transitioning to circular economy help the environment and Madaster's role in conveying it as a platform. But how do you think Madaster and platforms like that help in bringing the change in business models of the companies by talking about the financial benefit's this transition may generate?

Pablo [00:14:16]: One of the benefits of this is knowing what materials and products are used in a construction object, you can valuate materials dependent and independent of the total structure. So, look at it as a as a derivative. So the building is the total product that is decomposed in small products and materials which can be independently treated or taken out of salt just like with a derivative financial product, various components that you can evaluate and trade independently. It also gives you a better insight into the risk. What if there was a health issue where the materials that are intact, or what if you have a construction issue where you exactly know where it is, so it can reduce risk. If you create, let's call it, waste but if you have residual materials because of maintenance, instead of throwing them away pay to get them disposed, you can start trading them and you can sell them to a new user. So that gives them a financial composition. If you have proper documentation, you can save costs on the assessment of what materials and constructions were used. So, these are some elements of financial gain, if you properly document or if products can be reused in a circular economy.

Q7. When you talk about reuse and mentioned that concrete which has a longer lifespan must be used while considering the demountability after 25 years. Could you also tell us about what is the trend for materials that have a shorter lifespan and are easily demountable, like a window panel?

Pablo [00:17:10]: There's an easy solution there. Or do what I see as the direction that we're having to be in the construction sector that marketplace to buy and sell goods, currently, mainly includes virgin products and materials, but that will change and reuse products will get to the market. So, you need a marketplace where you can provide your supply of materials, products that you don't need anymore. If you do that physically, it's difficult. If you physically must transport all these products from building, after deconstructing building, then take it to market then hope for somebody to pick it up. You will have transportation costs, but you also have storage costs in the meantime. So, the physical marketplace is going to be a difficult, expensive market. Therefore, I trust in the digital marketplace where you digitally provide a supply of materials to a digital marketplace. There a buyer can say that he wants to buy this product and instead of using a physical hub. This means transport to a hub; store there and then transport to the new destination. The trade process takes place digitally, and the physical process takes place straight from the source towards the new destination. That is the ideal situation. And to do so, you need to have digital marketplaces that are provided with digital twins of the products and materials that will be released from the existing built environment.

Q8. And Madaster is one of the companies that such doing it in terms of providing that sort "The digital marketplace"?

Pablo [00:19:17]: No, that's a logical statement, but we explicitly do not want to be the marketplace. We only want to be the register where you can store your digital twins and the marketplace is where everybody can start a marketplace if, it needs to be sourced with digital twin information. It's not Madaster that does it but it's the owner of the products and materials that can use their Madaster registration platform to forward to digital twins to the marketplace.

So, we separate out the storage, keeping, managing, securing the digital twins. We separated that from the marketplace because when you own a bike and you use the bike every day and you want to sell your bike after three years' time, you do not want to store your bike data at a second hand bike shop. When you buy the bike, you only want to do that when you work, when you want to sell off the bike when you stop using it. In the meantime, it is useful and valuable if you keep the information on the bike that you just bought. So that you have it available and you don't have to look for the information after three years, when you want to sell off your bike. So, what we've done is you can trust us guarding on your data when you want to do something with your bike. You want to sell it off. You can use your documentation on our platform to share it with the marketplace of your choice, That marketplace can be a consumer to consumer platform. Or it can be consumer to business platform, which can be an open marketplace or maybe a marketplace where they already buy off your bike, give you a price and then try to sell it for a higher price. That's up to the market to come up with smart shops. We're not doing that. Madaster is just a register, keeping your data in a safe and secure way. So that you can manage your data.

Q9. Are there any marketplaces that you are aware of where such a trade is happening?

Pablo [00:21:44]: In the Netherlands, there are ten to sixteen digital marketplaces. They are not big. They're slowly growing. Some of them are insert, gebouwmateriaal.nl and others.

Q10. Apart from digital trading, how does trading of materials from a demolished site works in the traditional sense?

Pablo [00:22:55]: Well it works, when you are managing the deconstruction in time. If you only have three weeks to get rid of a building, it's impossible to physically reuse all the materials that are out there because it's just too short of a time to get new destinations for the products or materials if you have to do that in three weeks' time. But three years in advance to find proper new destinations for the products and then decomposes it in three weeks, then it can be done. So, it is like your bike that you might have at this moment. And if I gave you one day to get rid of your bike, the chance that you get a lot of money for your bike is not very big. Physically, it's no problem. But who would you ask for it? So, the physical deconstruction of buildings, we've got very capable construction companies that can construct and deconstruct so that the classical demolisher can very well deconstruct instead of demolishing. They do have the skill, and the tools. They don't have the time because demolishing is something that always needs to take place in a very short time frame. And the reason for that is it's not leading to any additional revenue. If you tell the owner of a building that can be demolished during your time and I'll give you the revenue of all the materials instead of giving me three months and I'll get rid of the building. That's the kind of shift that needs to take place and that will lead to the circular economy.

Q11. If demolition planning is done in advance and one can state on these platforms that the demolition of this building would generate these products, then the deconstruction could generate some revenue. Is that right?

Pablo [00:25:37]: Time needs to be bridged, that's an important thing. And the other thing is you need to bridge the physical issue. So, if I want to buy a set of tiles, I want to see what kind of tiles are there, what is the condition of the tiles, and when will they be available? And if I now drive to you with my truck full of tiles, you may say that, “What do I have to do with those tiles? It's rubbish. I don't need it.” But if I explain to you that I have a full truck of reused tiles in this condition in a digital format. Then you can start looking for the right new application. And the nice thing about the products and materials used in the built environment is that very often we even don't see the difference between used and new products. We just don't see it. You can refurbish it, paint it, and upgrade it. And some products even hardly age like an iron beam which can be used repeatedly depending on the way it is, sometimes it is the condition or the measurement. Vut very often the difference between virgin and reuse is hardly to be experienced. So, I'm convinced that we can increase the efficiency of the construction industry with respect to the usage of materials and happily reducing the amount of waste that's being produced, from a quality perspective, it's not a problem from a pricing perspective we need to take a couple of steps because buying new is currently fairly often cheaper than buying reused and that's something that's not good.

Q12. According to you, what measures should be taken to make the use of reused material cheaper than virgin materials?

Pablo [00:27:57]: Make the system transparent. Make it simpler to sell off the reused products. Make sure that there is a market for these products. Make sure that the data on products and used products is there and is available. And, the economy will in the end lead to a situation where reuse is required because we use, in our current economy, more products than our earth is producing. So, in the end, our planet will force us to reuse materials and then we can do two things. Either we wait until we have an issue because we cannot build anymore, or we are going to invest in a circular economy by supporting initiatives that reuse materials.

One of the easy things is if you transport a product, a virgin material let's say, hardwood from South America to Europe, why is that cheaper than reusing woods that's been grown here. We should stop doing that. And I'm not a lawmaker. I don't. I don't decide on Taxes and don’t decide on penalties. I don't decide on permits which you can use. But I think it would be good if this initiative would be supported as well by ruling out things like transporting a long value product from China to Europe, that pollutes our air. Let's change that. But that's not up to me and that's not what I am dependent upon. But I think as a human being, there is a couple of things we should change to have a prosperous economy for not only today, but also for the future.

Q13. There are some initiatives that have started due to the EU’s decision to be circular by 2050. But so far for now, for a construction project, what do you think happens when somebody wants to find materials, how do they find it?

Pablo [00:30:57]: There are steps that are being set right now. So, the markets for reuse products is not developed. The way to develop a market is to make sure that people are aware of the possibilities and to market this to tell that this is a possibility. And the fact that you sent me an email is because you are interested in the possibility. So, you would take this conversation into account when you will be part of the construction sector. If you are going to work in that one, you will take it into account, and you'll want to develop or build a building. You say, do we really have to use everything with new products covering new regional products? And then we will start looking for the marketplace. That is what is going to lead to a change. And that will not be taking place overnight and it will take some time. But I already see that in a lots of new development projects, the requirement for proper documentation of materials being used, a requirement to at least attempt to use reused products or design in such a way that you can reuse the products after their functional lifetime that is typically something that's currently already taking place and the market is not so fast. Also, buildings do not pop up and get down within a year's time. So that's matter of a couple of years, but we can already see this happening.

Q14. How does ownership rights and procurement procedures will change with the idea to use reused products?

Pablo [00:33:17]: That is the same as your bike. I don't know if you are familiar with the concepts of a Swap Bike, the bikes with the blue tires. Three years ago, everybody owned their own bikes but now the student cities are full of swap bikes where you don't own the bikes. I see that there will be similar models also within the construction industry. Then people will say that "I not going to own the stuff, or I am going to lease it or I'm going to use it or I'm going to get a retail contract. By that contract, I will buy this stuff and you are going to buy back from me after I am done using it. There are variations to that that will take place. And, the procurement department can initiate all those kinds of contracts depending on what is the requirement for procuring materials. That can be to give the cheapest or give the best or give the most beautiful one or give the most circular one. It can be whatever you want. What we see in the construction industry is that everybody seems that it must be the cheapest stuff. And that's just a contractual way and it's limited. If you think that you can only get a product if you buy them, it's just like cars, bikes, etc. If you go to a bike dealer and you don't want to buy the stuff and ask what is needed to be paid for using it for one day. There is no shop that will say take a walk and I'm not going to do it. You can get whatever you ask. The traditional industry is not always an advocate, but I'm pretty sure that this is going to change.

For example, do you want to do you want to buy a house, or you want to rent the house. If I tell you that you can rent my house for one or two euros a month, but you can buy it as well for $10000.What are you going to do? If you think that the value will go up, you will buy it, but from a cash perspective, I'm happy renting as well. In the end, it is your expectation. And what do you expect with houses or with materials? What is the benefit of having a cubic meter of concrete? You're not getting any happier if you own it compared to using it unless you think that the concrete will get a higher value. And so in theory, there are ways of looking at ownership, ways of living and how do you develop those things. It is also about asking the right questions. If you ask for the cheapest, you get the cheapest. If you ask for the best, you get the best.

Q15. Does Madaster offer a circularity assessment scores for the quality of the material?

Pablo [00:37:23]: It is the same way of dealing like one deal with new stuff. We trust the seller or the manufacturer. So, what if the seller shows you existing stuff? You trust the seller just like you do now. And you can ask the seller. If you think about a secondhand car, the seller says to you, you can buy a new Volkswagen Golf or you can buy the secondhand Volkswagen Golf which is five thousand kilometers on the clock. That's one year old with five 5000 kilometers on the on the clock. If you buy the new one, I give you five years guarantee and if you by the second hand one I will still give you five years guarantee. But then it's up to you. Do you want to have a new car because it's new? Or do you want to have the exact same quality with the exact same guarantee that somebody else drove too. Well, some people say that they only buy new. But I honestly don't care if car is not new if I get the same quality for half the price. Because I care more about getting a rebate than driving a brand-new car. The same is the case with the materials. If the seller says I give you the same quality, you'll ask how do you guarantee that? And then the seller assets. I'll put it on paper. I'll give you a calculation where I did some tests depending on the type of material. But this is not a big thing.

It is about the supply chain needs to become aware that selling material is not about selling new material but about selling functionality. And then the seller can give a guarantee on that particular quality in a particular price or a set way of using it for an exchange of effort or money or whatever.

If you think about the construction sector and make comparisons to other sectors. And, of course, it's a way easier to not change and do as if we have been doing it for the past hundreds of years. But if there is no material available, what if the price goes up of virgin material, what if we pollute the air with carbon because we use all the energy to create new materials on the one hand, and generate enormous piles of waste because we're not reusing materials on the other hand. So try to be a bit more innovative without losing the quality or without losing the service. It definitely is possible and we just have to think a bit differently and that's what we tried to do, to support others in the supply chain of the construction industry and make ways that are easy for them.

Q16. In the construction industry, there is a vast variety of a material. Each of it has a different lifespan and a different depreciation value. How do you think that affects the reuse of a material? How do you assess what can and cannot be reused?

Pablo [00:41:51]: So, there is no doubt that I can measure everything I want to measure and give a quality assessment on materials and use materials. The question is, is it worth doing it? So if you have a concrete block with some steel in it and you want to reuse it for another 50 years, it's going to cost you two thousand euros to do the quality assessment while creating a new block with that particular steel in it where you already know the quality is going to cost you some hundred euros. I think this market is not going to fly. But if we're talking about a very high-quality oak door. The reused door is more valuable than the old one. So, it will differ per element or per material or per product.

Just like you have in all sorts of markets. The reused market for designer clothing is better than the reduced market for normal clothing that you buy at flea market, because the quality of designer clothing is better, and the value is bigger. So, cleaning and putting it to a sewer for a designer clothing, the designer clothing is a better deal than for normal clothes. That is the same for construction materials. One would not put a lot of effort in reusing low value material that has a high cost to check for quality, reuse will be very limited. So, the question is, should you use that material, or should you use high quality materials? It depends. So, we are not going to change the variation in materials and products. We are going to change the starting principle where you do not build, to throw away, with the concept of take, make, and waste. We are going to start with the concept of take, make, use, and reuse. And that will lead to all sorts of variations at the construction site.

Q17. There are a lot of assessment techniques for circularity and material passports that are being floating online, every organization that is dealing with the industry have their own way of defining these indexes on his assessment scores including Madaster. So, what do you think is a common ground based on which one can chose the assessment criteria?

Pablo [00:45:03]: Of course, it depends on what's the easiest. What is the most transparent? Is there a proper organization structure or a financial foundation and what is the proper power base? Because this is new. You see all sorts of initiatives. That's how it starts with a million-dollar initiative where it crystallizes to a couple of key market players. So, that's a combination of market practice, science, insights, and marketing. At this moment. This is this new market is very dynamic and very diverse. It will have a clearer structure.

8.2 Interview with an expert on circularity in built environment

An interview with the expert on 20 December 2019 who is researching circularity from a wide range of angles.

Q1. What do you understand by sustainability and circularity?
Circularity Expert [00:00:31]: I like the definition (Huesemann & Huesemann, 2011)[a] which has three criteria for circularity, and you could, at that point, say sustainability. As they become the same at that point. One way to define circularity is that you as humankind can use globally renewable energy at or below renewability rates. So, there you could put a number on that. Its budgeted and the budget grows when technology gets better. You can put a specific number on that. It's a boundary.

The second condition that they define circularity by is the use of materials at or below renewability rates again. So again, you can also have a number there. The wonderful thing is that with, for example, bio-based materials, those numbers could be quite high. So, you could use them a lot. And with other materials the renewing is very problematic. If we forget about recycling and reuse, and talk about renewing, it is difficult. For example, renewing of metals like stocks of iron ore is quite hard. But for materials like sand, and clay, which through erosion can be renewed. And so, there's also a number there too.

Then the third condition is that waste which includes emissions too. So, carbon. ammonium, etc. are emitted below the regeneration rate or the rates that Earth can handle to break down these emissions without being harmful. So, there's also a number there.

So, I think that these three conditions best define circularity and sustainability, because they are specific. There's a budget. There's a boundary. There's a number. And we can see that if we are careful or not and to what extent. So, I would use that definition. (Huesemann & Huesemann, 2011)use it in the book: *Techno -Fix: Why Technology Won't Save Us or the Environment.*

[a](Huesemann & Huesemann, 2011)*define 3 clear conditions for a Circular Economy:*
1. All energy comes from renewable sources at or below renewable rates.
2. All materials come from renewable sources at or below renewable rates.
3. Waste can only be released at or below assimilation rate, without negative impacts for the ecosystem or biodiversity.

Q2. People approach circularity in diverse ways depending on their perspectives. Is this how an architect may define circularity? With such different perspectives on circularity, how do you think the European union's goal to be circular by 2050 can be achieved in the construction industry?

Circularity Expert [00:03:26]: This is a very general definition, not just for architecture or any industry. There are many definitions some of those definitions are not neutral. I think the one that I just gave, it is neutral. This is pure and exact science. Many definitions state that we want all that (criterion mentioned above), but we don't want to hurt the economy. They use circular economy. And what I talk about is purely strictly ecological definition. So many definitions are more compromised due to vested interests, societal lobby industries, politics, etc. So, they are not too radical. But I think the pure definition is the one that I just gave you. But it's also very confronting because then we have a severe problem if we use this definition.

For the second part of the question where you asked about the political goal in the Netherlands and Europe to reach a hundred present (circularity), which is a theoretical number. I think it will probably be ninety-five or ninety-nine, but not a hundred. But that is OK. Circularity. But there's one other thing with the goal. For example, if you say circularity is that we reuse or recycle all the materials that we have. That's nice. But even though the economy grows in the construction sector, it's still by far not enough. For example, in the Netherlands, if you would reduce or recycle all the demolition materials, it would cover only 40 percent of the new construction. Globally, if you include China and India, other countries, then that number will be even much more dramatic. So, then you can say, oh yeah, we are 100 percent circular, but that covers only 5 percent of your ecological impact and your use of resources. So that's very problematic, I think with the political definitions that are here in the Netherlands and in Europe because they feel good. It's like, oh yeah. You know, we do 100 percent circular. So, we still haven't covered the real problem that the economy and its production and consumption habit that also includes buildings is growing amazingly fast as the global population grows. So just keeping things loop in the loop in circle is not going to do it. That's covers only a little part of what we produce. So, you must be careful which definition you use. Otherwise, you can have a very feel delightful story. And it sounds great, but it's not actually great.

On a side note, for example the steel industry in the Netherlands states that they recycle almost all the steel or aluminium industry states that they recycle 95 percent of the aluminium which is nice. But on a global scale this recycling of aluminium maybe only 5 percent of all the aluminium that's been used. So, you must be careful while looking at the definition. And that's why I like this definition as it's gives you no escape there. It's extremely strict.

Q3. With such different approaches to circularity, how do you think it can be achieved on a global scale? Where can we start?

Circularity Expert [00:09:27]: The only way you can keep growing economy is to grow bio-based materials that are renewable. So, if you plant a few billion trees on earth, for example, they have a lot of timber to work with and to build your cities in India and China and everywhere else. And if you do that at the rate that earth can regenerate. Let say you have a tree with 30 years' time of lifespan, you cut it and then after that time you need a new tree. So, there is a number of trees you can use per year, per square meter or whatever.

So, the only way humans can keep growing the production and consumption is by replacing the non-renewables by renewables. And non-renewables like the metals that we already used we should circulate them. I mean, I'm totally for that, but there's just not enough. We should also move to renewable alternatives resources now.

Q4. You are of the opinion that not all renewable is truly renewable. What do you mean by that?

Circularity Expert [00:10:49]: I did not mean renewable sources. I was talking about renewable energy. It relies heavily on materials that are not renewable. So, for example, smart grids have a lot of metal such as copper. Copper has the highest footprint of all common materials per kilogram. So that's not so good. Also, there are metals in photovoltaic technology or batteries in a windmill that use a lot of rare earth metal. So, the recycling and reuse and reduction and switching to renewables in aspects of the materials that are used for the renewable energy is not solved yet. Though energy itself is renewable. The sun is shining, but we always need the technology as an intermediate factor to use energy. And the technology is not yet renewable. In my lecture as I said that the energy is renewable but the materials that we use for the energy are not renewable.

Q5. With this aspect in mind and the definition by (Huesemann & Huesemann, 2011) **, how do you think we can make circular economy work?**

Circularity Expert [00:12:49]: First, I think that the economy is being redefined and reinvented as we speak because, for example, at this point, we don't pay the actual price of things. So, we don't pay the actual costs. It's not happening now but if we would wait five or 10 years and we'll see that it includes earth, environmental and social costs, at least environmental ecological goals. Then we also start to redefine what is progress and what is growth. Earlier it was just financial transactions of growth that is gross domestic product (GDP). And now you see genuine progress in the indicator, for example, it also includes the damage and the cost and there are some other factors. So, you get a more realistic idea of what is growth or progress and value creation. And I think also an important and essential notion is the Doughnut economy by Kate Raworth. She has very clearly defined a ceiling in her book that I recommend. She is clearly defining a ceiling - ecological boundaries. She says that do not cross the maximum ecological boundary. And at the same time, she's also concerned about the social minimum. I'm speaking, just talking about ecology. If you want to add another layer to that, you could also talk about the social minimum values for human beings. That's particularly important as a notion of thinking about the economy. So that's unique to these types of models to see and to reshape our thinking.

But as a last note, I think I mentioned also during the lecture something like steady state economy or degrowth economy where economy is shrinking. And that is where I'm worried. Because so far, I mean, we could say that in Europe and the US, we're sort of done growing, we are developed so to speak. In China, India, Nigeria, and other places, there is a huge growth potential, but it all takes lots of resources and energy. And the energy comes from fossil fuels. That's not so good. And it also takes just simply a lot of resources. And, it is not renewable. So, we have already now, depending on your method of calculation, it's been said that we use now already two or three and some say five or six earths in 2019. And then if we say, yeah, in 2050 we expect two billion people more or 3 billion people more and we expect especially India, China, Nigeria and others. to also start consuming and producing at much higher levels and flying around the globe et cetera, then I'm seriously worried about that. So, the last notion is about the economy that if we already use several earths and we're going to grow even more. Then how are we going to do that? And I have no answer to that. The simple answer would be that we must shrink the global economy by factor 3 or so, but I don't see that happening. And this is not something that's not what humankind is prepared to do, at least at this point. So, at some point you get a clash there. And the immense risk is, of course, that this clash results in the total depletion of natural resources and only then there are hard boundaries. And we start feeling the boundaries and we can move further, but we hope that we stop before that. So, these notions about the boundaries it's really worrying me a lot now.

Q6. With introduction of models such as Doughnut Economics, steady state economics or degrowth economy, there are notions that population growth will increase, and resource consumption will increase. There are also some studies that state that the world's population is projected to nearly stop growing by the end of the century (Cilluffo & Ruiz, 2019; Hawks et al., 2000; Max Roser et al., 2013)***. There are different models based on different nations. For a circular economy model, given these different parameters and notions, what do you think is the least that one can do in terms of defining a circular economy, at least specific to the construction industries?***

Circularity Expert [00:18:47]: If we look at the global picture, there are policies that comes into play. I mean, for example, in the Paris agreements for carbon emissions, it was agreed that growing developing countries like China, India, Nigeria etc. did have the right to emit more than the Western countries could because of this difference in history and situation. And for resources, that is complicated. I think in the end it based on the economic condition. The thing is that I don't have a concluding answer there. But, yeah, if you just look at the global picture, you can be noticeably clear about this global warming issue. One can say that although whoever did it, we as humankind, we emit too much. And then one can start arguing about who should do less in first place. And that is going to be politics. And that's a power play and all that. It's becomes very humans' slippery slope in a way.

To define it locally, you can have so many opinions about deaths and so many views, and so that's why it's politics. It's essentially a fight between arguments and power. And that's it. It doesn't get more scientific than that's, I think. But of course, you can have good arguments to start with.

Then for construction, let's talk about construction. Well, for example, you could say that in Asia, the fast-growing economies, ecologically speaking, it's a disaster. But who we are here in Europe and in America to say to India or China that they cannot grow anymore? That is the uneasiness of the problem. There's not sort of one science that's going to solve that for you. That's just reality. And we can try to make the development of India and China at least less damaging and help there. We can help there by sharing knowledge of what we have learnt so far. You may hope that, for example, all those huge cities that are being constructed there are at least done and constructed in a sustainable fashion with a minimum ecological footprint. I really, really hope that and I'm not so sure that that's the case. That would really help because ninety five more percent of the global construction happens in those countries. So, if we in the Netherlands have started to phase out, that's all nice but we are a tiny country. Netherlands is not relevant at all in terms of size and scale. But it really, really matters if all those huge urban developments' there are done in an effective way with minimal footprint and with a good lifespan. And I believe that they know that too. And I am speaking in terms of energy, material resources and emissions cetera. So that would help very, very much. Furthermore, we should really discuss population growth predictions. You said it's going to decline. I am still assuming that it's going to increase. But who really knows as its future prediction? But yeah, one can argue about that. But I think it would be particularly good if we have smaller families, etc (where the per person carbon footprint is high). That would really help.

And I think we should go bio based essentially. So, it would really help to have a plan for planet Earth to use the surface for maximum productivity of bio-based materials resources and have a plan for that. Then try to stick within those boundaries. But I'm afraid that reality is going to be more complicated.
Q7. What trends do you see in reusing construction materials or as stated in your answer biobased material as such in the industry at this moment?

Circularity Expert [00:23:54]: Well, I think I'm not against using some steel, for example, and some metals but we should be very selective in where we used to measure it. You really need them there. You should use them and should be able to use them that this should be fine. But to construct entire buildings out of lots of steel, that isn't helpful. I mentioned biomass-based, but concrete is not actually that bad either. The Smart Crusher, for example, which is really a smart innovation to recycle concrete, not just crushing it to make granulates, but dissecting the three basic components. So, you really get sand, gravel, and cement at the end. And yet you can really use them 100 percent in the new circular fashion, so those innovations are very welcome. But concrete is also not so bad. It's mostly steel. You need concrete if you need a basement or a foundation.

On top of that, you could really start using more timber if we produce more timber. So, it's not that we should just cut down our forests, but we should replant them on that same rate. And things like Amazon forest and others should be off guard. Well, for example, you see a trend in cross laminated timber and other materials (that I present in my lectures), for example, for straw, bamboo, reed, loam, flax, hempcrete, cardboard and mycelium. There are several more but when you're designing buildings well, those materials can be used very well. So, there are many technical people who think, that they may rot, make the building vulnerable and prone to fire. There are a lot of prejudices. But if your design is right with the correct detailing technically then you can make perfectly fine buildings with vital waste material. So yeah, I think we should just start with that.

The trend is to make everything demountable. For concrete that has been an issue. But with the smart crusher now, that could start happening in a responsible way. I would prefer that everything is assembled and then disassembled at the end of life. And in my lectures I show an example of how brick work, for example, can be used separately. So, you don't always need to cement to bind all together. So, then also you can take everything apart. Well, steel and aluminium they are already being regained and recycled to a significant extent. But again, it doesn't by far cover the demand for materials. And re-enforcements in concrete is something I think could use an innovation. Now you can take them out of concrete. So, I think that would be nice if you find technical innovations.

So that could be an option. But for existing buildings, those are your options, I think, and then I think, yeah. Again, the smart crushers deserve real credit for being a real good idea for all those buildings that were not designed for disassembly and use concrete from them.

Q8. In buildings or dwellings that are older and need renovation and reconstruction, we have gas furnaces for heating purposes which can be now replaced by heat pumps, if the owner wishes to, how do you think these old furnaces can be used again? Or is there any other innovation that is happening which is concerned with heating establishments?

Circularity Expert [00:29:51]: Hydrogen is being speculated to be used as a new gas that you could use in those same old furnaces in your house. That is being speculated as a candidate. But yeah, if you replace them by heat pumps there is another crucial point that I talk about in the lecture. It is about metals used in energy technology, but also in the heating system for your building ventilation. There's a lot of metals used in ventilation systems, the heating systems, cooling systems, electricity transmission. And the metals for energy and comfort do make up 50 to 60 percent of the size of the footprint in the Netherlands of our buildings. And so, it's a crucial factor. I guess gas furnaces for the houses that being replaces by heat pumps. You should try to be smart about it. I mean you have millions of gas heaters. So, if you're smart about it you could try to recycle those metals in an organized manner.
In my lectures, I also talk about these in terms of operational energy. Buildings that are poorly insulated use a lot of energy. So that is a big issue. It's not so hard to convert one old building into a new building. The technology is there. In the Netherlands, we know how to do it. And so, the problem is that in the Netherlands alone, we have millions of those houses. And we have hardly the labour force to do such replacement or the time to do it. We're a rich country, but we're not willing to spend that much money on this. And we should be fast. So, the question in such case with regards to operational energy, how to get the results as soon as possible for as little money as possible.

Q9. A follow up question is that all that you have stated before is using the furnaces for the same purpose that is heating. How can we transform these components, for example, gas furnaces, to use them for a different purpose or modernize them?

Circularity Expert [00:33:36]: That's an interesting idea. We're not really used to that. So, then the option is to dismantle them and put them in a furnace and the recycled steel or aluminium or whatever you have. And it would be an interesting new line of thinking to see if those old heaters could be transformed instead of completely recycled. You must really manufacture that to a new model. Yeah. So, you must transform the heater into a heat pump. Well, that's a very inspiring idea. I have no idea if that's possible at all, but the idea is very inspiring.
Also, I notice, not so much in construction industry, but in the other industries. For example, rather than replacing the cars like electric cars and self-driving cars, we can just transform old cars into those modern technologies to save some embodied energy. I think it's a remarkably interesting idea. And I don't have examples of heaters being transformed into ribbons, but I'd love to see this happening that it would be brilliant.

Q10. How does the trading of building material take place in the construction industry?

Circularity Expert [00:36:17]: Small scale construction demolition waste can still be disposed away. But for big projects under professional companies that is not the case. So, they bring their concrete rubble to a recycling sites for concrete and they bring their goods to recycling or use sites in some cases for their wood. And, they have their partners to take away certain materials and that goes into a new loop.

Q11. Are there platforms for these big companies all over the Netherlands to trade building materials among each other?

Circularity Expert [00:38:12]: I think it's limited. So, I don't have enough information about that to answer about it. You have these sites, for example, gebruiktebouwmaterialen, that I think even that belongs to one of the bigger contracting companies. So that's their outlet for used materials for re-use. There is a platform Harvest map by Superstudios. But that's not really restricted to the construction industry. That's globally. I mean, for all industries. But I don't have enough information to give you better answer.

Q12. As an architect, do you also investigate materials that you can reuse on your projects?

***Circularity Expert [00:39:35]**:* I mean it has been a while since I was an architect and I had private clients for small to medium projects and then it was not an issue at all. So, it wasn't even a discussion topic to look for used materials or recycled materials especially for the type of clients that I had. It was ten years ago. So, at that point, circularity was not even a word yet. And sustainability was a discussion topic. Nobody really cared about. Yeah. So, no, it was not an issue at all.

Q13. What about the present-day architects or students who have graduated and working in the industry? Do you have an idea if they do such investigations?

***Circularity Expert [00:40:43]**:* For example, super studio, they are a company that does this. So, they look for sources of materials using this harvest map that they have made. Gebruikbouwmaterialen also investigates materials from contractors, other industries, even interior designers, architects, regular waste flows for municipal dumps. There's sort of a list there. And I know that they just look around and they search around in the region. Certainly, when they started to do this, it was manual labour and it was not automated. So, the trading platform could be helpful for that when it becomes a standard practice. And what they did, they developed also an app called as Cyclifier. But that is applied and agreed upon in a certain region and by the industry to use that. So, then the older industrial companies in certain city or region, they agree to use that. And then you have the database. And that is not just about construction industry. So, you must agree upon something to doing something. But I think in their first projects, I know that it was manual labour and they were just calling people if those people know where they can get wood or steel. Also, we need a standardized database for buildings with digital archives of all the construction material. With new buildings, it is possible using BIM but with older buildings it is more difficult.

Q14. What is your opinion on procurement approaches in construction industry transitioning to a circular economy?

***Circularity Expert [00:47:36]**:* You could just give a percentage in procurement. You could just say, I want this percentage of reused or recycled and this percentage of bio waste sourced, something like that. So, for the client, it could be basic. I think the end's how to get to those percentages is the responsibility of the architects and structural engineer and the contractor, et cetera. And they would like to have a database, for example, to get access to the passports. And the numbers and the prices, etc., and I think, for example, structure engineer will want to know also particularly the quality of material e.g. steel. It can be the type of steel, it’s strengths. It can also be quality of concrete or wood. I think particularly for structure engineers, it's a technical issue of guarantees. And so, they must guarantee that the building stands right. So, they must be able to trust the technical quality of the second-hand reused materials while doing procurement. This shouldn't be the concern of the client, it should be the concern of the design, engineering team, and building construction team to make it really happen and how they do that.

Q15. How does procurement work if we talk about building materials being used as a service?
***Circularity Expert [00:49:38]**:* Products as a service works very well for, for example, lights up so you can use an amount of lux of lights. Philips has this deal called “pay per lux”. Your pay per lux and they remain the owner of the armature of the lighting and they replace it and do maintenance. So that could work well as this is a short cycle product. So, in a few years’ time, this outdated framework will be replaced and reused, recycled, etc. But a building stays there for 50, 100, 200 years. So, the end of life is very insecure. You get a sort of a renting mechanism. So, you can rent a building. But we like to own our space as it can be for our retirement. But as a business model renting is completely different than “pay per service.”

Another product that can be an interesting candidate is steel. Let's say we have a steel frame from Tata Steel, and they may stay owner of that steel forever. Then it's a very weird deal because you have a contract until eternity, and you have a lease. What happens if Tata steel does not exist 20 years or building does not exist due to some unforeseen event in the future. So, the long term is a problem. You get the infinity clause. It's a problem for staying owner of something. Phillips can do that with these lights because you know, they have a short life spans and its minimal risk.

***Circularity Expert [00:49:38]**:* For the previous example for steel, another way of thinking is benefit of ownership for TATA. For example, I could just use building and in 70 years, I can just look for a party and put it on a trading platform. And I say, I have this amount of steel and these qualities and these profiles and who wants to buy it? And it's just for the highest bidder. So, what is the benefit of having just one owner rights? You can also just trade at that point when it's needed and not trade ownership as such.

***Circularity Expert [00:55:26]**:* So, what is also the benefit of that ownership? And for these small products. Thomas Rau had the deal with Philips and said that I don't to the owner of these materials and in this way it forces the building Operation and Mantainence to be efficient in the energy used and the model that they proposed to me for the lighting can generate benefits. And if you translate the example of lighting to the whole building you could say that you want the efficient solution for the building with the energy price included in my deal, then I have the benefits. Maybe because the one that designed the building and owns the building has an interest in making efficient use of energy because it's included in the deal. So that would be the parallel with the lighting model. Those are some form of integrated contracts that have the design, build, finance, maintain, operates, and deconstruction clauses in the contract. That is actually that sort of parallel to the pay per lux model maybe because then you as a design team and as a construction team, you have an interest in making building energy efficient and maintenance and low maintenance and having a good end of life scenario for dismantling. I'm thinking aloud because I don't have to answer prefabricated for your question, but I think that would be a parallel deal. Then you must integrate such deal with the owner of the building. Otherwise, it's going to cost them.

Q16. How do you think quality of a material up for reuse assessed or perceived as such?

***Circularity Expert [00:58:09]**:* “Assessed” or “perceived” are two different things. One is science and the other is psychology. That's why you have the field research. So, you have concrete, for example, old concrete that is in all those millions of buildings that you already have and it's not in a BIM model. With some magnetic device you can locate the reinforcement. And sometimes you need to make a small cut at some strategic place to really decide the diameter of the reinforcement. But then still, there's also different qualities of concrete and different qualities of steel, and that is not so easy to decide. You always must do advanced tests there. So, field labs are interesting to say the least to determine the quality of the products that we find. There can be different type of strength, proportions of steel, and stiffness.

When you have wood, you also want to figure out what type of wood is, which type of tree is this that we're dealing with? You want to figure out something about moisture or humidity or fungus or if it is not damaged.

And I know from Super use studio, for example, that they use sort of a safety factor. So, they just add it. They add a bit more material than they would normally do with new products, because there is no certification there. But that's an interesting issue. We have new products, you get a certificate, you get a guarantee. It's tested in a lab, and you know exactly what you're dealing with. With existing products, that is not the case always. So, you must be able to measure it and assess it.

Perception is a different thing. But that is related to this. I mean, once the numbers are reliable perception is also safe. People start trusting it. But yeah, when you create a building with used materials, and it collapses, then you have a big image problem. And For example, in a bridge you have metal fatigue. So, it can collapse after some time. And those things are what you want to know about the quality of this metal and what's its remaining strength or remaining quality. So, after use, the quality can decrease, and then what is the what's the remaining quality? And that's something you would want to have in the passports also. And that's technically actually one of the bigger challenges to find effective ways to assess the quality of materials.. And, if the building is deconstructed or demolished in a not too cautious way, it also gets hidden damage, somewhere and especially the hidden damage is tricky. Or if you have glass panels, and they're not vacuum anymore, that is an example too.

I think we do, theoretically have the ways of assessing it, but it's not a widespread practice yet. So, we need to have companies, new businesses that do that and provide that service. On a sort of standards, it should be a standard operation. Yeah. So, you demolish a building, you determine what is what? And yeah, it's truly relevant for a material database.

So, the prices of second-hand materials and products in construction, also, they're exceptionally low. So, it's not so interesting to sell them and to try to retain them. And, if there's a technical label, and the material has been tested and you can give a guarantee that this is a useful product, then the price can be higher. So that would be especially important also, economically.

8.3 Interview: Bob van Bronkhorst, Aveco de Bondt

This is an abridged excerpt of the Interview with Bob van Bronkhorst, advisor and project manager in Aveco de Bondt, about the transition to a circular economy in the construction industry on 24 December 2019 with some parts removed for information protection and privacy.

Q1. In the context of the construction industry, how can you define circularity and sustainability?
Bob: So, circularity is much better defined than sustainability. Circularity means that you reuse something or close the loop of the lifecycle of a product or a commodity. And sustainability is somewhat harder to define. What I understand by sustainability is making sure that the impact of the product and materials, you are building on the environment is as minimal as possible. They should have a minimal impact on the environment. So, this could be very specific in nature for the phone, but it could also be complex while making a building which will last several generations because it won't become a nuisance for the area. So, all buildings which are ugly from a design point of view and have

inferior materials, poor quality and which will have to be demolished in my opinion, are not sustainable. So that is my short opinion on my understanding of what sustainable is.
So circularity, in my opinion, is that it is more based on re-use. Circularity is more oriented on physical objects. Sustainability could also be abstract things. Such as the opinion of neighbors or some social and aesthetical qualities. These could also be incorporated in terms to describe sustainability. But these are in my opinion not the necessary for circularity. So, circularity is more the physical part of sustainability.

Q2. How does Aveco De Bondt as an organization approach sustainability and circularity in the construction industry?
Bob: This is kind of hard to answer because we are services companies, so we deliver services needed by our clients. But what we do, for example, is we make sure our clients meet the BREEAM certificate that they aspire to obtain. Other things are helping with sustainability strategies or plans for governmental bodies or companies. So, they want to be sustainable but do not know what this entails. So we help in making plans and stuff like that.

Q3. Have you heard the term circular economy?
Bob: Yeah

Q4. What does a circular economy mean to you?
Bob: Well, I think there always has been a circular economy. However, we are now focusing more on improving it. In physics, we say that matter or energy cannot be created or destroyed. So, any process always has input and output. And we are now starting to use the output of our economy better. So, we have better waste management. And I think the goal is to close that loop entirely and have no more use for the word "waste". However, yeah, it's a slow process, so it's a kind of a new term. However, I think it's always been there. Only it's getting more economically feasible now because the population is increasing. Everything is getting scarcer and we now see the impact we have of just dumping everything. So it's becoming more economically feasible. That's why it's now becoming a trending term, but I think it's always been there.

Q5: How can do you define the “traditional” nature of the construction industry?

Bob: That's a good question about how I can define Conservatism. We are used to a business model and this business model we have been using for an exceedingly long time and only shake up the construction industry has had in their business model has been in 2007. I think somewhere around that when there was a big scandal in the Netherlands in the construction industry (bouwfraude). And since then, we had a change of contracts, but not a change of mentality. And because contracts changed and got stricter. The construction industry had to adapt. They adapted by trying to make your own business more, more economically efficient. So they're trying to make the process more cost-efficient to do the same thing they always do in the late stage of an industry. And they are not reaching for innovative solutions. So, they are cost-driven industry, who is trying to cut cost mostly by doing things more efficient and not as much by looking at a more integral, innovative standpoint.

Q6. Does it mean that the industry prefers cost driven approaches to meet their sustainability goals? What is the reason behind this?

Bob: Yeah. However, the approach could be more cost-efficient for everybody while having a more sustainable goal or more circular usage. However, the contract doesn't allow for this. Or the incentive is not properly aligned for the contractor to make it more sustainable. Thus, in the short term, they are cost driven. So eventually, the decisions are made based on cost and these decisions are mostly made from the standpoint of the contractor and limited to the constraints of contract. And that (contract) often doesn't allow for optimisations for the total life cycle. Even if the contract incentivises the optimization of the lifecycle, it is mostly it will limit the horizon of the life cycle to a fraction of the potential. And the decisions made are focused mostly on the construction phase of the building lifecycle.

Q7. As you said that the contracts don't allow the contractors to adopt a more sustainable path or an innovative path. So how is the industry transitioning to a circular model?

Bob: So, the scope of work is limited by what the contract defines. And mostly the contract defines only the construction phase. And sometimes in a DBFM contract, which has become less popular because of the huge risk, and you have somewhat more scope, but mostly the scope in those contracts is also very limited, like a maximum of 30 years, which by the way, is one of the longest contracts I've seen. Mostly something like five or fifteen years. So, the DBFM contracts give them a little bit of lifecycle scope and still the contract doesn't allow for the full scope. And because they don't see the full scope, they're not moving towards the most lifecycle efficient solution.

Q8. After the EU Construction and Demolition Waste Protocol, 90 percent of construction waste is recycled. What is the trend of reusing material in the construction industry?

Bob: Yeah, sure there is. Clients are asking for the reuse of construction materials and thus there is a huge benefit for the way the contracts are handed out. You mostly do a tender and, in a tender, sustainability often is an important thing. And reuse of materials is often required by the client or also declined, to fill in the sustainable admissions the client has. After the contract is closed, everything is locked in. So, there is no more additional reusing of the construction materials added afterwards, which if done could be a huge benefit as soon as the designing starts that you still are able to add sustainable materials.

Q9: How does the trading of construction and demolition waste work in the industry when you're talking about construction? So you procure this concrete, which was obviously used somewhere. So how did you find out about this concrete that it's there and you can use it?

Bob: That's one of the parts that you really must ask the purchase manager to do this. I have no clue how we found it. The company had to go to Norway because as far as I know there is a huge demand at this moment for demolished concrete, and that not all demolished concrete is usable as you also have polluted demolished concrete. Maybe, it can be used for the foundation of a road or something, but not in actual construction for buildings. In case of the purchase manager, it is usually their own network.

Q10. So there's no such platform from where you can procure material for reuse, as was the concrete in your case?

Bob As far as I know, there is no such platform. However, our purchase manager may know about something like that. In my opinion, there is no such thing as a main place which I have come across. It's all network based. And that way that it’s also quite a traditional market. The purchase manager calls somebody, he knows at a company who possesses a certain kind of material and he calls them. If I would be in the role to do it, I would start looking up on the Internet, which industry uses in the neighbourhood, this material and call them. That is as far as I get with this.

Q11. What role do contracts play in enabling a circular ecosystem in the construction industry?

Bob: The contracts we are mostly using in the Netherlands is the UAV-GC. This contract is used for requirement-based design. So, you're free to use the material you want if it's within the requirements. And it depends on how specific the client has been in their contract. Sometimes they are requiring a certain type of materials so that they are saying it should be concrete as it is a concrete bridge. Sometimes they have just function describing their requirements. We want a bridge and it has to be this high and it has to be able to bear this load. But mostly, asset managers from clients had very strict requirements on the type of materials used and its mostly asset managers that determines the outcome of the contract. And therefore, in most contract, there is not a lot of room. However, for example, in case of concrete, it does not matter how or what kind of aggregates you put in or where the steel came from, it's up to specifications and the qualities. You can get it wherever you want. So again, there's a lot of room for using these reuse materials within the contracts. However, there is no incentive for using sustainable materials. Incentives are for the cheapest material used within the specifications. Cheapest inclusive construction time and labor of course.

Q12. How do you plan to work on the demolition phase? Is there a plan to reuse the materials as you own the property?

Bob: The project management organization is very abstract. It is on a city planning level and therefore is mostly driven on that basis. So, they are on a zoning plan level. On zoning plan level, they are making decisions and they have a lot of sustainability goals. They are referred to in the tender I'm not aware of what's in there now. So that, I am not long enough on the project to know what the sustainability ambitions of the project are. I assume that again that it is mostly cost driven, and every sustainability goal will probably be for the final product and not for the reuse of materials in the final product. And that will mostly be based on EPC norms so the energy use of the buildings. As that's what the clients requires. There is a lot of energy requirements and energy use requirements. However, there is not for the energy used for the construction.

Q13. If there was a way where you can estimate the value of this material and sell it then will the project management team focus on reusing materials because it actually is generating some sort of revenue for you by cutting costs and also giving you a way to actually sell it?

Yeah. Indeed, however, awareness and ease of use are the limitations at this moment, for the project management team. However, indeed if you had an effortless way to value the project, it will be able to convince them of the value.

Q14. Do you have BIM models for the old buildings that you're going to demolish?

Bob: No. They're old. So, the municipality of Amsterdam does not have a virtual archive of these. However, it's a real archive. I think there are some documents everywhere. They are like real paper documents not even PDF scan. It's quite well documented and goes back to 1923 as far as I've seen. And these are hand typed on type machine. They contain tables and everything in there. It's quite well documented. However, it's extremely old. So there has not yet been a BIM model and I don't think there will be a BIM model of demolishing part but yeah for a new part there may be.

Q15. So if you get a chance to see the documentation of the materials that they have been using in the buildings or anything like that will that be a way to see and assess the building and conclude on what could be reused?

Bob: Yeah sure you could. However, I know that doesn't happen for reuse purposes (it happens for HSE reasons). So everyday’ s tasks dominate a constant construction project. So, there is not much of the time there for this. There is not somebody who thinks of these exceptional and innovative parts.

Q16. So, you just go ahead and demolish a building and don't think about if we can use something from it?

Bob: Yes, this is how it mostly goes from the developer point of view, maybe through competition between demolishers you'll earn back some of the recoupable value, again not my expertise.

Q17. You have answered one of my questions early on about the quality of reuse material in the construction industry by giving me an example of the concrete that you had procured? Could you also give us your opinion on general trend of assessment of reusable material?
Bob: So, I know for concrete it's an important thing. A lot of concrete gets reused. They have special machines also to clean it if it's a little bit dirty which make it less cost efficient because you must handle it more. But I think, for concrete, the trend is quite clear because concrete is one of the most CO2 intensive building materials. And a lot of projects have some CO2 material calculation for the tenders. So the trend for concrete is quite clear.
However, I do not know about steel. We can use reuse steel on the different level. I guess a good example for that is the main TU building where they reused the steel bars from the floors by rearranging them and reusing them. And that is reuse without melting or giving it another shape. Just, reusing the bar. That is a good thing. Another example is someone I know is also building a house and is also reusing steel bars from older construction projects. So, I think there is definitely a market for art for that. However, it's hard because you must really inspect the material looking for cracks, deformations, and it's quite an intensive process.

Q18. What is the opinion of your company on this issue? Does the company investigate places or organizations which can help you assessing your materials as such?

Bob: As a commercial organization we our client driven. It's more relevant how our clients look at it or the contractors at Volker vessels investigate it. However, I think it will be huge for the purchase manager. It will help them achieve a better result with a more transparent selection or a procurement process. So if you develop a platform or something where you can offer or buy or matchup the used materials, there is a huge market for it. I think it's hugely beneficial for the construction industry.

Q19. So you say if we have a platform which actually gives the purchase managers access to the construction materials that are being used and kind of make it secure and private so that it still stays black box because that's what the business model is like, that would be good.

Do you agree with it?

I agree with your first point. Purchase managers know how to get the right contracts with their suppliers and manage that correctly. If you build a platform, you lose that flexibility of the contract in a part which they have now. However, there is, of course, the other side. Now it's done by the purchase manager and the purchase manager is not an expert on all the fields, but you are able to make it easier for it via the platform where the expert on this field can search for the materials. Then you will have the expert finding new materials for the project. So that's also one of the benefits of opening this black box could do. That's because the purchase manager is not experts in a lot of fields. They are experts in making contracts however they rely on input of experts for the technical details. And if you make it easy and accessible for the experts or the designers, they will be easily involved in this process and it would be beneficial for the construction process.

Q20. So if you are given a platform that is more secure or private and you can deal with reusing your material. Or if you can be provided with the agency which can help you assess your own building and put it on the platform, say for other purchase manages to procure your materials as such. So,

will that be a good way of doing it? And will that help you achieve more circularity and have an assurance of getting some money out of it in the future?

Bob: It also opens a competition. A little bit of competition is good and therefore it will make everything cheaper and whatever is cheaper will eventually be used more so, therefore, it is also good for sustainability goals because it will get economically more feasible to get to the circular economy if the market is more transparent and more centralized and more competitive.

Q21. Do you have any overall conclusion and sense of what the market is as such for reusing materials and how it should be in terms of quality, quantity, and cost?

Bob: First I want to ask you a question. As this is all my opinion and I want to ask before I really restate it. You said, in the beginning, that there are some online platforms already where you can buy reuse materials. Is that correct?

Q22. Yeah, there are online platforms. And that is what Swap Circle (hypothetical platform for the thesis) aims to provide such materials online. We are trying to see if there are other platforms on how they are assessing the materials and if we can help the companies to put their products online. Let's say that you know in 10 years you're going to get a building demolished if there is anybody who wants to buy it. Does this answer your question?

Bob: That's interesting. Also, a future timeline-based deal. This is also a remarkably interesting point and is also stipulated by the team. This is stipulated by the point that the company had to go to Norway to get the concrete because at this moment, we are building a lot of houses in the Netherlands. And therefore, a lot of those houses have a sustainability goal to reuse concrete and there is no reusable concrete available.

The second part is we do not demolish much in the Netherlands. So, there is also not much. So, if you add the planning part to it, so when's what going to be demolished. You can also improve the shipping rates because Norway is not close. We did not get a lot of benefits from the reuse of concrete because we had to ship from Norway. So you are trying to meet a lot of times because you have to put it on the ship, to get it onto shipping, to get to the location and handling is cost inefficient and also caused CO_2 emission. So that's an interesting addition. You just sort of revealed. So, for my conclusion. – "*What do I think of the circular economy in the construction industry for reusing materials?*" It's an underdeveloped market which is kind of a black box from my standpoint so maybe if you spoke to a purchase manager who has a different opinion, and his opinion is more valuable. But in my opinion, it's a black box which could hugely benefit from being open and more transparent. It relies heavily on the network function of the purchase manager. However, because it's a person with a black box it's kind of an obscure market and so it could usually benefit from centralizing and being more transparent which is good. It's the underdeveloped market at this moment because the incentives of the clients are not always formulated correctly in the contracts. So, the contracts are now mostly dictating how sustainable contractor will behave. Mostly because they are cost-driven so they will only opt for more sustainable jobs in the contract that are cost beneficial. The client formulates the sustainability requirements wrong or inefficient in the sense that they over-specify, for example, they'll require you to use concrete often a certain quality which is not necessarily needed for the function they desire but because of lack of expertise, they limit the options. There leaves no more room for the contractor to switch during the design phase to a more sustainable option and a more cost-beneficial option. So, in addition to the transparency of the materials market this is also the second part of the industry which should be opened up / improved. The proper formulation of requirements in the contracts to alleviate restraints on choice of material and place proper contractual incentives for lifecycle design could help to have a better sustainable construction industry.

9. Appendix B: Literature Review Criteria

9.1 Google Scholar

The google scholar is a web search engine that indexes the full text or metadata of academic articles and case laws. It looks like Figure 86.

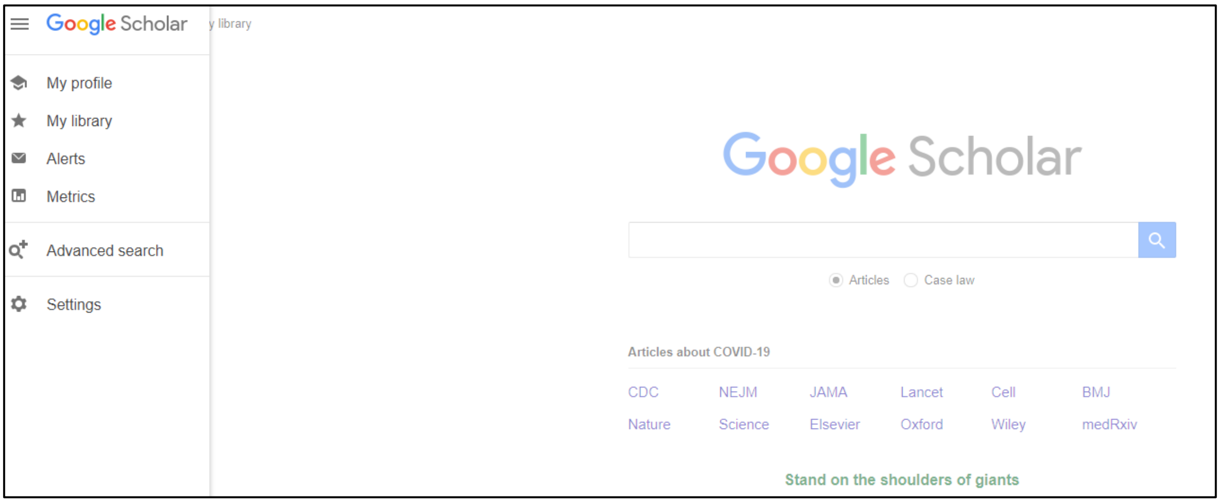


FIGURE 86 GOOGLE SCHOLAR INTERFACE

Based on the research strings shown in the Literature Review for sub research question 1, advanced research was performed as shown Figure 87.

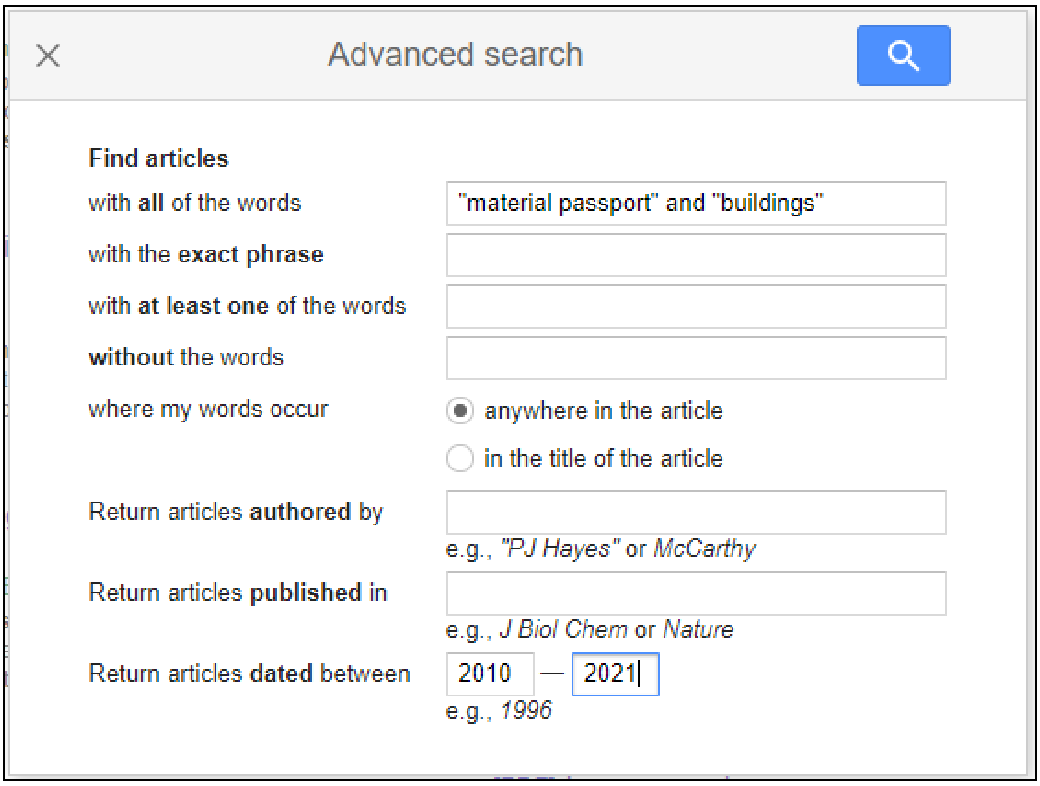


FIGURE 87 GOOGLE SCHOLAR ADVANCED RESEARCH

The following results were generated as shown in Figure 88.

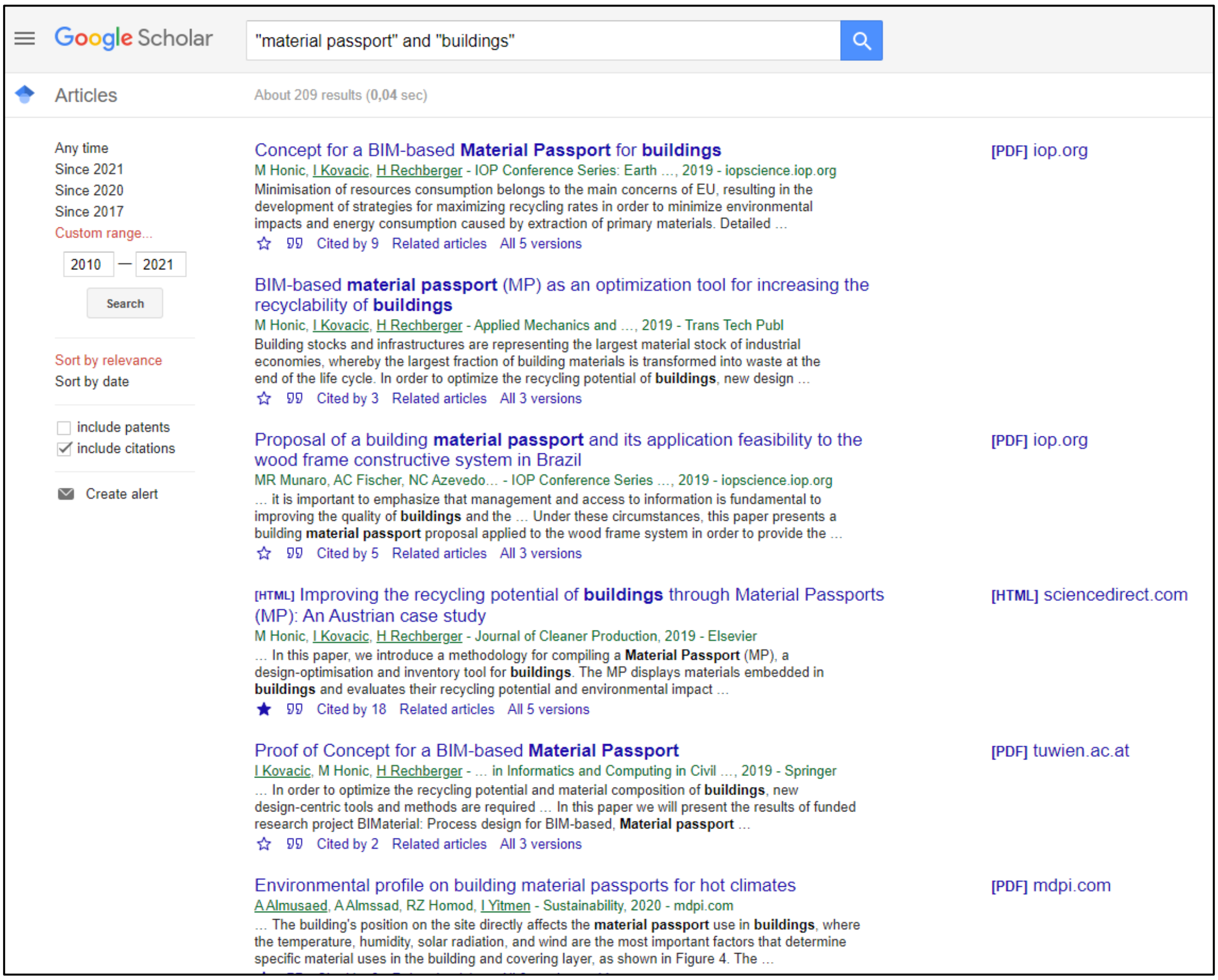


FIGURE 88 GOOGLE SCHOLAR SEARCH RESULTS

To export these results as csv/ bibtex as shown in the literature review methodology and perform further analysis, it was necessary to click on the star mark on each generated result so that it is transported to the My Library section of google scholar where it could be further exported. As this was a time-consuming process, another solution in form of Publish or Perish software by Harzing. com was used. It is free for personal non-profit use.

Figure 89 showcases the interface of the software. Adding keywords from the search strings and verifying years of search and adding maximum number of results generate the same results as generated by google scholar and sorted by relevance.

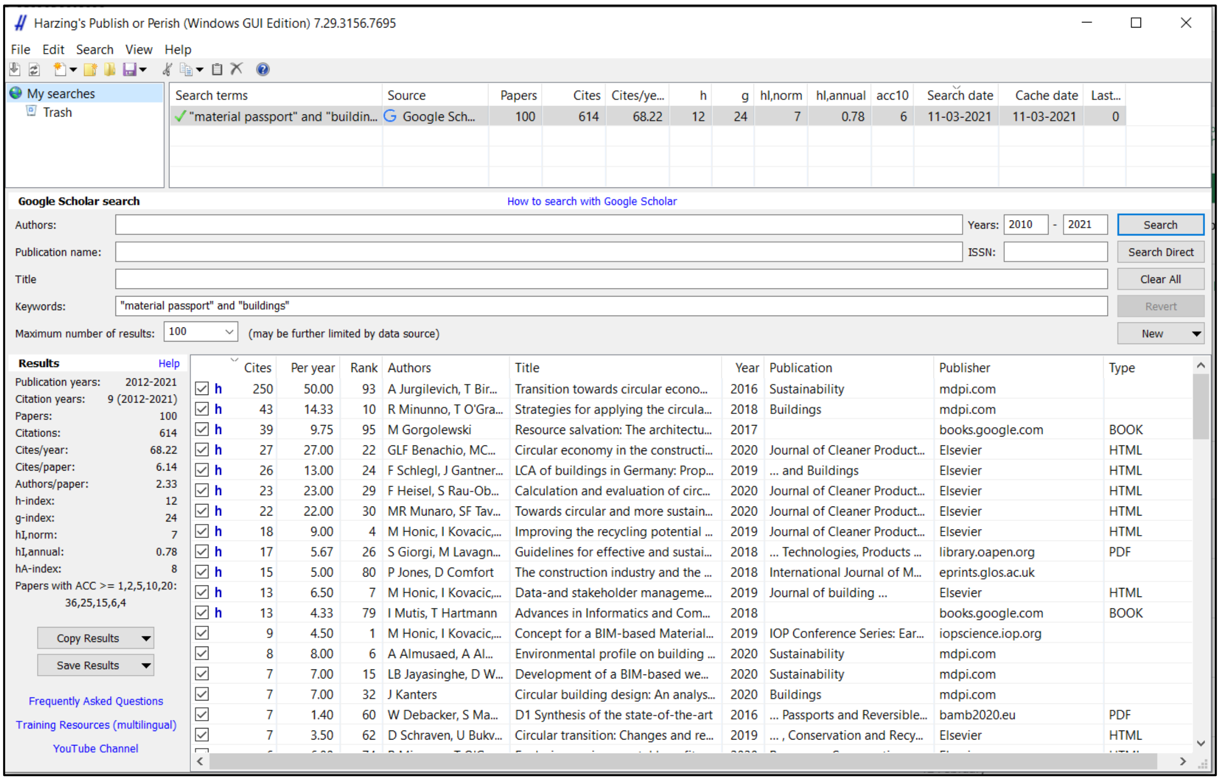
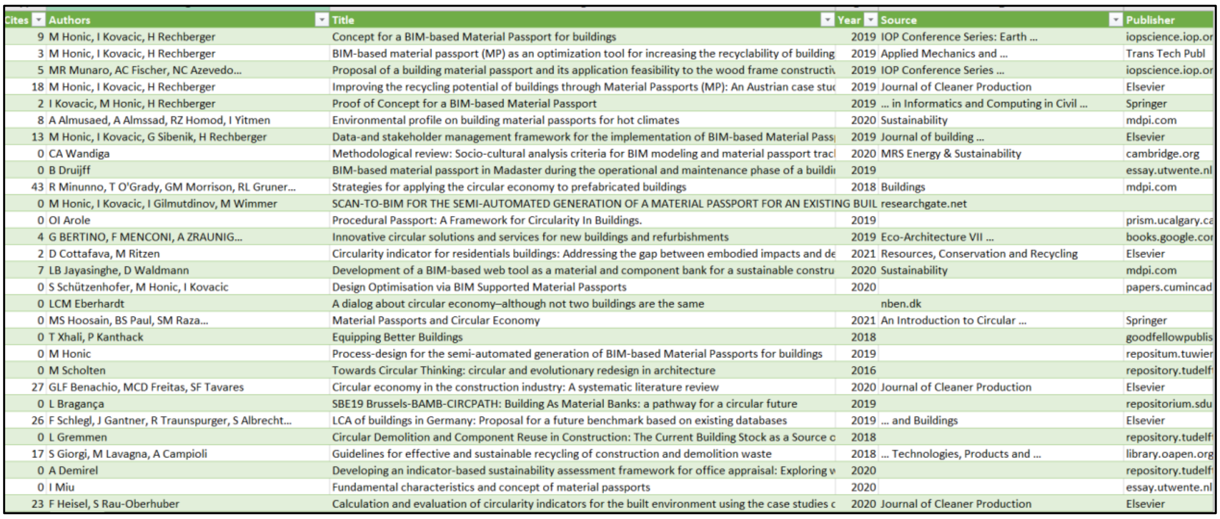


FIGURE 89 POP INTERFACE

The first 100 results are exported as a .csv file and stored to perform further analysis. The csv file is shown in Figure 90.



Cites	Authors	Title	Year	Source	Publisher
9	M Honic, I Kovacic, H Rechberger	Concept for a BIM-based Material Passport for buildings	2019	IOP Conference Series: Earth ...	iopscience.iop.or
3	M Honic, I Kovacic, H Rechberger	BIM-based material passport (MP) as an optimization tool for increasing the recyclability of building	2019	Applied Mechanics and ...	Trans Tech Publ
5	MR Munaro, AC Fischer, NC Azevedo...	Proposal of a building material passport and its application feasibility to the wood frame constructiv	2019	IOP Conference Series ...	iopscience.iop.or
18	M Honic, I Kovacic, H Rechberger	Improving the recycling potential of buildings through Material Passports (MP): An Austrian case stuc	2019	Journal of Cleaner Production	Elsevier
2	I Kovacic, M Honic, H Rechberger	Proof of Concept for a BIM-based Material Passport	2019	... in Informatics and Computing in Civil ...	Springer
8	A Almusaed, A Almssad, RZ Homod, I Yitmen	Environmental profile on building material passports for hot climates	2020	Sustainability	mdpi.com
13	M Honic, I Kovacic, G Sibenik, H Rechberger	Data-and stakeholder management framework for the implementation of BIM-based Material Pass	2019	Journal of building ...	Elsevier
0	CA Wandiga	Methodological review: Socio-cultural analysis criteria for BIM modeling and material passport tracl	2020	MRS Energy & Sustainability	cambridge.org
0	B Druijff	BIM-based material passport in Madaster during the operational and maintenance phase of a buildii	2019		essay.utwente.nl
43	R Minunno, T O'Grady, GM Morrison, RL Gruner...	Strategies for applying the circular economy to prefabricated buildings	2018	Buildings	mdpi.com
0	M Honic, I Kovacic, I Gilmutdinov, M Wimmer	SCAN-TO-BIM FOR THE SEMI-AUTOMATED GENERATION OF A MATERIAL PASSPORT FOR AN EXISTING BUIL		researchgate.net	
0	OI Arole	Procedural Passport: A Framework for Circularity In Buildings.	2019		prism.ucalgary.ca
4	G BERTINO, F MENCONI, A ZRAUNIG...	Innovative circular solutions and services for new buildings and refurbishments	2019	Eco-Architecture VII ...	books.google.cor
2	D Cottafava, M Ritzen	Circularity indicator for residentials buildings: Addressing the gap between embodied impacts and de	2021	Resources, Conservation and Recycling	Elsevier
7	LB Jayasinghe, D Waldmann	Development of a BIM-based web tool as a material and component bank for a sustainable constru	2020	Sustainability	mdpi.com
0	S Schützenhofer, M Honic, I Kovacic	Design Optimisation via BIM Supported Material Passports	2020		papers.cumincad
0	LCM Eberhardt	A dialog about circular economy–although not two buildings are the same		nben.dk	
0	MS Hoosain, BS Paul, SM Raza...	Material Passports and Circular Economy	2021	An Introduction to Circular ...	Springer
0	T Xhali, P Kanthack	Equipping Better Buildings	2018		goodfellowpublis
0	M Honic	Process-design for the semi-automated generation of BIM-based Material Passports for buildings	2019		repositum.tuwier
0	M Scholten	Towards Circular Thinking: circular and evolutionary redesign in architecture	2016		repository.tudelf
27	GLF Benachio, MCD Freitas, SF Tavares	Circular economy in the construction industry: A systematic literature review	2020	Journal of Cleaner Production	Elsevier
0	L Bragança	SBE19 Brussels-BAMB-CIRCPATH: Building As Material Banks: a pathway for a circular future	2019		repositorium.sdu
26	F Schlegl, J Gantner, R Traunspurger, S Albrecht...	LCA of buildings in Germany: Proposal for a future benchmark based on existing databases	2019	... and Buildings	Elsevier
0	L Gremmen	Circular Demolition and Component Reuse in Construction: The Current Building Stock as a Source c	2018		repository.tudelf
17	S Giorgi, M Lavagna, A Campioli	Guidelines for effective and sustainable recycling of construction and demolition waste	2018	... Technologies, Products and ...	library.oapen.org
0	A Demirel	Developing an indicator-based sustainability assessment framework for office appraisal: Exploring w	2020		repository.tudelf
0	I Miu	Fundamental characteristics and concept of material passports	2020		essay.utwente.nl
23	F Heisel, S Rau-Oberhuber	Calculation and evaluation of circularity indicators for the built environment using the case studies c	2020	Journal of Cleaner Production	Elsevier

FIGURE 90 GOOGLE SCHOLAR RESULTS .CSV

9.2 Science Direct

Science direct is a website that provides access to a database of scientific and medical publications of Elsevier. Figure 91 showcase the interface of the database.

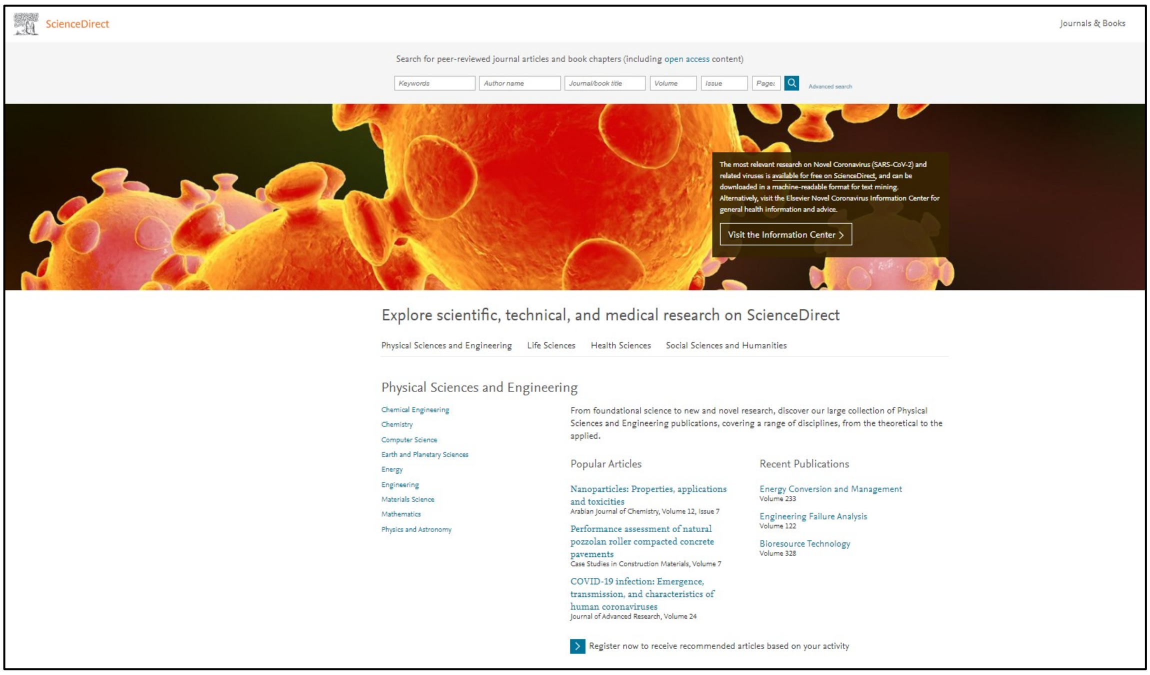


FIGURE 91 SCIENCE DIRECT INTERFACE

Figure 92 showcases the search string in the advanced search feature of the website.

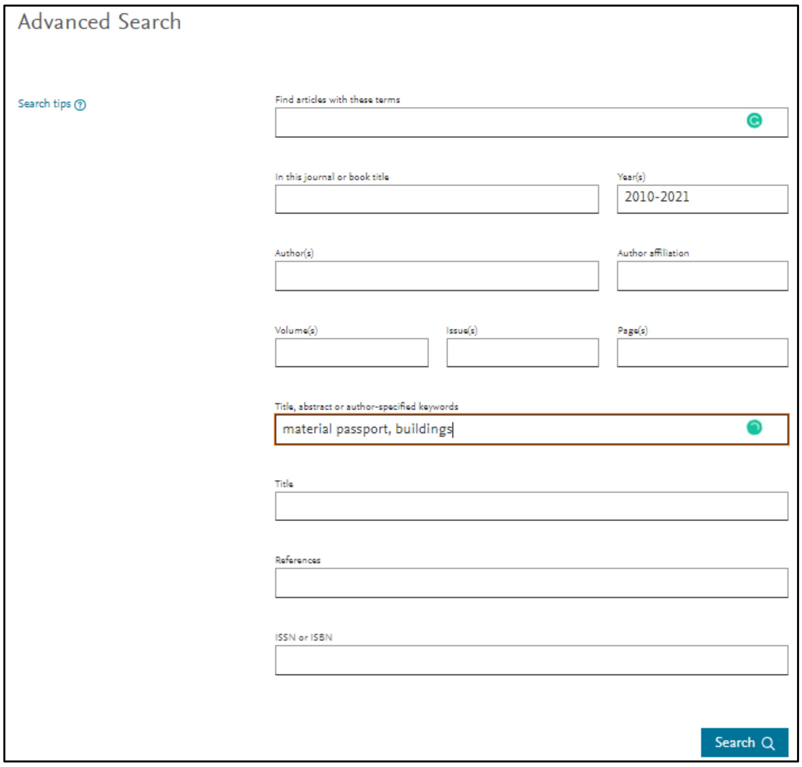


FIGURE 92 SCIENCE DIRECT ADVANCED SEARCH

The results generated as shown in Figure 93 are downloaded as BIB tex file.

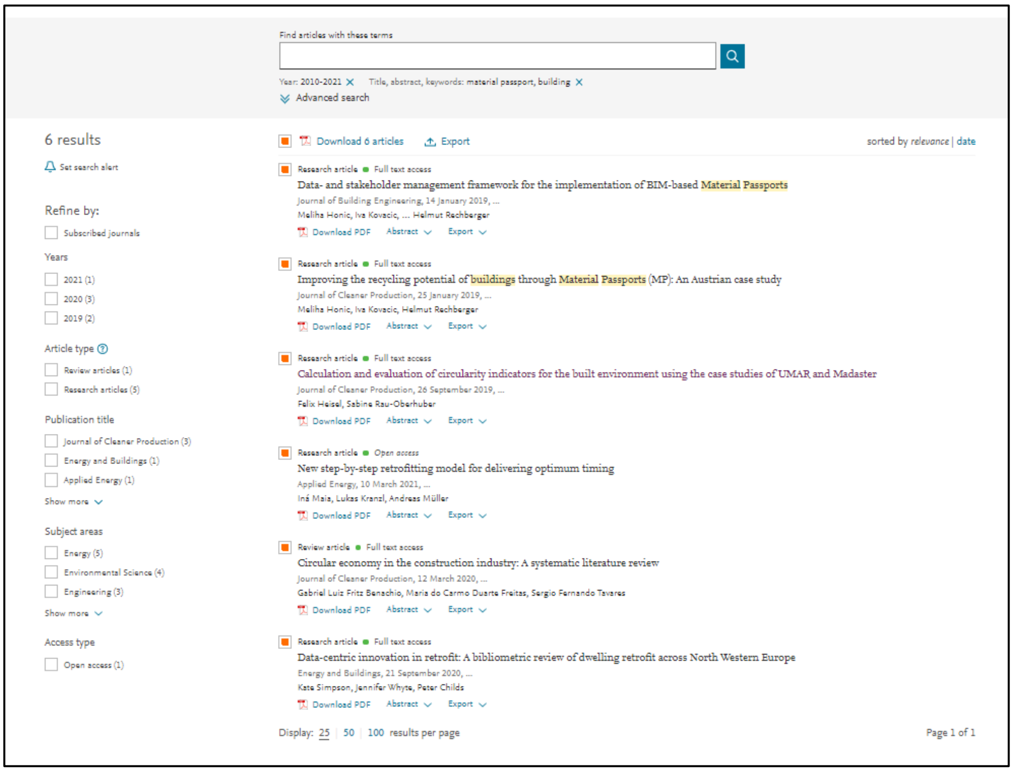


FIGURE 93 SCIENCE DIRECT SEARCH RESULTS

The BibTex file is stored in the folder and is converted to csv using JabRef software which is an open-sourced, cross-platform citation and reference management software. Figure 94 showcases the interface of the software.

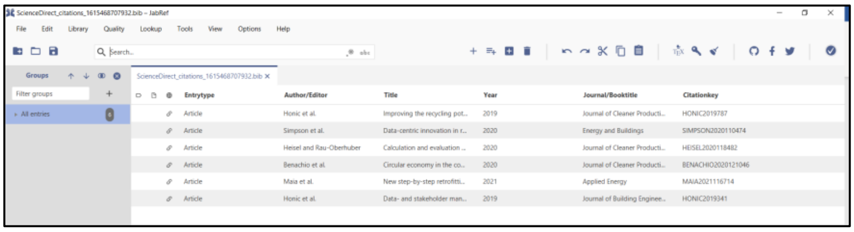


FIGURE 94 JAB REF INTERFACE WITH IMPORTED.BIB FILE

The results are shown as .csv in the Figure 95.

BibliographyType	ISBN	Identifier	Author	Title
7		BENACHIO2020121046	Benachio, Gabriel Luiz Fritz; do Carmo Duarte Freitas, Maria; Tavares, Sergio Fernando	Circular economy in the construction industry: A systematic literature review
7		HEISEL2020118482	Heisel, Felix; Rau-Oberhuber, Sabine	Calculation and evaluation of circularity indicators for the built environment using the case studies c
7		HONIC2019341	Honic, Meliha; Kovacic, Iva; Sibenik, Goran; Rechberger, Helmut	Data- and stakeholder management framework for the implementation of BIM-based Material Pass
7		HONIC2019787	Honic, Meliha; Kovacic, Iva; Rechberger, Helmut	Improving the recycling potential of buildings through Material Passports (MP): An Austrian case stuc
7		MAIA2021116714	Maia, InÃ¡; Kranzl, Lukas; MÃ¼ller, Andreas	New step-by-step retrofitting model for delivering optimum timing
7		SIMPSON2020110474	Simpson, Kate; Whyte, Jennifer; Childs, Peter	Data-centric innovation in retrofit: A bibliometric review of dwelling retrofit across North Western E

FIGURE 95 SCIENCE DIRECT RESULTS .CSV

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10. Appendix C: Survey Design

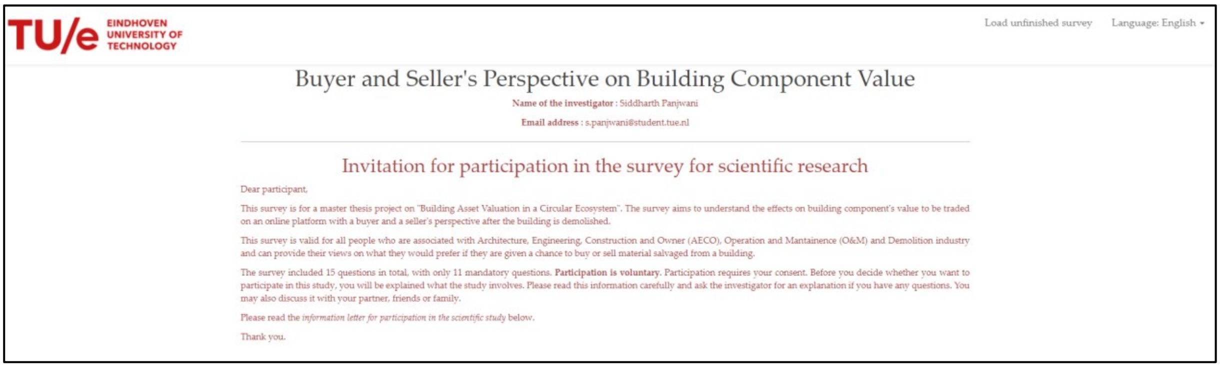


FIGURE 96 SURVEY: WELCOME MESSAGE

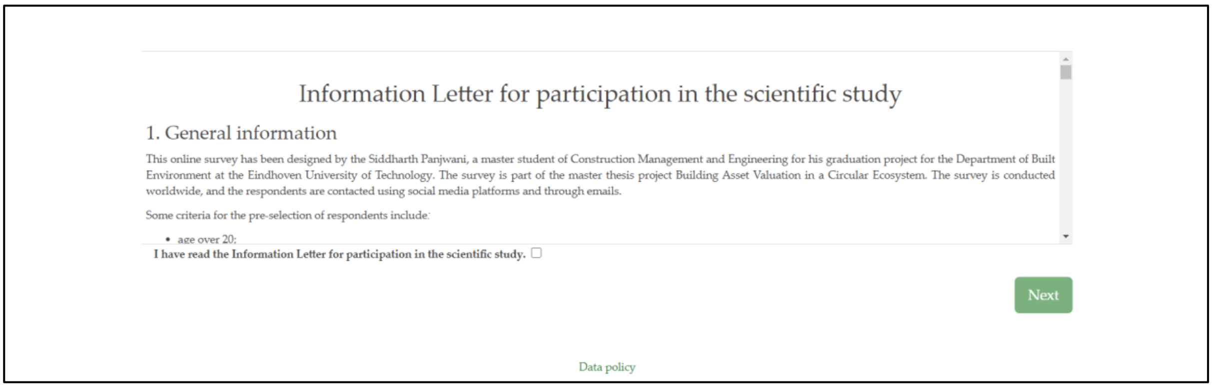


FIGURE 97 SURVEY: TERMS AND CONDITIONS

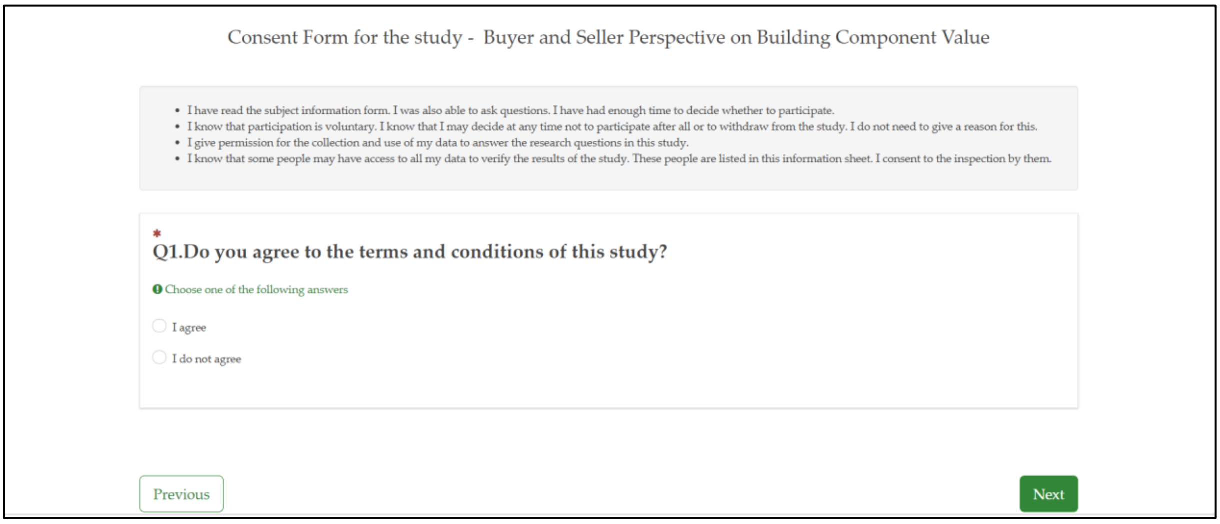


FIGURE 98 SURVEY: QUESTION 1 CONSENT

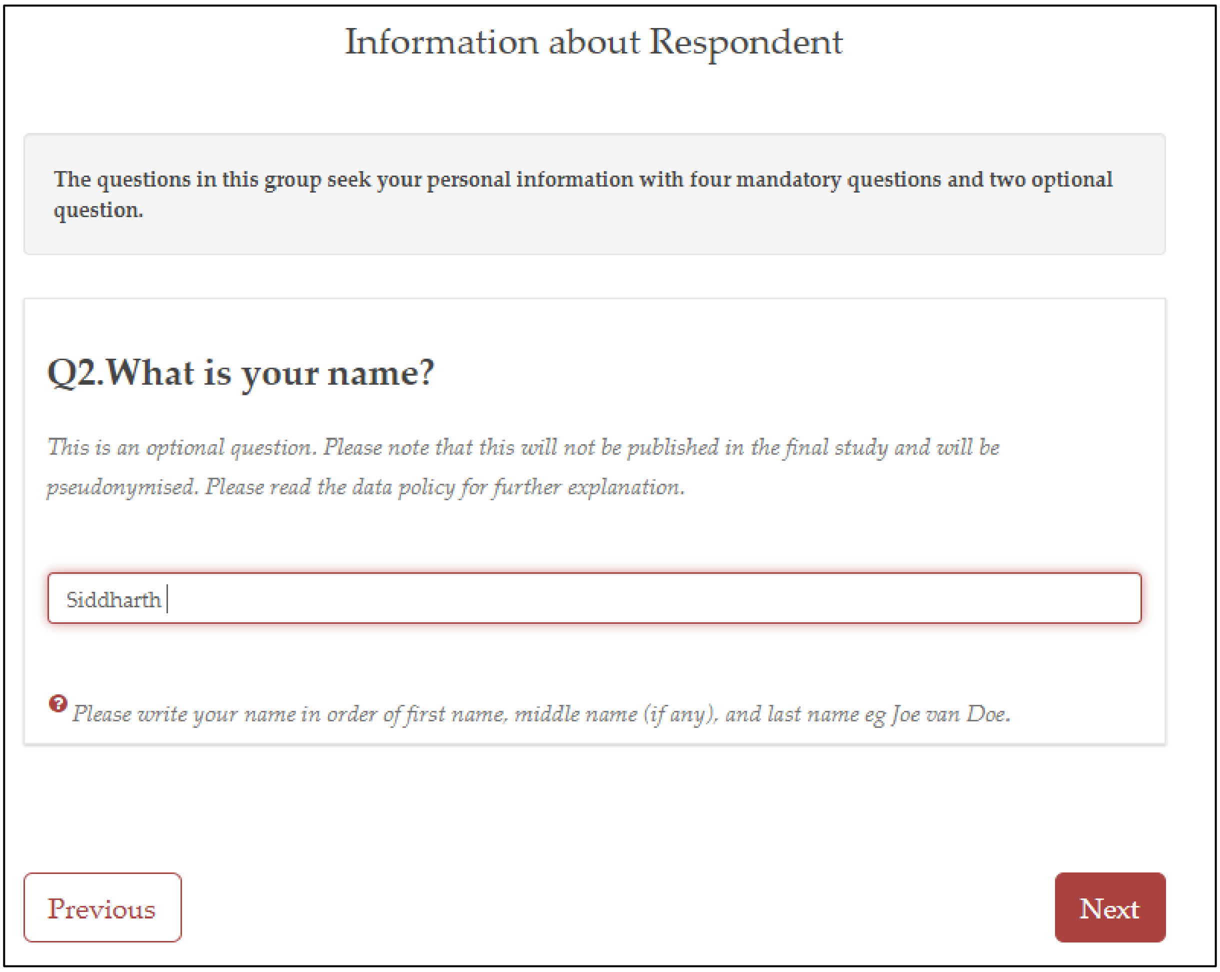


FIGURE 99 SURVEY: QUESTION 2 NAME(OPTIONAL)

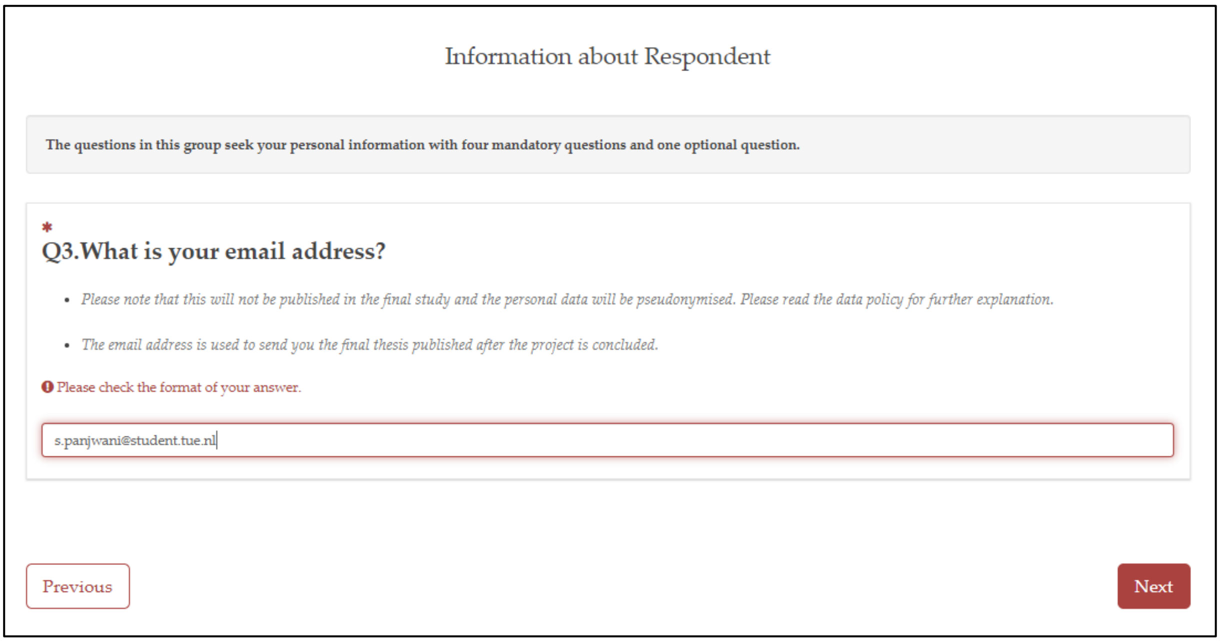
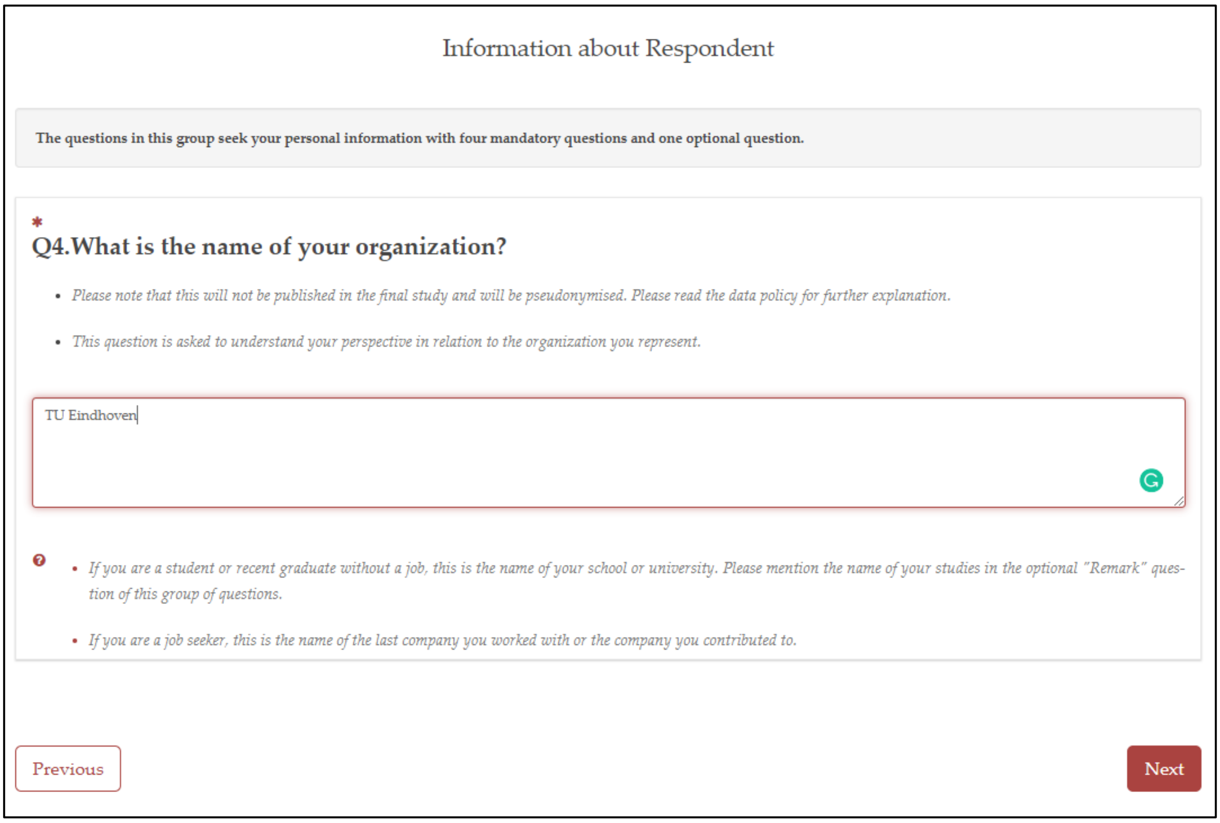


FIGURE 100 SURVEY: QUESTION 3 EMAIL



Information about Respondent

The questions in this group seek your personal information with four mandatory questions and one optional question.

*

Q4.What is the name of your organization?

- *Please note that this will not be published in the final study and will be pseudonymised. Please read the data policy for further explanation.*
- *This question is asked to understand your perspective in relation to the organization you represent.*

TU Eindhoven

- *If you are a student or recent graduate without a job, this is the name of your school or university. Please mention the name of your studies in the optional "Remark" question of this group of questions.*
- *If you are a job seeker, this is the name of the last company you worked with or the company you contributed to.*

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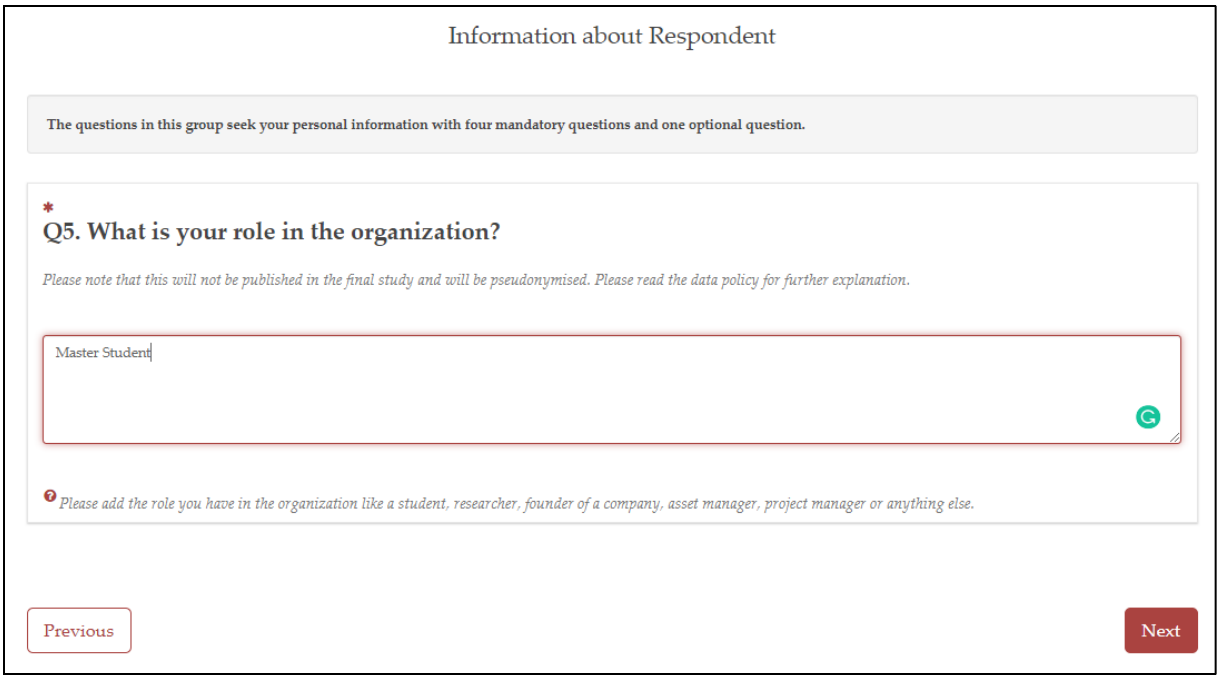
FIGURE 101 SURVEY: QUESTION 4 ORGANIZATION



Information about Respondent

The questions in this group seek your personal information with four mandatory questions and one optional question.

*

Q5. What is your role in the organization?

Please note that this will not be published in the final study and will be pseudonymised. Please read the data policy for further explanation.

Master Student

Please add the role you have in the organization like a student, researcher, founder of a company, asset manager, project manager or anything else.

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FIGURE 102 SURVEY: QUESTION 5 ROLE

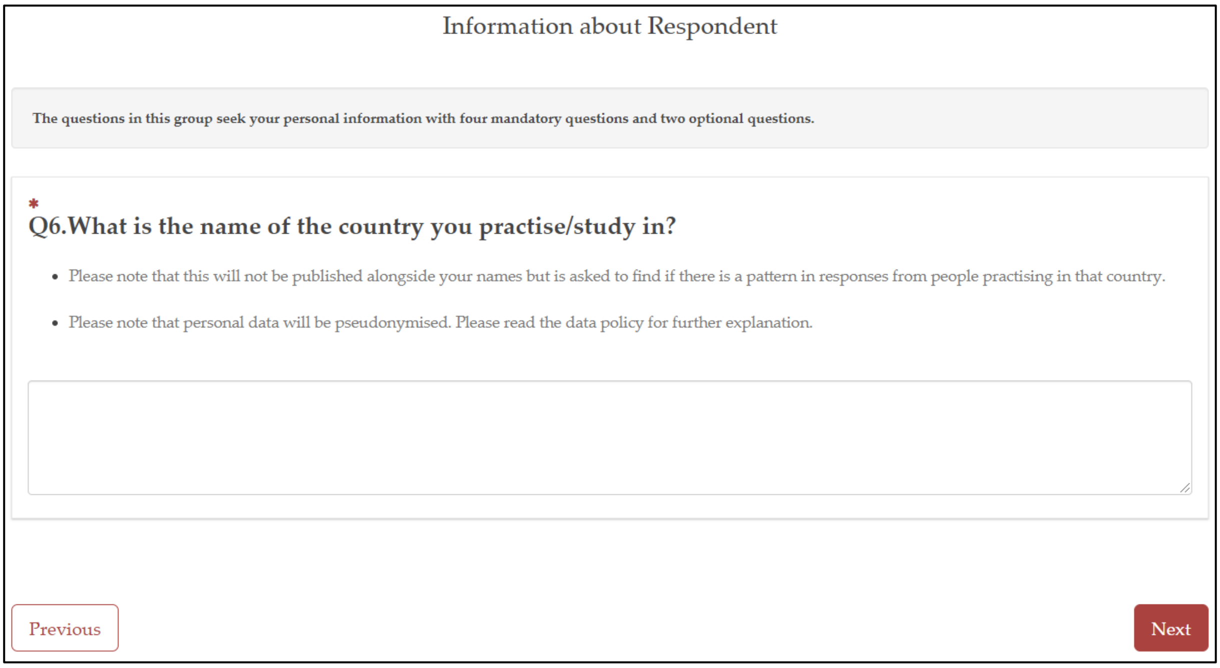

FIGURE 103 SURVEY: QUESTION 6 NAME OF THE COUNTRY

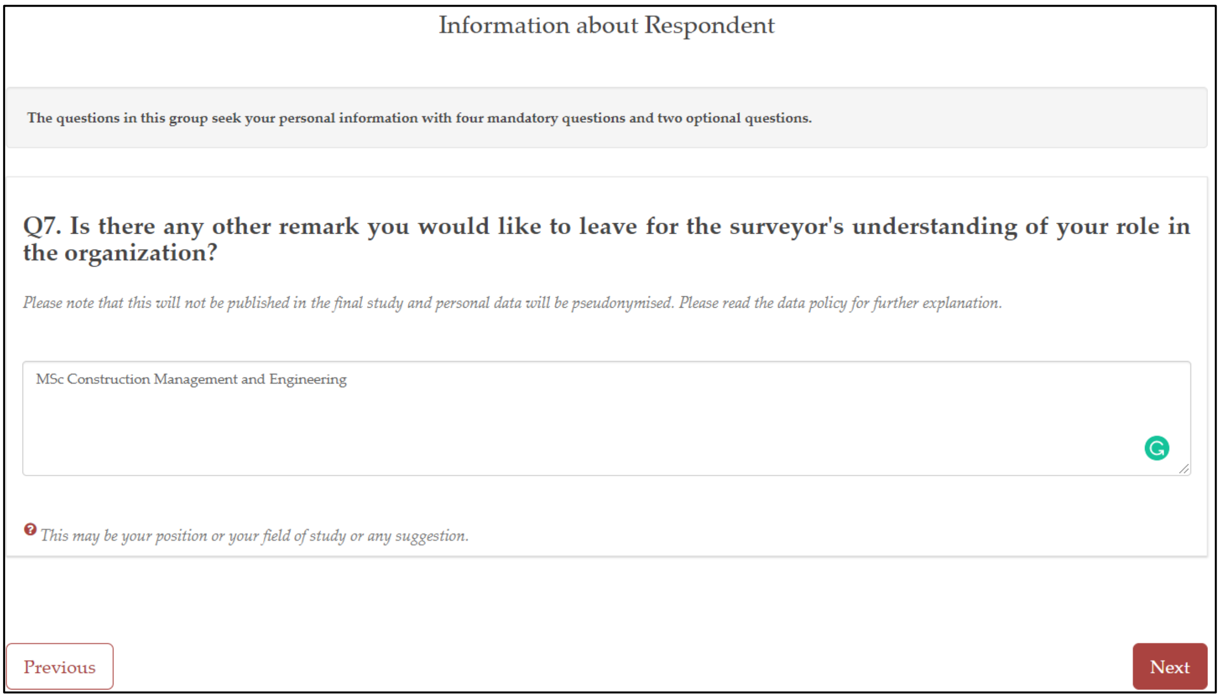

FIGURE 104 SURVEY: QUESTION 7 REMARK

Scenario 1 - Buyer on the platform

- There are two mandatory and one optional question in this section. Please read the description carefully.
- Imagine that you are responsible to procure/buy materials for a construction project for an organization. You came to know that there is an online platform that sells materials from demolished buildings that are processed using one of the 9R Framework strategies.

R Framework Strategies	
R0 REFUSE	Make product redundant by abandoning its function or by offering the same function with a radically different product.
R1 RETHINK	Make product use more intensive e.g., by sharing product.
R2 REDUCE	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials.
R3 REUSE	Reuse by another consumer of discarded product which is still in good condition and fulfil its original function.
R4 REPAIR	Repair and maintenance of defective product so it can be used with its original function.
R5 REFURBISH	Restore an old product and bring it up to date.
R6 REMANUFACTURE	Use parts of discarded product in a new product with the same function.
R7 REPURPOSE	Use discarded product or its parts in a new product with a different function.
R8 RECYCLE	Process materials to obtain the same (high grade) or lower (low grade) quality.
R9 RECOVER	Incineration of material with energy recovery.

Answer the questions that follow.

FIGURE 105 SURVEY: SCENARIO BUYER ON THE PLATFORM

*

Q8. What products would you be willing to buy from the website for the construction of your project?

Check all that apply
Please select at least one answer

- [x] Architectural Components like tiles, doors, windows, etc.
- [ ] Structural Components like concrete, steel bars, etc.
- [ ] Mechanical and Plumbing Components like pipe, heat pumps, AC's etc.
- [ ] Other:

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FIGURE 106 SURVEY: QUESTION 8 BUYER'S CHOICE

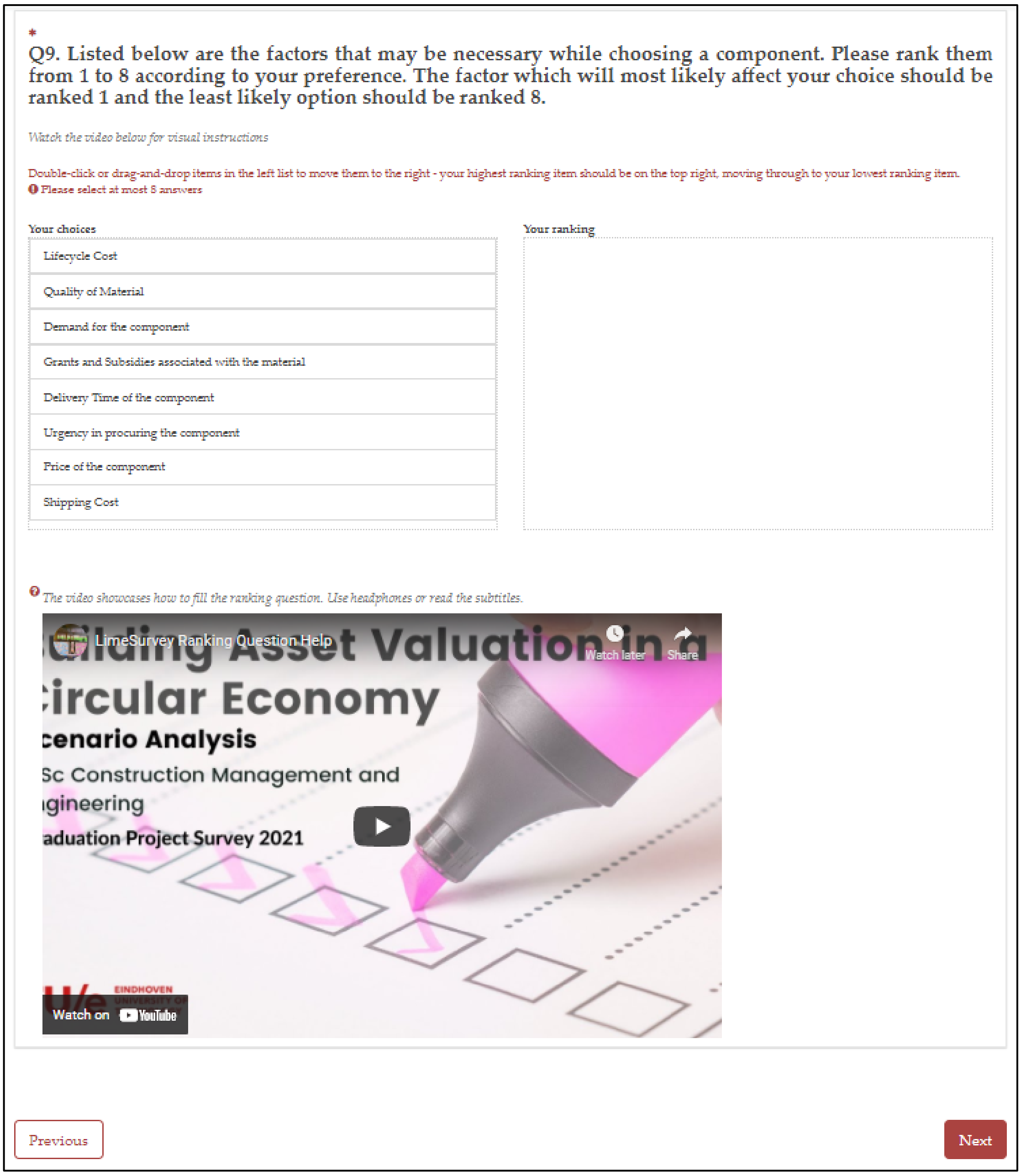


FIGURE 107 SURVEY: QUESTION 9 BUYER'S ORDER OF PREFERENCE

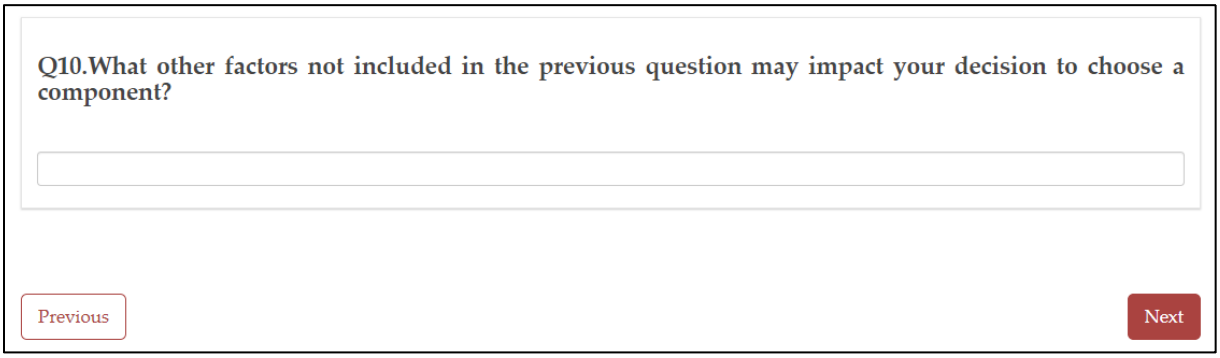
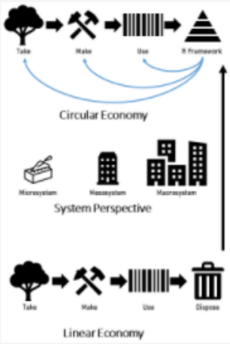


FIGURE 108 SURVEY: QUESTION 10 BUYER'S OTHER FACTORS

Scenario 2 - Seller on the platform

- There are two mandatory and one optional question in this section. Please read the description carefully.
- Imagine that you are responsible to sell materials that were salvaged in a demolition project for an organization. You came to know that there is an online platform that sells materials from demolished buildings that are processed using one of the 9R Framework strategies.



R Framework Strategies	
R0 REFUSE	Make product redundant by abandoning its function or by offering the same function with a radically different product.
R1 RETHINK	Make product use more intensive e.g., by sharing product.
R2 REDUCE	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials.
R3 REUSE	Reuse by another consumer of discarded product which is still in good condition and fulfil its original function.
R4 REPAIR	Repair and maintenance of defective product so it can be used with its original function.
R5 REFURBISH	Restore an old product and bring it up to date.
R6 REMANUFACTURE	Use parts of discarded product in a new product with the same function.
R7 REPURPOSE	Use discarded product or its parts in a new product with a different function.
R8 RECYCLE	Process materials to obtain the same(high grade) or lower (low grade) quality.
R9 RECOVER	Incineration of material with energy recovery.

Answer the questions that follow.

FIGURE 109 SURVEY: SCENARIO SELLER ON THE PLATFORM

*

Q11. What products would you be willing to sell at the website for the construction of your project?

Check all that apply
Please select at least one answer

- [x] Architectural Components like tiles, doors, windows, etc.
- [ ] Structural Components like concrete, steel bars, etc.
- [ ] Mechanical and Plumbing Components like pipe, heat pumps, AC's etc.
- [ ] Other:

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FIGURE 110 SURVEY: QUESTION 11 SELLER'S CHOICE

*

Q12. Listed below are the factors that may affect your pricing strategies while selling a component. Please rank them from 1 to 5 according to your preference. The factor which will most likely affect your pricing strategies should be ranked 1 and the least likely option should be ranked 5.

Please watch the video below for visual help.

Double-click or drag-and-drop items in the left list to move them to the right - your highest ranking item should be on the top right, moving through to your lowest ranking item.

Please select at most 5 answers

Your choices	Your ranking
Subsidies in verband met het materiaal	
Verlangen voor het onderdeel	
Kwaliteit van materiaal	
Gemak van te verwijderen het onderdeel	
Prijs van het onderdeel	

The video showcases how to fill the ranking question. Use headphones or read the subtitles.

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FIGURE 111 SURVEY: QUESTION 12 SELLER'S ORDER OF PREFERENCE

Q13.What other factors not included above may impact your decision to decide pricing strategies while selling the component?

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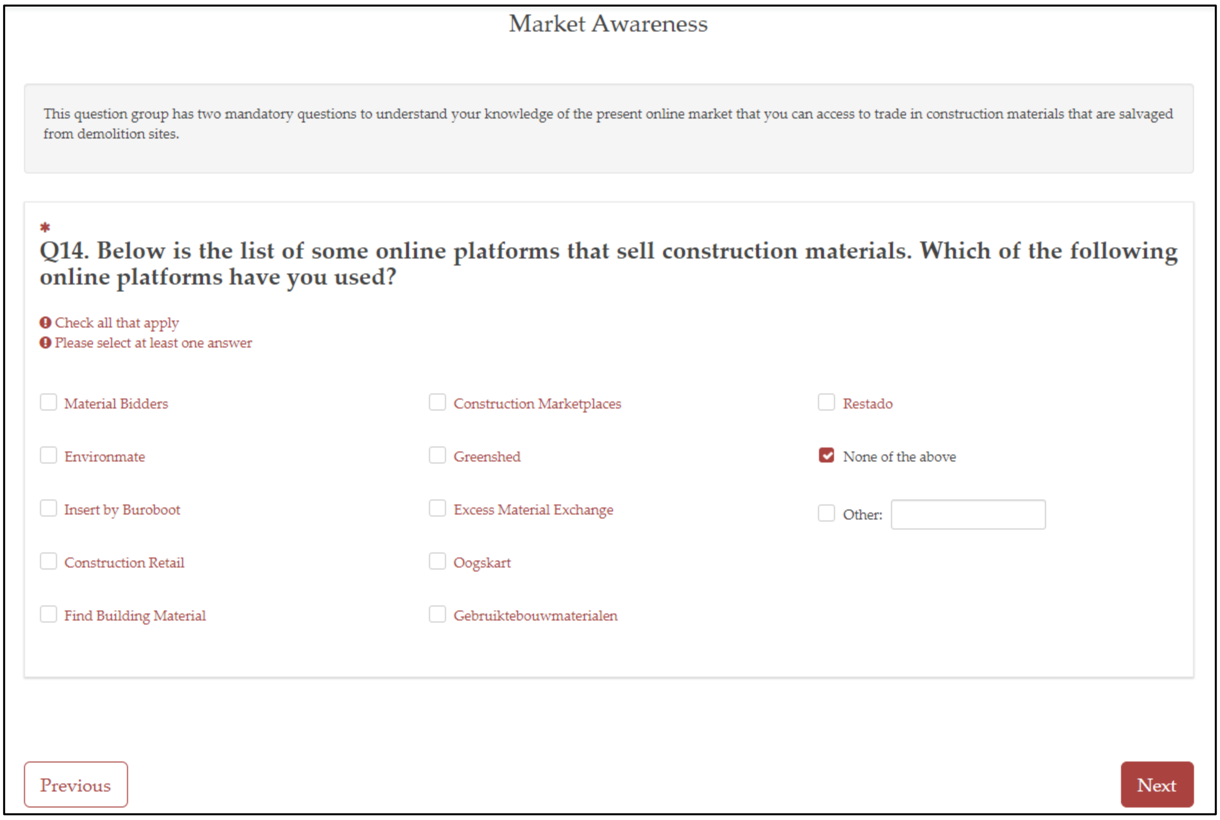
FIGURE 112 SURVEY: QUESTION 13 SELLER'S OTHER FACTORS


Market Awareness

This question group has two mandatory questions to understand your knowledge of the present online market that you can access to trade in construction materials that are salvaged from demolition sites.

*
Q14. Below is the list of some online platforms that sell construction materials. Which of the following online platforms have you used?

Check all that apply
Please select at least one answer

- [ ] Material Bidders
- [ ] Construction Marketplaces
- [ ] Restado
- [ ] Environmate
- [ ] Greenshed
- [x] None of the above
- [ ] Insert by Buroboot
- [ ] Excess Material Exchange
- [ ] Other:
- [ ] Construction Retail
- [ ] Oogskart
- [ ] Find Building Material
- [ ] Gebruiktebouwmaterialen

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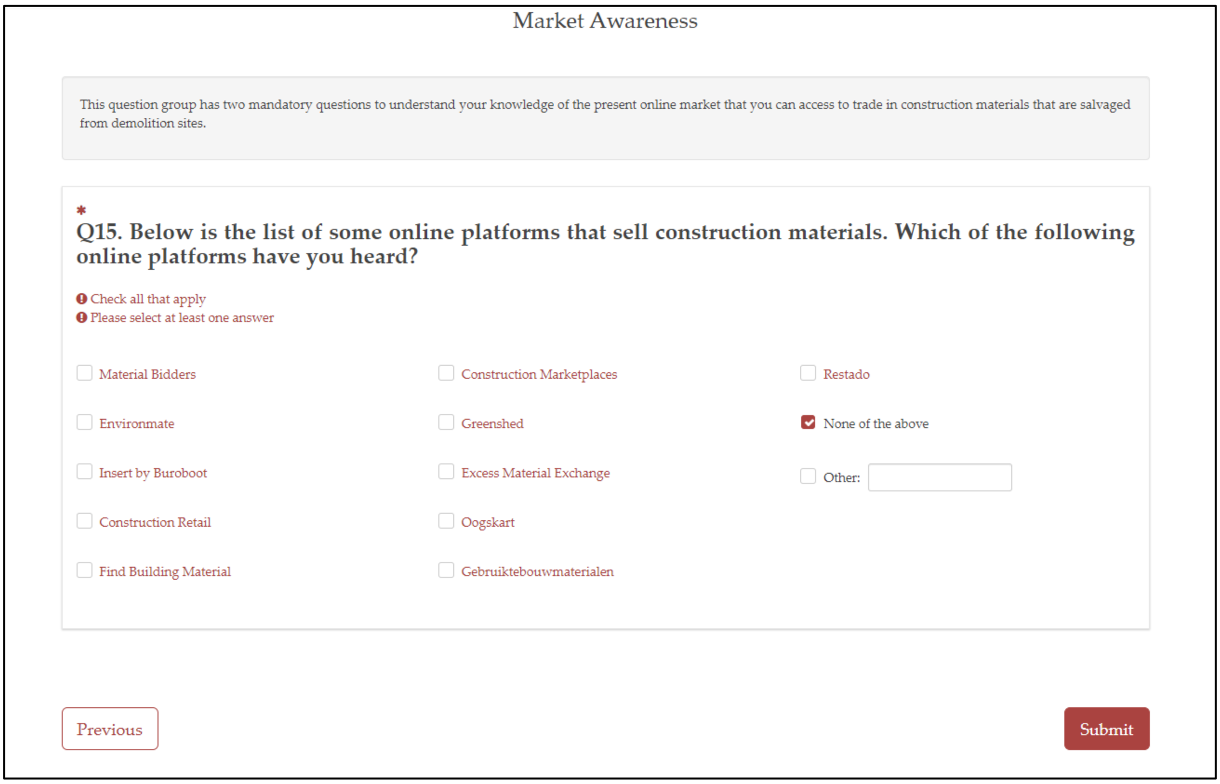
FIGURE 113 SURVEY: QUESTION 14 MARKET USAGE


Market Awareness

This question group has two mandatory questions to understand your knowledge of the present online market that you can access to trade in construction materials that are salvaged from demolition sites.

*
Q15. Below is the list of some online platforms that sell construction materials. Which of the following online platforms have you heard?

Check all that apply
Please select at least one answer

- [ ] Material Bidders
- [ ] Construction Marketplaces
- [ ] Restado
- [ ] Environmate
- [ ] Greenshed
- [x] None of the above
- [ ] Insert by Buroboot
- [ ] Excess Material Exchange
- [ ] Other:
- [ ] Construction Retail
- [ ] Oogskart
- [ ] Find Building Material
- [ ] Gebruiktebouwmaterialen

Previous Submit

FIGURE 114 SURVEY: Q15 MARKET AWARENESS

Thank you for your time and your responses.

Contact Details for study - Buyer and Seller Perspective on Building Component Value

Lead Investigator:

Siddharth Panjwani
Email: s.panjwani@student.tue.nl
Tel: +31 686221644
Supervisors

- Associate Prof Pieter Pauwels, Vertigo 9.14, Design Systems Group, Department of Built Environment, Eindhoven University of Technology, 5600 MB, Eindhoven
- MSc. Ir. Hajo Schilperoort, Vertigo 7.15, Architectural Design and Engineering Group, Department of the Built Environment, Eindhoven University of Technology, 5600 MB, Eindhoven

Data Protection Officer

Annuska van den Eijnden
Email: Dataprotectionofficer@tue.nl
Tele: 040 - 2476079
For complaints: please e-mail Prof Pieter Pauwels at p.pauwels@tue.nl and Tel: +31 40 247 8335
Print your answers.

FIGURE 115 SURVEY: CONCLUDING MESSAGE

11. Appendix D: Indicators, Assessments, Methodologies and Tools for Measuring Circularity (and Its Subsidiary Concepts)

11.1 Scope of Research

The scope of our project is material procurement from an existing building. Hence, the following circularity indicators at micro and nano levels, as shown in Figure 116, are chosen and listed in Table 33.

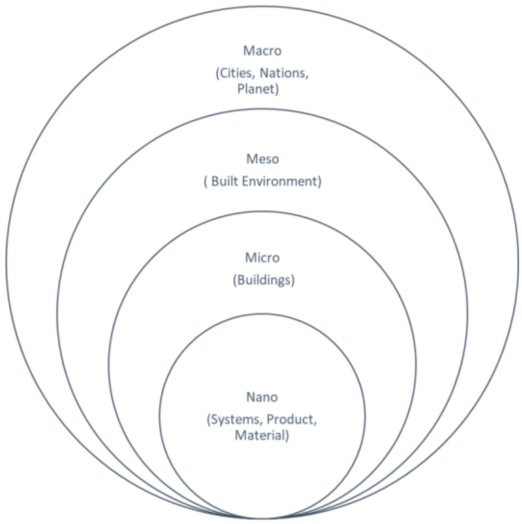


FIGURE 116 SYSTEMS OF CIRCULARITY

Table 33 further adds whether the indicators are relevant to CPP or not.

TABLE 33 CIRCULARITY INDICATORS, ASSESSMENTS, METHODOLOGIES, FRAMEWORKS AND TOOLS INVESTIGATED

S. No	ACRONYM	Name	Author(s)	Relevant for CPP (Yes/No)
1	IOA	Input Output Analysis	(Corona et al., 2019; Leontief, 1970)	No
2	ReM	Remanufacturing Metrics	(Hammond & Bras, 1996)	Yes
3	ReF	Remanufacturing Framework	(Ferrer, 2001)	Yes
4	DP	Disassembly Potential	(Arko van Ekeren, 2018; Durmisevic, 2006; van Vliet, 2018)	Yes
5	REPRO	Remanufacturing Product Profiles	(de Pascale et al., 2021; Gehin et al., 2008; Zwolinski et al., 2006)	Yes
6	CBA	Circular Building Assessment Prototype	(BAMB, 2012; de Oliveira et al., 2021)	No
7	MQV	Material Quantity Variance	(Boyd, 2013; CFA Journal, 2020)	No
8	MPV	Material Price Variance	(Boyd, 2013; J. Verberne, 2016)	Yes
9	ZWI	Zero Waste Index	(Saidani et al., 2019; Zaman & Lehmann, 2013)	No
10	CET	Circular Economy Toolkit	(Evans & Bocken, 2014; Saidani et al., 2017)	No

11	-	EU Ecolabel	(Baldo et al., 2014; Sönnichsen & Clement, 2020)	Yes
12	RPI	Reuse Potential Indicator	(Corona et al., 2019; de Pascale et al., 2021; Park & Chertow, 2014)	Yes
13	EOLix	End of Life Index	(de Pascale et al., 2021; Lee et al., 2014)	Yes
14	CLC	Closed Loop Calculator	(de Oliveira et al., 2021; Kingfisher, 2014)	No
15	MIS	Multi-dimensional Indicator Set	(de Oliveira et al., 2021; Nelen et al., 2014)	Yes
16	CEI	Circular Economy Index	(de Pascale et al., 2021; di Maio & Rem, 2015)	Yes
17	RP	Resource Productivity	(Saidani et al., 2017; Z. Wen & Meng, 2015)	No
18	LCA	Lifecycle Assessment	(Vale, 2017; J. Verberne, 2016)	Yes
19	MSCR	Material Supply Chain Risk	(McKinsey, 2020; J. Verberne, 2016)	Yes
20	MFA	Material Flow Analysis	(Arko van Ekeren, 2018; Brunner & Rechberger, 2016)	Yes
21	MCI	Material Circularity Indicator	(Ellen MacArthur Foundation & ANSYS Granta, 2019; Gupta, 2019; Jiang, 2020; Saidani et al., 2017; van Vliet, 2018; J. Verberne, 2016)	Yes
22	PCI	Product Circularity Indicator	(J. Verberne, 2016)	Yes
23	SCI	System Circularity Indicator	(J. Verberne, 2016)	Yes
24	BCI	Building Circularity Indicator	(Cottafava & Ritzen, 2021; J. Verberne, 2016)	No
25	ECVR	Eco Cost Value Ratio	(Klaassen et al., 2020; Scheepens et al., 2016)	Yes
26	LI	Longevity indicator	(Corona et al., 2019; de Pascale et al., 2021; Franklin-Johnson et al., 2016)	Yes
27	RICE	Recycling Indices (RIs) for the CE	(Saidani et al., 2019; van Schaik & Reuter, 2016)	No
28	CC	Circularity Calculator	(de Pascale et al., 2021; IDEAL & co, 2016)	No
29	MRS	Material Reutilization Score (C2C certification framework)	(Cradle to Cradle Product Innovation Institute, 2016; de Pascale et al., 2021)	No
30	ReNtry	PRP Circulare-Procurement Tool and The ReNtryR©-module	(de Oliveira et al., 2021; Rendemint, 2016)	Maybe
31	PLCM	Product Level Circularity Metric	(de Pascale et al., 2021; Linder et al., 2017)	Yes
32	CEIP	Circular Economy Indicator Prototype	(Cayzer et al., 2017; Saidani et al., 2017)	No
33	Circ(T)	Circ(T)	(Corona et al., 2019; Pauliuk et al., 2017)	No
34	CI	Circularity Index	(Corona et al., 2019; Cullen, 2017)	Yes

35	CEV	Circular Economic Value	(Corona et al., 2019; Fogarassy et al., 2017)	Yes
36	SCIx	Sustainable Circular Index	(Azevedo et al., 2017; Corona et al., 2019)	Maybe
37	LCA - CPI	LCA- Circular Economy Performance Indicator	(Corona et al., 2019; de Pascale et al., 2021; Huysman et al., 2017)	Yes
38	CP	Circular Pathfinder	(ResCom & IDEAL and CO Explore, 2017; Saidani et al., 2019)	Yes
39	VRE	Value-Based Resource Efficiency	(de Pascale et al., 2021; di Maio et al., 2017; Moraga et al., 2019; Saidani et al., 2019)	Maybe
40	HLCA	Hybrid LCA Model	(Genovese et al., 2017; Saidani et al., 2019)	No
41	GRI	Global Resource Indicator	(Adibi et al., 2017; de Pascale et al., 2021; Moraga et al., 2019)	Yes
42	EOLi	End of Life Indices	(de Pascale et al., 2021; Favi et al., 2017)	Yes
43	EEI	Economic-environmental Indicators	(de Oliveira et al., 2021; Fregonara et al., 2017)	No
44	PRDI	Product Recycling Desirability Index	(de Oliveira et al., 2021; Mohamed Sultan et al., 2017)	Yes
45	EER	Economic-Environmental Remanufacturing	(de Oliveira et al., 2021; van Loon & van Wassenhove, 2017)	Yes
46	BREEAM	Building Research Establishment Environmental Assessment Method	(Circle Economy et al., 2018)	No
47	EEI	LCA- Eco-efficiency index	(Corona et al., 2019; Laso et al., 2018)	Yes
48	eDim	Ease of Disassembly Matrix	(de Pascale et al., 2021; Moraga et al., 2019; Vanegas et al., 2017)	Yes
49	TRP	Total Restored Products	(Moraga et al., 2019; Pauliuk, 2018)	No
50	CMCI	Circ Material Circularity Indicator	(Moraga et al., 2019; Pauliuk, 2018)	No
51	LMAS	Lifetime of Materials on Anthroposphere	(Moraga et al., 2019; Pauliuk, 2018)	No
52	PRecI	Potential Recycle Index	(Mesa et al., 2018)	Yes
53	PReuI	Potential Reuse Index	(Mesa et al., 2018)	Yes
54	LFI	Linear Flow Index for Product Families	(de Pascale et al., 2021; Ellen MacArthur Foundation & ANSYS Granta, 2019; Mesa et al., 2018)	Yes
55	EDT	Effective Disassembly Time	(de Pascale et al., 2021; Marconi et al., 2018)	Yes
56	BWPE	BIM-based Whole-life Performance Estimator	(Akanbi et al., 2018; de Oliveira et al., 2021)	Yes

57	MKI	Environmental Cost Indicator / De milieukosten indicator	(Ecochain, 2022; Piano, 2019; Stichting Nationale Milieudatabase, 2020)	Yes
58	LCCA	Lifecycle Cost Assessment	(Braakman, 2019)	Yes
59	REV	Retained Environment Value	(Haupt & Hellweg, 2019)	Yes
60	MSb	Material Stock (MS) of buildings	(Arora et al., 2019)	No
61	PR-MCDT	Product Recovery Multi-Criteria Decision Tool	(Alamerew & Brissaud, 2019; de Oliveira et al., 2021)	Yes
62	Circularity Check	Circularity Check	(de Oliveira et al., 2021; Ecopreneur, 2019)	Yes
63	CEBI	Circular Economy Benefit Indicators	(de Oliveira et al., 2021; Huysveld et al., 2019)	Yes
64	QC	Circularity of Material Quality	(de Oliveira et al., 2021; Steinmann et al., 2019)	Yes
65	APL	Assessment of Circular Economy Strategies at the Product Level	(de Oliveira et al., 2021; Niero & Kalbar, 2019)	No
66	MPG	MPG Shadow Cost	(Stichting Nationale Milieudatabase, 2020)	No
67	-	Platform CB23 Guide	(Platform CB’23, 2020)	Yes
68	-	Madaster Circularity Indices	(Heisel & Rau-Oberhuber, 2020)	Yes
69	MDI	Material Durability Indicator	(Mesa et al., 2020)	Yes
70	RVI	Residual Value Indicator	(Jiang, 2020)	Yes
71	MCEM-PLCS	Multi-Criteria Evaluation Method of Product Level Circularity Strategies	(Alamerew et al., 2020; de Oliveira et al., 2021)	No
72	EPD	Environmental Product Declarations	(EPD, 2021)	Yes
73	-	Levels	(Díaz-López et al., 2021; Karabınar, 2021)	No
74	BCAM	Building Circularity Assessment Model	(Zhang et al., 2021)	Yes
75	RP	Reusability Potential	(Kentie, 2021)	Yes
76	C2C Product Circularity	C2C Circular Product	(Cradle to cradle products innovation institute & MBDC, 2021)	Yes
77	C2C Air	C2C Clean Air and Climate Protection	(Cradle to cradle products innovation institute & MBDC, 2021)	Yes
78	C2C Material Health	C2C Material Health Assessment Methodology	(Cradle to Cradle Products Innovation Institute, 2022)	Yes

11.2 Rejected Indicators

Table 34 provides the reasons for rejection for some of the indicators, assessments, methodologies, frameworks and tools as stated in Table 33.

TABLE 34 CIRCULARITY INDICATORS, ASSESSMENTS, METHODOLOGIES, FRAMEWORKS AND TOOLS REJECTED

S.NO	NAME	REASON TO REJECT
1	Input Output analysis	Not enough information

2	Circular Building Assessment Prototype	It is valid for use in early design phase and can be further used to enhance the information
3	Material Quantity Variance / Material Usage Variance	It has not much impact on decision of buyer or a seller or even can be used by the medium
4	Zero Waste index	Focused mainly on waste management system at meso level even though the test subject of the indicator lies on micro level.
5	Circular Economy Toolkit	There is no distinction of circularity loops and there is a lack of support in data construction. It does not provide concrete guidance for product circularity improvement. Even though business opportunities are covered (including financial viability and market growth potential). Other aspects are not directly addressed.
6	Closed Loop Calculator	Relevant information related to indicator could not be found
7	Resource Productivity	It focuses on PCBs and electronic sector.
8	Building Circularity Indicator	The focus is on building level and CPP focus for this research is focused on reusing parts of building and the BCI is a combination of different SCIs.
9	Recycling Indices (RIs) for the CE	This indicator is focused on circularity in recycling process and identify the bottlenecks in recycling to create new CBMs. It focuses on product-based recycling approach. Although the principle of product-based recycling is essential for CPP to identify different recycling opportunities. However, the products here are LEDs and hence can't be used for recycling for building materials in its proposed form.
10	Circularity Calculator	It compares the circularity and value capture potential of different circular design strategies in the early design process.
11	Material Reutilization Score (C2C certification framework)	It has been decoupled in the new C2C product certification standard and is used in a different manner.
12	PRP Circulare-Procurement Tool and The ReNtryR module	It seems to be a paid application tool with very less information provided publicly to investigate further
13	Circular Economy Indicator Prototype	The CEIP is intended to be used by manufacturing and/or retail companies of tangible goods with access to bill of materials.
14	Circ(T)	The Circ(T) builds on Material Flow Analysis to gives a relative measure of the cumulative mass of a material present in a system, over a time, in terms of an ideal reference case where the material is kept functional throughout the entire time period. It assigns the benefits of recycling to the material being recycled, following a closed loop approach. However, this relative measure is not essential for the CPP as this is also measured by MCI which has more flexibility in terms of aggregating other indicators such as disassembly potential which is not included here.
15	Sustainable Circular Index	The index proposed in this work is for an individual company and not for a supply chain.

16	Value Based Resource Efficiency	It estimates resource efficiency and circularity of product and services in terms of the prices of exploited resources in terms of the whole supply chain. The VRE indicator checks and cope the performance of actors in the total value chain. It provides quantitative results. The calculation utilizes the monetary value of resources. Resource efficiency is equal to the relationship between the added product value and the value of exploited resources utilized in production or in a process. It may have an indirect help for CPP in terms of the medium, but it does not directly seem to relate to CPP elements
17	Hybrid LCA Model	The aim of this indicator is verification of a potential enhancement of sustainable supply chain management practices by aligning them to circular economy concepts. Hence the focus is on the entire supply chain rather than a product or its sub- assemblies.
18	Economic-environmental Indicators	The methodology uses LCA and LCC principles to give an economic and environmental indicator while considering disassembly and residual values. This methodology can be used in the CPP scenario based on existing tools but does not directly help in CPP.
19	Building Research Establishment Environmental Assessment Method	It focuses on maximising amount of reused and renewable materials but is just a checklist of whether it is there or not. Hence, it does not assist much in easing CPP decisions for stakeholders.
20	Total Restored Products	Insufficient information
21	Circ Material Circularity Indicator	Insufficient information
22	Lifetime of Materials on Anthroposphere	Insufficient information
23	Material Stock (MS) of buildings	It entails the inflow and outflow of material in a building over its lifecycle which is essential for predicting material usage and maintenance plans but at the end of CPP the inflow and outflow rates do not amount to much use apart from survelling the present state of material stock which is done anyways at the start of deconstruction. If this ifnformation has been carried out already, then it would be a great start for profit estimating during stocks.
24	Assessment of Circular Economy Strategies at the Product Level	The APL is a combination of MCI and MRS indicators included in the list. It is combined with lifecycle indicators for the beer packaging. An MCDA is conducted relevant for beer industry. Hence the methodology to get an indicator for building products can be workable and weights must be determined on the basis of that. However, APL for beer packaging can’t be used in its proposed form.
25	MPG Shadow Cost	This is redundant as MKI is already there for CPP
26	Multi-Criteria Evaluation Method of Product Level Circularity Strategies	The proposed method uses an integrated approach to evaluate the environmental and economic benefits of circularity strategies together with social, legislative, business, and technical aspects. It is characterized by criteria independence without correlation which is not true and hence there is a need to find the correlation to remove redundancy in scoring. Also, the scoring and grading is verbal in nature

		leading to subjective ambiguity and hence need to be discussed over and over before being used.
27	Levels	It is a framework to measure and to report environmental performance of buildings, based on circular thinking principles. It considers the whole life cycle of a building and tries to answer how sustainability affects the value. It is applicable for office and/or residential building projects. It is a very broad framework which aims to address the most critical topics in the construction industry to achieve environmental and financial sustainability by circular thinking. Some parts of the framework are still under development and not fully completed yet.

11.3 Relevant CPP Indicators

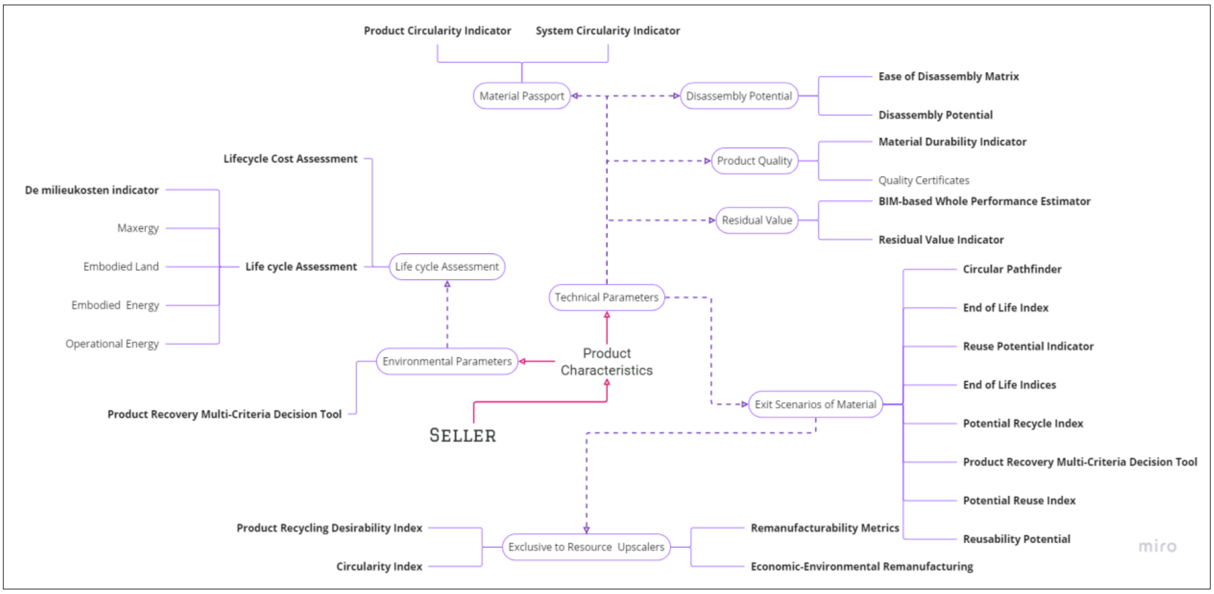


FIGURE 117 CPP INDICATORS RELEVANT FOR SELLER

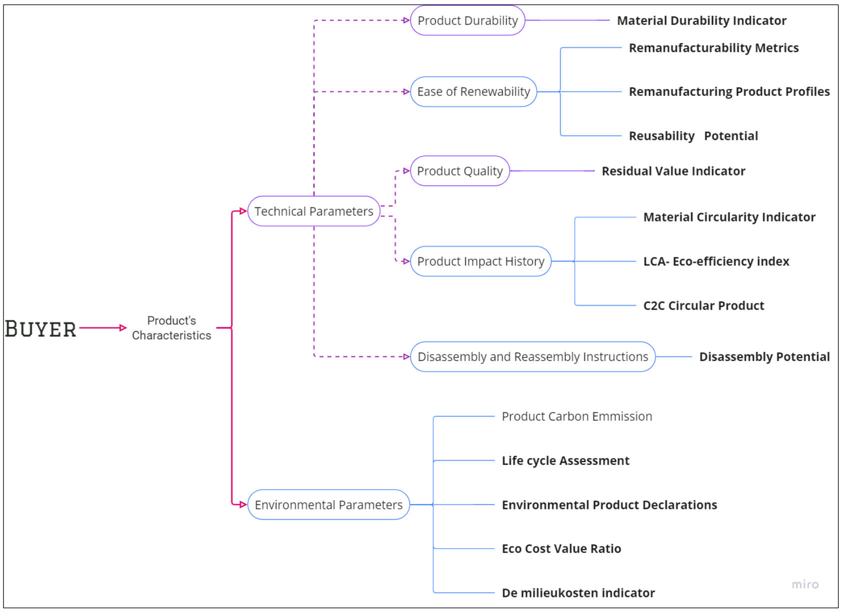


FIGURE 118 CPP INDICATORS FOR BUYERS

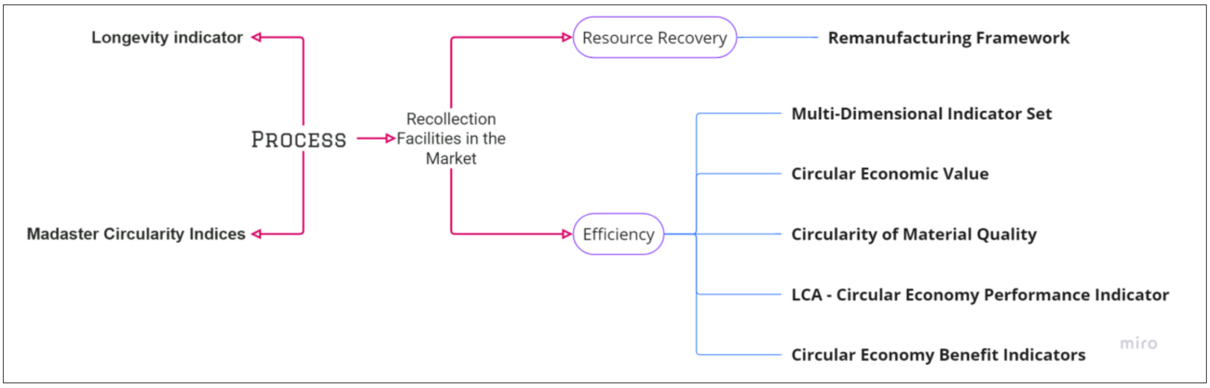


FIGURE 119 CPP INDICATORS FOR PROCESS

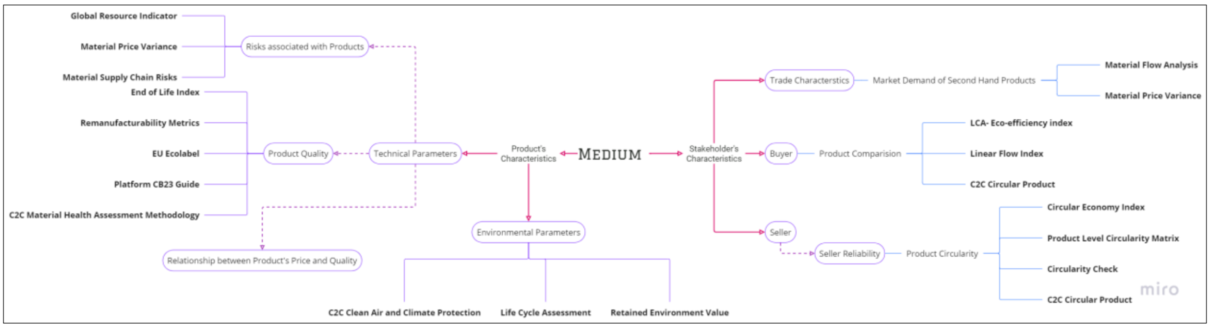


FIGURE 120 CPP INDICATORS FOR MEDIUM

12. Appendix E: Disassembly Potential Factors

12.1 Disassembly Factors as defined by E. Durmisevic and A. van Ekeren

Durmisevic (2006) emphasized the significance of a building's transformation capacity and used fuzzy logic to provide a means to quantify the disassembly Potential and compare designs. To assess the disassembly potential, the material hierarchy decomposition of a building was used. The concept framework for the decision support tool proposed in the research as shown in Figure 121.

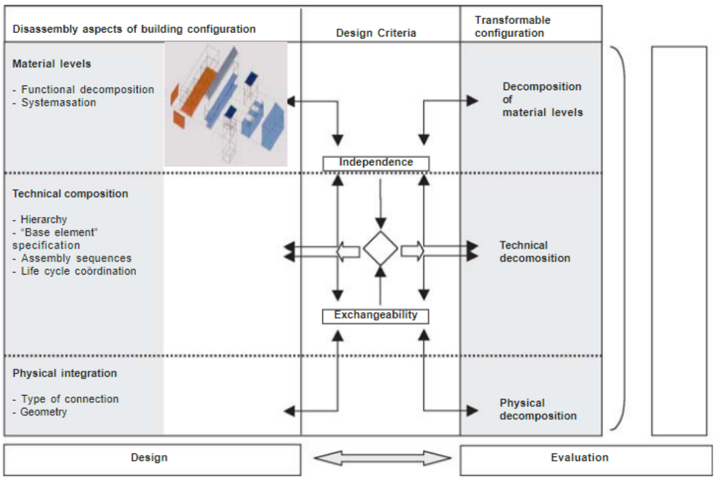


FIGURE 121 A CONCEPTUAL FRAMEWORK OF THE DECISION SUPPORT / EVALUATION MODEL (DURMISEVIC, 2006)

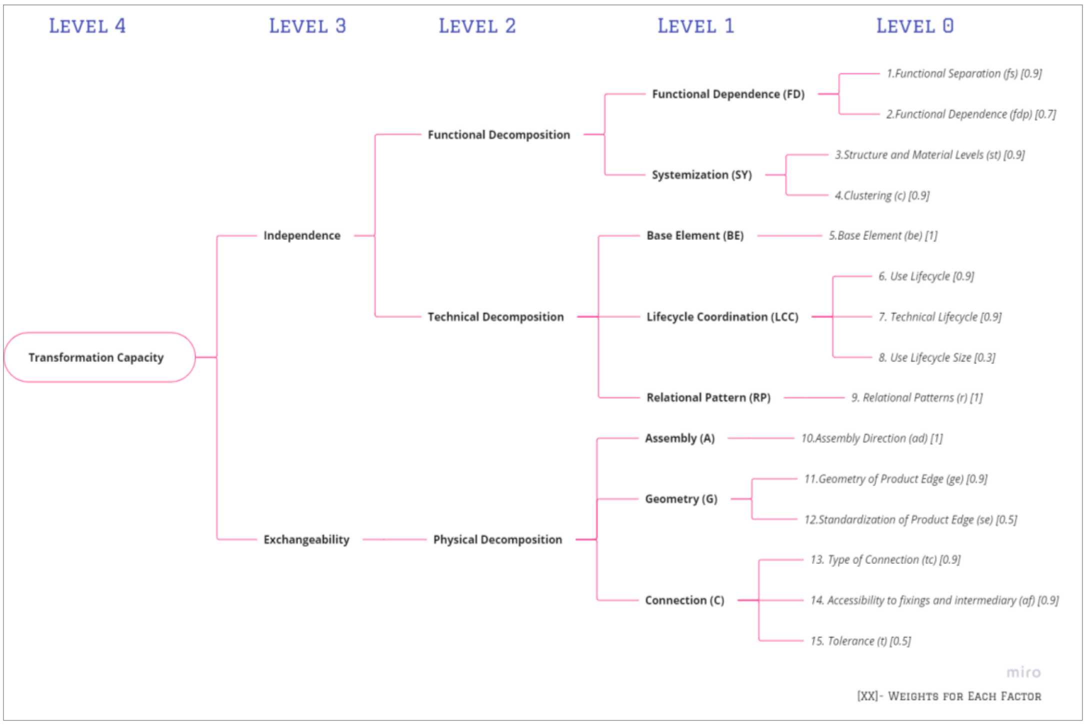


FIGURE 122 DURMISEVIC' S DISASSEMBLY POTENTIAL FACTORS' BREAKDOWN, (ARKO VAN EKEREN, 2018)

According to Arko van Ekeren (2018), disassembly potential is measured in accordance with the design principles of Independence and Exchangeability. These are further subdivided into three different but overlapping categories: physical, functional, and technical. The level below contains eight factors that have a significant impact on decision-making and determine whether the eventual construct can be deconstructed. All these options are rated, and they receive a score between 0 and 1, with 0 being the lowest score and 1 giving sufficient reasons for disassembly. These factors are further subdivided into 15 essential characteristics, each of which is assigned a weight and used to calculate a disassembly score. It is depicted in Figure 122.

These 15 factors under the eight aspects can be used to assess the disassembly potential and can cater as the input for decision framework.

Functional Dependence
Functional Dependence classifies building products depending on how many functions they must perform. The product is then evaluated using two criteria: functional separation and functional dependency.

Durmisevic (2006) defines a building product as having four primary functions: supporting, enclosing, servicing, and partitioning. These are then broken down into sub-functions. For example, within the functional area of enclosing, several sub-functions such as insulating, water tightness, air tightness, translucency, and so on may be expected. Because they have different life cycles and maintenance rates, all these functions should be kept separate from one another. Durmisevic defines this as functional separation (fs) and investigates how functions are related to one another.

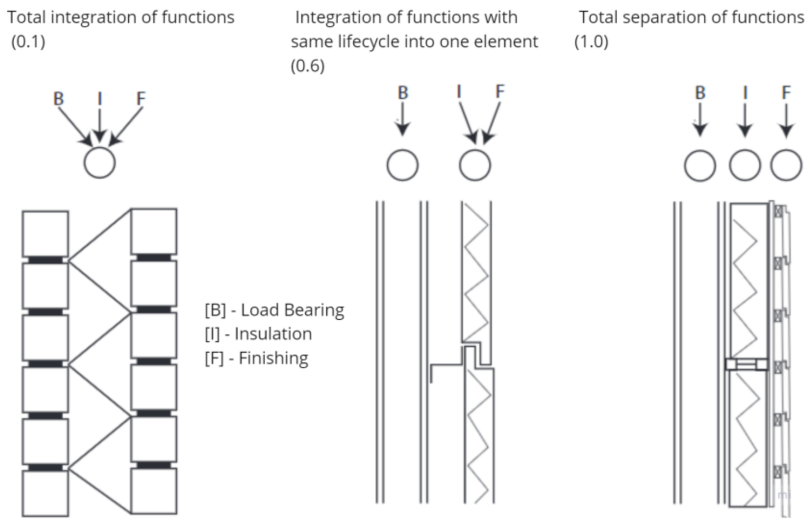


FIGURE 123 FUNCTIONAL SEPARATION (ARKO VAN EKEREN, 2018)

The second factor, the functional dependence Figure 124, evaluates if a product can change its function when the original function is no longer in demand.

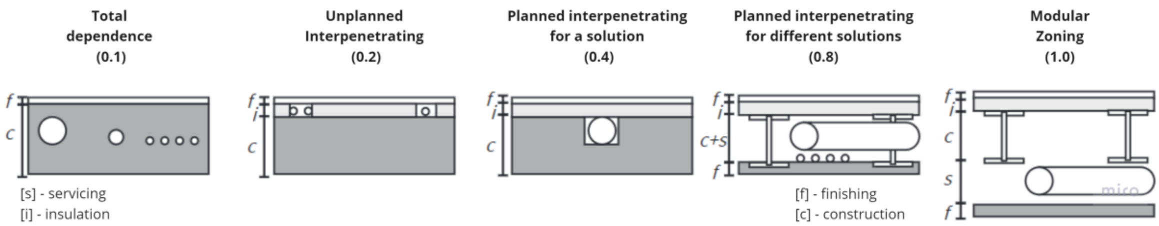


FIGURE 124 FUNCTIONAL DEPENDENCE (ARKO VAN EKEREN, 2018)

Systemization
By analyzing the systematization of a product, i.e., the relationships between distinct material layers, a developer can determine the relationship between parts of a product. These relationships dictate

the sequence of assembly, which can be performed on-site, at work, or in a factory. The fabrication sequence and location can help determine cluster material levels. This, in turn, expedites assembly and disassembly on-site. Combining materials into components decreases construction site labor. Assembling a structure with minimal connections and methods facilitates its deconstruction. Too many hours of disassembly diminish the value of the dismantled elements. This may result in the building's demolition. Therefore, systemization is an essential criterion for assessing disassembly potential.

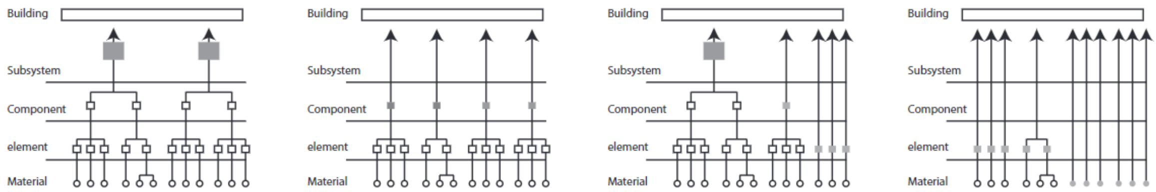


FIGURE 125 SYSTEMIZATION IN A BUILDING (ARKO VAN EKEREN, 2018)

Evaluation of systematization is based on the relationship between different material layers and the reason for cluster formation. The initial evaluation in the systematization is structure and material levels (st). For this evaluation, the material levels are ranked as follows: components (1), elements/components (0.8), elements (0.6), material/element/component (0.4), and materials (0.1). The second criterion for consideration is the rationale for material clustering (c). In ascending order of weight, the evaluation categories are functionality (1.0), material lifecycle (0.6), rapid assembly (0.3), and absence of clustering (0.1).

Base Element

Durmisevic (2006) and Arko van Ekeren (2018) state that each element added to the building serves a distinct function or sub-function. These elements may be joined in clusters, as stated in the previous paragraph. Additionally, these clusters must be interconnected. If left undefined, the components may grow interdependent, leading to unclear disassembly procedures. To ensure that components can be disassembled, it is necessary to incorporate a base element, which links the components to the load-bearing structure rather than directly to each other. The basic element can be identified in four instances as shown in

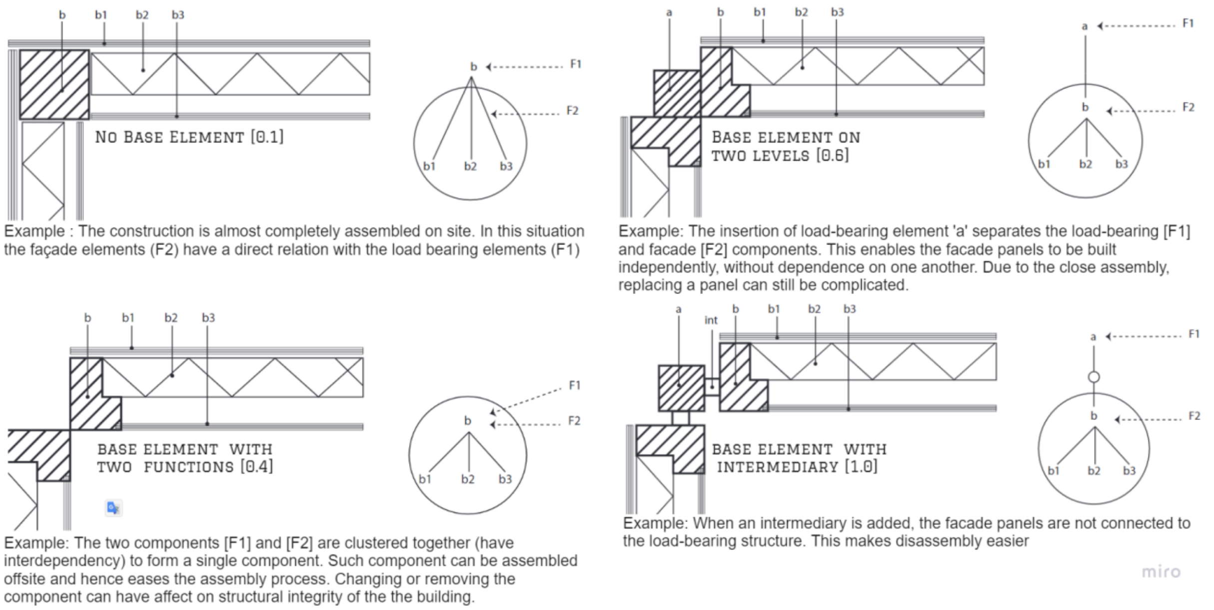


FIGURE 126 BASE ELEMENT (ARKO VAN EKEREN, 2018; DURMISEVIC, 2006)

Lifecycle Coordination

The lifespans of elements utilized in the design of buildings vary considerably. Some elements have a five-year lifespan, while others have a lifespan of over a century. Throughout their useful lives, these life spans are highly dependent on maintenance and cleaning. A building element has two lifespans: the "functional lifespan" and the "technical lifespan." The functional lifespan of an element is the amount of time it can continue to satisfy the needs of its users. The technical lifespan is the amount of time until an element's technical requirements for its intended use are no longer met. Using three criteria, the Life Cycle Coordination analyses these two lifespans.

Use Lifespan: Elements with a longer technical lifespan are utilized for load-bearing structures since they require the least amount of maintenance and are typically expensive or practically impossible to replace. When these materials must be replaced, all other building elements will have long since become outdated. Use lifespan of an element is therefore required. It compares the functional life of the element to its technical service life. The weights are based as mentioned in Table 35.

TABLE 35 WEIGHTS ASSIGNED TO USE LIFESPAN (ARKO VAN EKEREN, 2018)

USE LIFESPAN	WEIGHT
Long (1)/long (2) or short (1)/short (2)	1.0
Long (1)/short (2)	0.8
Medium (1)/long (2)	0.5
Short (1)/medium (2)	0.3
Short (1)/long (2)	0.1

Technical Lifecycle: The replacement of an element is contingent on its surrounding and related elements. Therefore, disassembly and maintenance would be more frequent and expensive if a component with a longer lifespan depends on one with a shorter lifespan. The technical life cycle studies the relationship between two different-level materials, material (a) to material (b).

TABLE 36 WEIGHTS ASSIGNED TO TECHNICAL LIFECYCLE (ARKO VAN EKEREN, 2018)

TECHNICAL LIFECYCLE	WEIGHT
Long(a)/long(b) or short(a)/short(b)	1.0
Long(a)/short(b)	0.8
Medium(a)/long(a)	0.5
Short(a)/medium(b)	0.3
Short(a)/long(b)	0.1

Use Lifecycle/Size: Small elements can have shorter lifetimes. When they are lightweight and controllable, it is rather simple to replace them. The final life-cycle coordination that must be examined is the size-related use life cycle.

TABLE 37 WEIGHTS ASSIGNED TO USE LIFECYCLE/ SIZE

USE LIFECYCLE/SIZE	WEIGHT
Big (small) element / long L.C.	1.0
Small element / short L.C. or medium component / short L.C.	1.0
Big component / long L. C.	1.0
Big component / short L. C.	0.4
Material / long L.C.	0.2
Big element / short L.C	0.1

Relational Pattern

According to Durmisevic (2006) and Arko van Ekeren (2018), the relational pattern displays the interdependence of many functions. In traditional design, all units (elements, components, materials having a function) are interconnected, resulting in a single cohesive diagram where no changes can be made without impacting another unit. Hence these inter-connected relations (Figure 127) define the ease of disassembly of two units from one another.

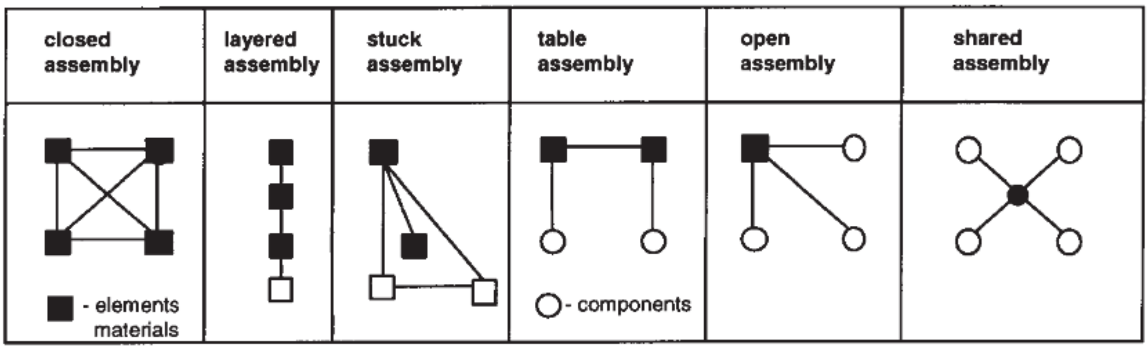
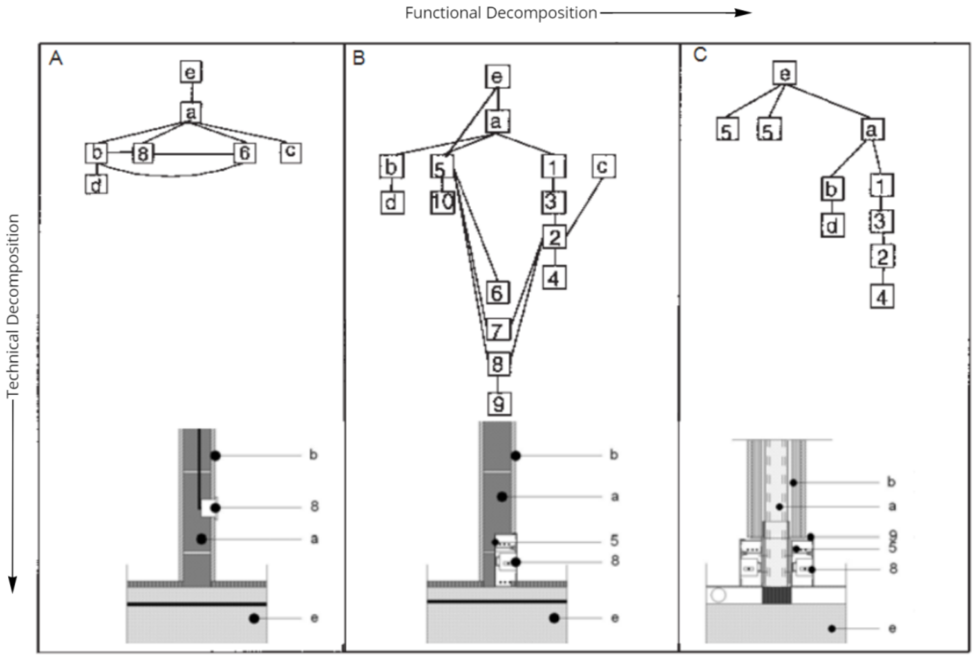


FIGURE 127 CLASSIFICATION OF ASSEMBLIES ACCORDING TO THE TYPE OF RELATIONAL PATTERNS, DURMISEVIC (2006)

These different assemblies/systems (Figure 127) comprise of sub-assemblies/sub-systems. The relational pattern as an analytical concept works based on the concept of relation within sub-systems (vertical relation) and relation among sub-systems (horizontal relation) as shown in Figure 128.



A depict a horizontal relation in which the separation wall, electrical installation, and finishing are interdependent in such a way that if one part has be changed, the surrounding elements will be harmed. *B* and *C* include stronger vertical relationships that indicate a partially open and open hierarchy of wall systems, with greater possibility for disassembly.

FIGURE 128 RELATIONAL PATTERNS IN A WALL SYSTEM, DURMISEVIC (2006)

As mentioned in the Base Element section, sub-system must only communicate with the load-bearing system. So that components that belong to a sub-system can be changed easily without influencing the load bearing structure. Hence, horizontal relations are the least preferred and vertical relations are the most preferred to ease disassembly. Based on the relational patterns, weights are assigned as shown in Table 38.

TABLE 38 WEIGHTS FOR RELATIONAL PATTERNS

RELATIONAL PATTERNS	WEIGHTS
Vertical	1.0
Horizontal in lower zone	0.6
Horizontal between upper and lower zone	0.4

Horizontal in upper zone	0.1

Assembly

Durmisevic (2006) and Arko van Ekeren (2018) state that the manner of assembly can determine whether components are independent. The direction of assembly influences the replaceability and speed of both assembly and disassembly. In order of increasing rank, a parallel assembly (1.0) is followed by stuck assembly (0.6), base element in stuck assembly (0.4) and sequential assembly (0.1). Durmisevic (2006) also included another factor to evaluate disassembly potential based on assembly sequence where material levels are included. This factor can be seen in Table 39.

TABLE 39 WEIGHT FOR ASSEMBLY SEQUENCE REGARDING MATERIAL LEVELS

CODE	DESCRIPTION	WEIGHTS
as 01	Component (1)/Component (2)	1.0
as 02	Component (1)/ Element (2)	0.8
as 03	Element (1)/ Component (2)	0.6
as 04	Element (1)/ Element (2)	0.5
as 05	Material (1)/ Component (2)	0.3
as 06	Component (1)/ Material (2)	0.2
as 07	Material (1)/ Material (2)	0.1
(1) - Assembled First, (2) - Assembled Second		

Geometry

The geometry of the product dictates the order of assembly; thus, it has a direct impact on the disassembly of the product. In the best-case scenario, components can be put and replaced without interfering with neighbouring components; in the worst-case scenario, the only alternative is destruction since components are trapped. There are six various versions of the geometric edge that may be created as shown in Figure 129 . The second criterion is the geometry's conformity to standards. This decides whether the geometry is created on-site fully (0.1), partially (0.5) or entirely in a factory (1.0).

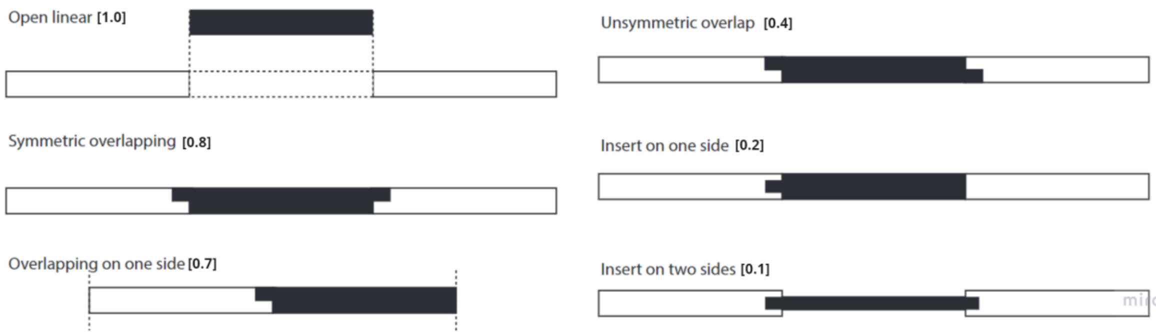


FIGURE 129 GEOMETRY OF COMPONENT'S EDGE, ARKO VAN EKEREN (2018)

Connections

There are four aspects on which connections are analysed for disassembly potential of a building component. It is the type of connections, the accessibility to fixing and intermediatory, the tolerance and morphology of connections. Arko van Ekeren (2018) does not include the last one. Based on findings of Durmisevic (2006), the weights for these criteria can be seen in Figure 130.

C CONNECTIONS	type of connection	tc 01	accessory external connection or connection system	1
		tc 02	direct connection with additional fixing devices	0,8
		tc 03	direct integral connection with inserts (pin)	0,6
		tc 04	direct integral connection	0,5
		tc 05	accessory internal connection	0,4
		tc 06	filled soft chemical connection	0,2
		tc 07	filled hard chemical connection	0,1
		tc 08	direct chemical connection	0,1
			tc= [tc1+ tc2 + ….tc(n)] / n	
	accessibility to fixings and intermediary	af 01	accessible	1
		af 02	accessible with additional operation which causes no damage	0,8
		af 03	accessible with additional operation / causes reparable damage	0,6
		af 04	accessible with additional operation/causes partly reparable damage	0,4
		af 05	not accessible - total damage of bought elements	0,1
			af= [af1+ af2 + ….af(n)] / n	
	tolerance	t 01	high tolerance	1
		t 02	minimum tolerance	0,5
		t 03	no tolerance	0,1
			t= [t1+ t2 + ….t(n)] / n	
	morphology of joint	mc 01	knot (3D connections)	1
		mc 02	point	0,8
		mc 03	linear (1D connections)	0,6
		mc 04	service (2D connection)	0,1
			mc= [mc1+ mc2 + ….mc(n)] / n	

FIGURE 130 CONNECTIONS AND THEIR WEIGHT, DURMISEVIC (2006)

12.2 Disassembly Factors as defined by M. van Vliet

van Vliet (2018) investigated the disassembly factors used in Building Circularity Indicator proposed by (J. Verberne, 2016) which were based on the Durmisevic (2006)'s work on transformation capacity of buildings, namely Function Separation, Functional Dependence, Technical Lifecycle Coordination, Geometry of Product Edge, Standardization of Product Edge, Type of Connections and Accessibility to Fittings. The study proposed 26 factors categorized into technical, process based, and financial based factors as shown in Figure 131 and used Fuzzy Delphi method to assign weights to a select few necessary for the updated BCI.

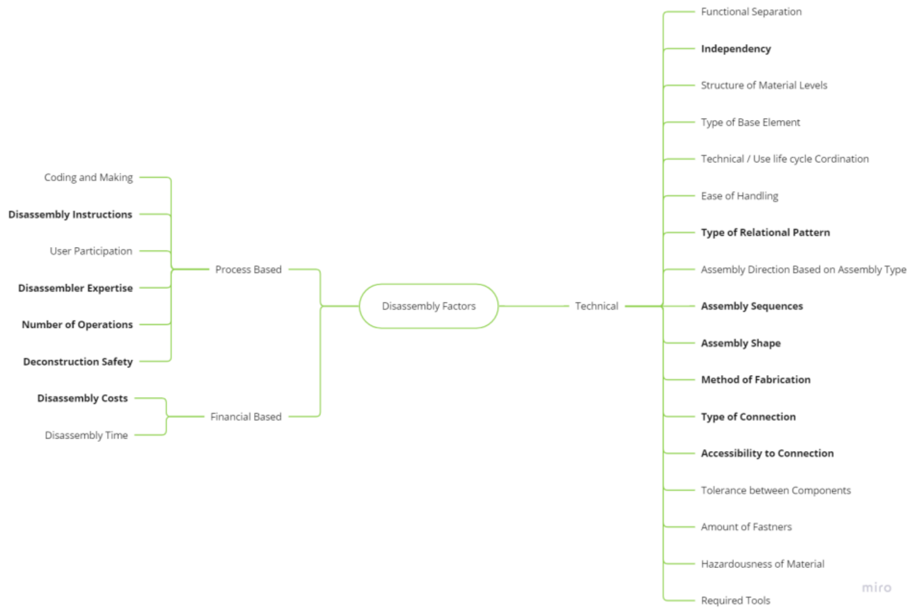


FIGURE 131 DISASSEMBLY FACTORS PROPOSED BY VAN VLIET (2018)

The technical factors in bold were chosen as factors to be included the updated BCI and the process-based factors in bold were addressed as pre-requisites for disassembly and the financial factor in bold was considered driver for disassembly. Table 40 briefly describes the disassembly factors proposed.

TABLE 40 DISASSEMBLY FACTORS PROPOSED BY VAN VLIET (2018)

S. NO	FACTORS	DESCRIPTION
1	Functional Separation	A building is composed of diverse materials and products with specific functions. The types of functions can be categorized generally or specifically. When a function no longer fits user requirements, it can be disassembled separately. When one function of a product with several functions fails, it leads to waste and the failure of the other functions. It is therefore less likely to be dismantled, replaced, or repaired. Single function products, on the other hand, are more likely to be simple to disassemble.
2	Independency	Functional dependence influences independence. Decoupling components is desirable, but systems should be grouped by functional and physical interactions. Incorporating and interweaving components creates dependency, affecting their integrity and disassembly potential.
3	Structure of Material Levels	Fewer products make disassembly easier. Fewer site connections result from integrating more building components into a single component. Multiple products can be assembled into a single unit for a higher building level, or individual products can be assembled on-site. Consequently, this level of material can influence the degree of freedom of the product during disassembly.

4	Type of Clustering	Depending on the type of clustering, disassembly can be made simpler since after the lifetime has expired or the function no longer meets the requirements, the entire cluster of goods can be dismantled as opposed to the individual components. If the cluster has products which serve different functions, then, it is a difficult and expensive process as products serving one function well, but not meeting requirements of others can lead to hesitancy while disassembling. But at the building's end of life, this factor means that the cluster though failing in one function can be reused for other function.
5	Type of Base Element	A base element can act as intermediary without compromising the products when disassembly is undertaken. Depending on the connections and presence of base element, ease of disassembly can change drastically.
6	Technical / Use life cycle Coordination	Technically, a product may be in excellent condition but no longer meet the functional specifications, or vice versa. Coordination of the life cycle necessitates that the element with the longest lifecycle be assembled first and deconstructed last. This assembly sequence in turn affects the disassembly potential.
7	Ease of Handling	Due to their greater manageability, smaller parts are simpler to disassemble than their bigger counterparts.
8	Type of Relational Pattern	Relational pattern represents how products and parts relate to each other. Open systems have a vertical and hierarchical relational pattern. This allows for isolation and separation of products and enables change through disassembly. The number of relations is very important for the disassembly potential as more relations lead to closed assemblies.
9	Assembly Direction Based on Assembly Type	Assembling resembles disassembling. Sequential assembly facilitates easy disassembly. The sequencing should be arranged so that parallel disassembly is possible, as this generates multiple disassembly angles that further simplify and accelerate the process.
10	Assembly Sequences	Researchers utilize both disassembly orientation and disassembly sequencing almost always. As a result, assembly sequence is essential, as the correct method for disassembly is dependent on how something was assembled. It is also one of the most effective ways to reduce the time required to disassemble a product. In addition, Durmisevic (2006) argues for a separation in which lower levels of components should follow higher levels while determining assembly sequencing such as separating mechanical and electrical components in product design to make it easier to deconstruct. Otherwise, if on same level, it would make disassembling them harder.
11	Assembly Shape	Product boundary geometry (shape) can result in an open or interpenetrating geometry. Hence, making it an important aspect influencing disassembly.
12	Method of Fabrication	According to van Vliet (2018), the fabrication method is an application of the factor standardization of the product edge proposed by Durmisevic (2006). The fabrication process indicates whether a product or assembly is prefabricated or assembled on-site. In addition to increasing the reusability of the goods, prefabrication facilitates disassembly through the uniformity of connections, the accessibility of connections, and the ability to disassemble whole components on-site and further separate components off-site.
13	Type of Connection	Typically, there are three primary sorts of connections. Indirect, direct, and filled. Mechanical connections are favored over adhesives for disassembly. Additionally, according to Soh et al. (2014), there are active connections that can be triggered and set loose. This is not often employed in the building sector, but it might lead to the creation of connections that are simpler to dismantle than conventional approaches.
14	Accessibility to Connection	Accessibility of connections refers to the ability to access product connections without damaging them. This not only influences the product's and its surroundings' reusability, but also makes disassembly easier and faster.
15	Tolerance between Components	Tolerance involves physically separating components. Tolerance is generally constructed to accommodate product dimensions, but it can also assist disassembly.

16	Number of Fasteners	Using fewer fasteners can facilitate disassembly and save time. However, the number of fasteners relies on the connection's strength and design, thus these factors must be considered while determining the number of fasteners.
17	Hazardousness of Material	The disassembly technique and duration are affected by hazardous materials. Due to the necessity for treatment prior to second use, the economic motivation for reusing items containing hazardous compounds is diminished.
18	Required Tools	Disassembly tools range from hand tools to specialized devices. This affects the ease of disassembly since changing tools takes time, a crucial component in disassembly.
19	Coding and making	According to Thormark (2001) and Peeters et al (2012), coding and marking refers to the identification of materials and connections. This will facilitate identification and streamline the process of sorting and recycling. This must be documented throughout the entire building development process. According to Guy & Ciarimboli (2005), labeling of connections and materials in the specification's aids in disassembly and deconstruction. Consequently, it is regarded as a process-based disassembly factor by van Vliet (2018). Implementing product identification technologies in items can facilitate coding and marking, according to industrial engineering literature such as the study by Vanegas et al (2017). The manufacturer of building materials can code and mark their items, and throughout the construction phase, the contractor must guarantee this.
20	Disassembly Instructions	According to Thormark (2001), instructions on a building's materials and assembly techniques aid disassembly. Hence, documentation of such information is required throughout the building development process, including any alterations. As stated by Guy & Ciarimboli (2005), as-built plans and disassembly instructions, if provided after construction, can aid deconstruction experts easily.
21	User Participation	Involving the end-user or property manager will prevent maintenance decisions that hinder disassembly. Renting the facility as a service that is repaired and maintained by the supplier can also help with material reusability.
22	Disassembler Expertise	The competence of the disassembler pertains to both worker expertise and labor practice and their expertise in disassembly can make the disassembly process simpler.
23	Number of Operations	The number of actions necessary to disassemble a product relies on a variety of factors, including tools, connection type, and accessibility. More procedures necessitate additional time, resulting in increased costs. Reduced labor resulting from fewer operations saves labor expenses. This increases the economic incentive for disassembly and is therefore a process-based factor influencing disassembly.
24	Deconstruction Safety	At the end of a building's useful life, it must be deconstructed safely. There are numerous standards governing construction and demolition safety plans. However, there are no formal deconstruction safety measures in place, which is crucial because the operations cannot proceed without safe disassembly.
25	Disassembly Costs	Costs may be an impediment to deconstruction. There is a prevalent misconception that deconstruction costs are higher than demolition and disposal. However, research by Rios et al (2015) indicates that this is not always the case. A reduction in disassembly time and expenses can boost the deconstruction's feasibility. In addition, the residual value of materials can aid in reducing expenses relative to demolition. According to Guy & Ciarimboli (2005), if "Upfront, operating, and back-end" expenses in supplying the services of the built environment are addressed in the initial building design, the financial model can change, and the financial viability of disassembly can grow.
26	Disassembly Time	According to Vanegas et al., (2017), disassembly time and disassembly costs are strongly related, as labor expenses are one of the largest contributing factors for deconstruction; hence, van Vliet (2018) considers labor costs a financially based disassembly component. Disassembly can take anywhere from three to eight times longer than mechanical demolition. According to Rios et al (2015),

		deconstruction may not be a viable option to demolition when time is of the essence.

Figure 132 highlights the weight assigned to the technical factors in bold were chosen as factors to be included the updated BCI. There are some similarities with Durmisevic (2006) and Arko van Ekeren (2018)'s disassembly factors' subcategories and their assigned weights but others have been changed.

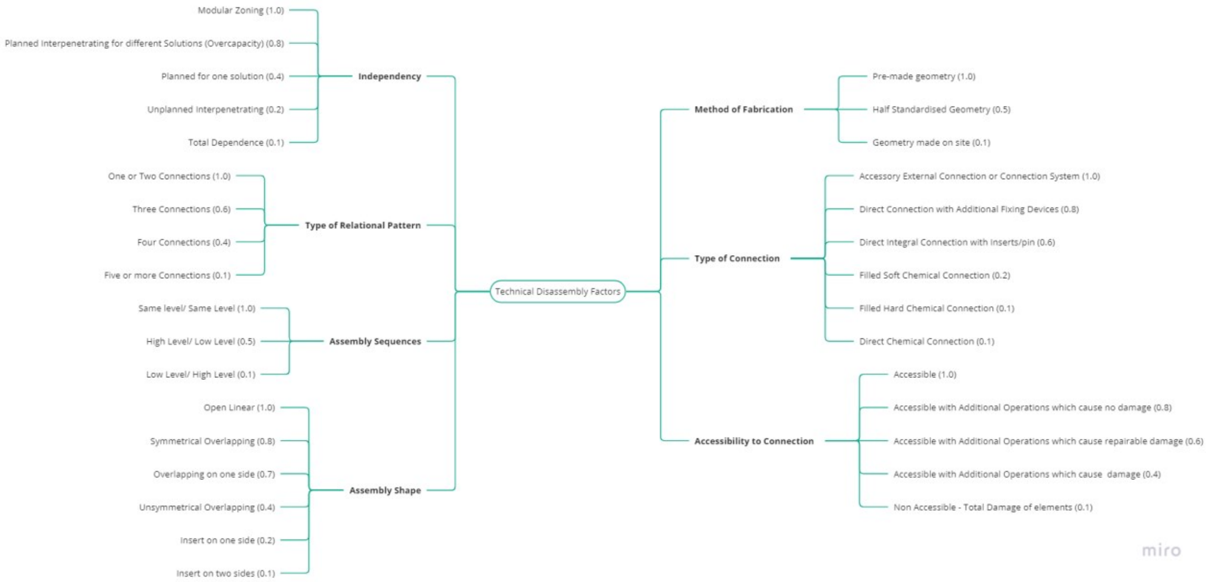


FIGURE 132 WEIGHTS OF TECHNICAL DISASSEMBLY FACTORS INCLUDED IN UPDATED B.C.I, VAN VLIET (2018)

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13. Appendix F: Stages, Phases and Processes of a Building Lifecycle

Stages of a Building Lifecycle

Design Stage

❑**Feasibility Study**
- Strategic Brief
- Site Analysis
- Zoning Analysis
- Project Scope
- Building Program
- Project Budgeting
- Selection of Project Team

❑**Concept Design**
- Outline Specifications
- Schedules of Accomodation
- Planning Strategy
- Cost Plan
- Procurement Options
- Programing and Phasing Strategy

❑**Detailed Design**
- Architectural Detailed Design Model
- Structural Detailed Design Model
- Services Detailed Design Model

❑**Post Design Phase**
- Document Handover
- Tendering

Construction Stage

❑**Pre Construction**
- Site Acquisition
- Selection of Project Team
- Permissions
- Mobilisation

❑**Material Procurement**
- Selection of Suppliers
- Material Supply

❑**Construction**
- Site Clearance
- Surveying and Building Layout
- Excavation
- Foundation
- Frame and Roof Construction
- Cladding Installation
- Fitting out
- Landscaping

❑**Monitoring**
- Health and Safety
- Construction Progress
- Inventory
- Budget
- Waste Disposal

❑**Handover and Closeout**
- Preoccupancy Evaluation
- Corrective Measures
- Payment
- Site Handover

Operation and Maintenance Stage

❑**Requirements Management**
- Requirement Planning
- Contracting and Outsourcing

❑**Commissioning**
- Planning
- Cordination

❑ **Operation**
- Asset Operation
- Energy Management
- Hazardous Waste Management
- Recycling
- Indoor Air Quality
- Inventory Management
- Communication Management
- Alteration Management
- Relocation
- Disaster and Prevention Recovery

❑**Maintenance**
- Planned Maintenance
- Preventive Maintenance
- Corrective maintenance
- Front-line maintenance
- Predictive maintenance
- Reliability Centered maintenance

❑**Post Occupancy Evaluation**
- Occupant and owner specific evaluation
- Monitoring of building's environment strategies
- Assessment of design quality of building

Demolition Stage

❑**Pre Demolition**
- Pre Demolition Assessment
- Cost Estimation
- Planning
- Inventory Managemen and inspections

❑**Demolition**
- Site Preparation
- Utility Processing
- Asbestos Removal
- Soft Strip
- Superstructure Processing
- Slab and Foundation Demolition
- Site Finishes

❑**Material Disposal**
- Waste Management Plan
- Waste Seggregation
- Waste Disposal

FIGURE 133 STAGES OF A BUILDING LIFECYCLE

13.1 Introduction

A building must go through several stages before it reaches it end in a linear economy. The building projects in the construction industry may differ in size, budget, contractual agreements, completion time or use, but they must go through these stages. The design stage comprises of ideating and agreeing on client requirements and creating drawings and models to be used in the construction stage. In the construction stage, the actual construction of the building takes place, which is then given to the operation agencies hired by the client to be used by users in operation and maintenance stage. In a linear economy, this stage is preceded by the demolition stage where the building turns to waste. brief about building data and querying.

13.2 Design Stage

The design stage is the first stage in the building lifecycle. The decisions taken in the design stage affects the subsequent stages of the building lifecycle drastically. Hence strategies followed in the processes in a design stage are crucial for the project. It comprises the following phases, as shown in Figure 134 .

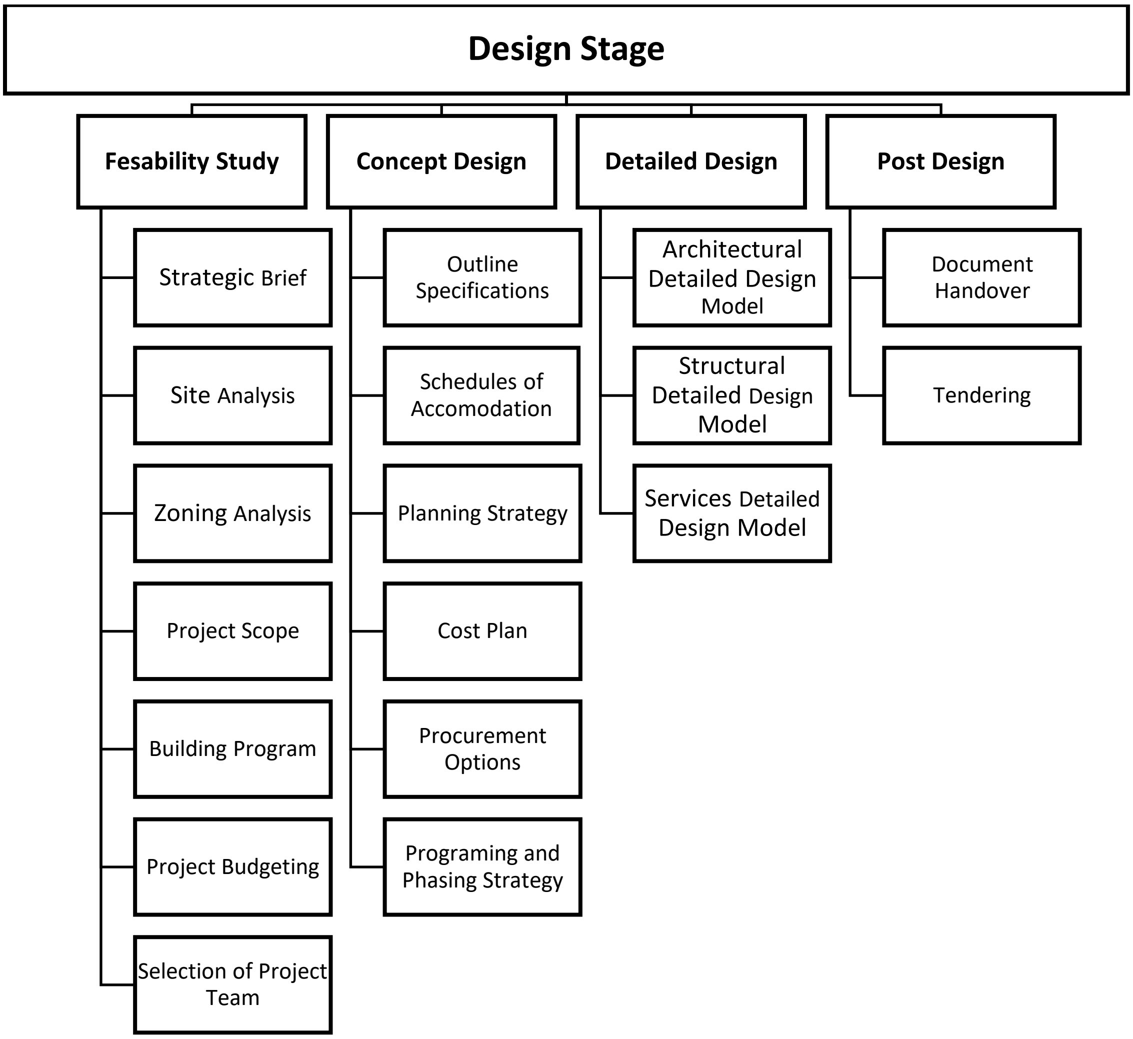

FIGURE 134 PHASES IN DESIGN STAGE

The Table 41 below explains the critical processes of the phases of the design phase.

TABLE 41 PHASES AND PROCESSES IN DESIGN STAGE

S. NO	PHASE	PROCESS NAME	DESCRIPTION
1	Feasibility Study	*The feasibility study consists of strategic brief, development appraisal (site and zoning analysis), project scope, building program, project budgeting and project team selection as explained below.*	
		Strategic Brief	The client decides the following about the project that needs to be built. •Client Needs and Requirements, in enough detail to allow the appointment of consultants. This is termed a strategic brief. • Purpose of the project. • Possible sites on which the project can be built. • Size of the project.
		Site Analysis	Site Analysis is critical and involves a lot of different stakeholders having different responsibilities. Some of them are listed below. • Client hires a land surveyor to survey the site. • Investigation of public transport, roads and other means to access the site is investigated • Architects, with the help of municipal bodies, investigate the availability of essential utilities like freshwater, electricity, plumbing, sewers near the site. • A geotechnical surveyor analyse the soil samples to detect the presence of hard rocks, fossils and send samples for soil testing, fault lines, drainage zones. • Site analysis for local weather is conducted.
		Zoning Analysis	Zoning affects what type of building can be built. It can also extend to property ownership investigation. It caters the following issues. •Building use and maximum occupants, which states whether it has to be a commercial building or a residential building •Property Air Rights, which cater to what can be built on a property as per zoning restrictions, determined by permissible floor area ratio. •Deed Restrictions, which can restrict the development choices. •Easements, which are rights to access the property by other parties. •Property Liens, or legal claims made by another party on land. •Legal use of property according to zoning regulations of the municipality. •Distance from the street. •Permissible build area. •Permissible parking types and their corresponding sizes. •Other special considerations like landmark or historical status built rules.
		Project Scope	Based on the client requirements, site and zoning analysis (development appraisal), the project scope is defined for the architects and other stakeholders to conduct their actions.
		Building Program	This includes the type of functional spaces based on zoning requirements and project scope. This also covers assessment of building already existing on the site focusing on hazardous material assessment, structural inspection, building system assessment and energy efficiency assessment. This is done based on a preliminary business case based on an evaluation of similar facilities.

		Project Budgeting	Based on the project scope and client requirements, a construction manager hired for this phase can give time and cost budget. This is the part where the consultants carry out initial cost appraisal at the request of the client. These include assumptions about the nature of the project, location-based cost estimate, cost adjustments based on market conditions and inflation, land cost, purchase prices, legal and agent fees, stamp duties, demolition cost for existing buildings if any, consultant team fees, an estimate of running costs, building cost based on comparable projects, fixtures fitting and equipment expenses, relocation costs, promotion and marketing costs, planning fees, insurance, grants, lifecycle cost of similar projects and much more.
		Selection of Project Team	Based on the strategic brief and subsequent processes, a team is formed by adding members one by one for the feasibility study and the following phases.
2	Concept Design	*The concept design takes place after feasibility studies. It consists of an initial design idea (concept design), and its development where it turns into a broader functional and practical scheme (schematic design). These are the processes of the design phase based on work involved.*	
		Design Concept	The design concept is one among the many initial ideas of how the building may appear that are then presented to the client for approval.
		Outline Specifications	An outline specification is a brief description of the main components to be used in construction such as substructure, superstructure, cladding, roofing, internal walls, partitions and doors, ceilings, flooring, finishes, lighting, heating, ventilation and air conditioning, water supply and drainage and other unique installations
		Schedules of accommodation	It is a list of accommodation facilities that are necessary for the end-user of the building and include room's reference number, location, name, areas, type and description. It also gives an idea about the type of occupants, the relationship between spaces, furniture, fixture and equipment requirements, environmental and user health requirements. This schedule provides the minimum space requirements for the building scope.
		Planning Strategy	The planning strategy is defined based on the planning policies of the municipality and the country. This process is essential to check if the design concept chosen by the client caters to the guidelines mentioned in the planning policies of the area.
		Cost Plan	In the concept stage, elemental cost plans are carried out. The elemental cost plan comprises of primarily construction costs and breakdown the cost limit of the building into cost targets for each element of the building. This leads to a cost break down structure (CBS) and work break down structure (WBS) and is developed in further phases of building lifecycle. The cost plan is crucial as it optimises the project steps such that the cost for project implementation and Mantainence is under budget with some amount given for unforeseen delays.
		Procurement Options	This process includes selection of the type of agreement that client enters with the other stakeholders for the whole or part of the building lifecycle.
		Program and Phasing strategy	This process develops a strategy to define the phases of the construction project and the sequence in which they are planned to be completed. Phases implies dividing a complex construction project into parts based on type of works involved in the building or the sections of a building.

		Based on the functions, the concept design provides models with the following information	
		Architectural concept design model	Architectural concept design comprises of concept and schematic design. It involves bringing an idea in form of 3D model or sketches that meet the client requirements. After client's approval of the concept design, a schematic design is obtained with outlines specified along with labelling rooms and adding relevant information to the architectural model. Factors such as location, landscape, building's dimensions and appearance and sustainability parameters are taken into consideration.
		Structural concept design model	Usually this is given after the architectural concept design is approved by the client for more detailing. It includes preferred foundation system, frame system, structural grid, size and spans of beams, loads, joints, critical openings in structural walls and floors, fire protection, edge details, and wind bracing elements.
		Services concept design model	A concept design model by the service engineer includes parameters focusing on environmental control strategies, geothermal requirements, drainage systems, energy budget, energy targets and sources, emission targets, acoustic information, solar and shading methods and insulation techniques.
3	Detailed Design	The detailed design phase is the phase where work is done in detail on the architectural and engineering aspects of the design and the phase ends with approval of the owner. It generates three different model types as explained below which are then merged and clashes are removed before consent of the client to move to the post design process of the design stage. A detailed design report is generated at the end of this stage.	
		Architectural detailed design model	At this point, the schematic architectural model is further developed after client's approval to add details to generate plans, sections, elevations, and 3D visualisations. This stage also consists of detailed layouts, facades, construction material to be used for generation of cost information and quantity of elements used for the architectural design of the building and subsequent structural and services design of the building. Further consultations with relevant authorities are done to make the information generated legal and binding.
		Structural detailed design model	The detailed structural model is made after the concept model is approved based on the strategic brief. It is an iterative process where designs are reviewed by architects and engineers and discussed again till a final approval is made. The design approved usually is dimensionally correct and coordinated describing all the main components of the building and how they are built together. Furthermore, the model should be investigated for stability, strength and rigidity by determining the suitable proportions, dimensions and details of the structural elements and connections. Detailed structural design is followed by the production information for the construction team to enable the project to be built in the post design phase of the design stage.
		Services detailed design model	The detailed service model is made in coordination with the architecture and the structural model and is an iterative process that include information such as plumbing and drainage, ductwork, heavy pipework, electrical connections and others.
4	Post Design	Document Handover	In the process, the architect and engineers finalise all the technical design and engineering including heating, ventilation and air conditioning systems, plumbing and drainage, electrical and gas lines, energy calculations, structural engineering and detailing, and all products and materials. The architect produces multiple drawing sets including a filing set for municipal and other relevant government bodies' approval from the and a collection of Construction Drawings for contractors and suppliers. Apart from

			that the lead consultant of the client depending on the contractual arrangement, create a detailed design report that include above mentioned documents and others like use of materials and their potential of reuse, recycle and waste management plan during construction; fire, health and safety strategies; risk assessments, cost plans and procurement strategies if mentioned in the contract or regulations laid by the local authorities.
		Tendering	After the previous process, the client or client's representative either select a group of suppliers and contractors or release the relevant information in public in an attempt to solicit bids and hire the contractors and suppliers with the proposal they seem appropriate for realisation of project.

13.3 Construction Stage

The construction stage starts after the design is finalised and the tendering process to hire contractors and suppliers is completed. There are separate contractual agreements under which this process takes place. And the methodology used for construction also may affect the operations in the construction stage. However, the phases involved broadly during this phase can be listed as in the Figure 135.

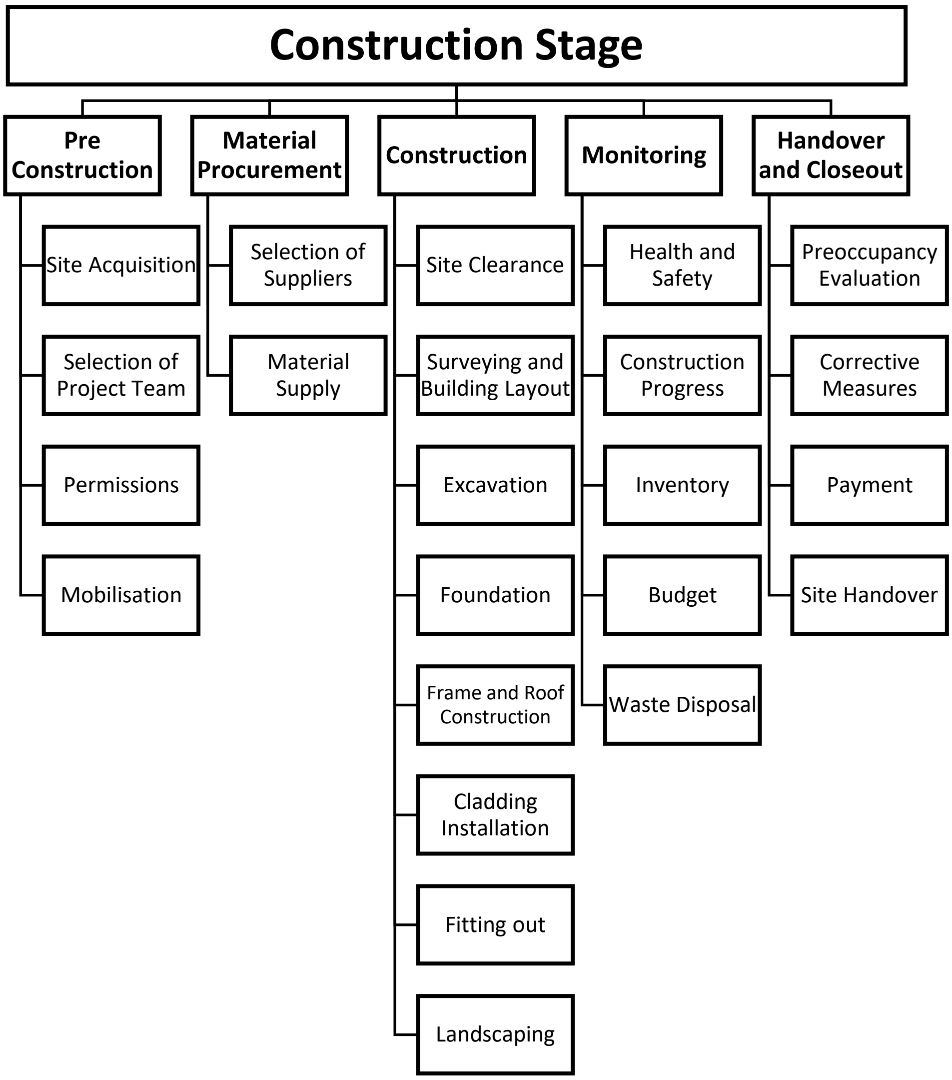

FIGURE 135 PHASES IN CONSTRUCTION STAGE

The processes in the construction stage are explained in the Table 42.

TABLE 42 PHASES AND PROCESSES OF CONSTRUCTION STAGE

S. NO	PHASE	PROCESS NAME	DESCRIPTION
1	Pre Construction	Site Acquisition	This phase is carried out when the client usually does not own the land. This process continues from the design stage, where site requirements are laid out and evaluation criteria is established, and a site is selected after a rigorous valuation done by hired consultants and the project manager as per the needs of the client. Legal consultants are appointed to discuss contract for the site acquisition after relevant investigations are conducted
		Selection of Project Team	The design phase ends with tendering processes where a contractor is hired based on a procurement policy adopted during the construction. The contractor then hires a team of people who act as advisors and sub-contractors to execute the structure according to the client's requests.
		Permissions	Before construction process starts there are permissions that are needed to be obtained based on the municipal rules, national rules and the land use. In Netherlands, it is the *Bouwbesluit* or the building decree against which the municipal bodies check permit applications for new and old construction. Apart from that zoning regulations and aesthetic issues are also needed to be verified.
		Mobilisation	The mobilisation is all the work the contractor, client and his consultant team might take just before the actual construction starts. The client and his consultant team must appoint inspection teams, engineering teams to verify that building complies with the necessary regulations and put procedures in place to move goods on site for effective operation during construction stage. They are also responsible for analyzing contractor's master program and hold the contractor accountable for quality of construction. The contractor arranges meetings to discuss responsibilities in the contract in detail, discuss construction processes, assign obligations to hired subcontractors and experts, establish a communication protocol, create a master program for construction works.
2	Material Procurement	Selection of Suppliers	The contractor based on the requirements set by the client and his consultant team select suppliers to supply inventory for construction work. This is usually done through private network of the stakeholders or tendering.
		Material Supply	The material to be supplied by the different suppliers or done by scavenging material from second-hand sites or nearby demolished sites should be at the site according to the schedule of the work. It is also essential to store the materials safe and monitor for safety. It is vital that the material meets the standards based on the contractual requirements.
3	Construction	Site clearance	The site is prepared for construction by removing unwanted material on the site such as vegetation, old building, or filling up the site for construction purposes.
		Surveying and Building Layout	The ground after being cleared is set out by transferring the levels on the drawing to the ground. This is done by setting up a temporary benchmark, a baseline and horizontal and vertical controls as the construction progresses. The other important spaces needed for construction are also set up such as inventory spaces, temporary sheds, monitoring bases and more.

		Excavation	Further excavation is done to set up the site for laying down the foundation such as trenches or building up a basement space for purposes like parking or making roads or drainage spaces.
		Foundation	After excavation, foundations are provided to support the superstructure. Foundation can be of various types depending on different applications or conditions like type of load, water presence, space availability, noise and vibration and other ground conditions. They can be shallow like footing, pads or rafts or deep foundations like piles or diaphragm walls.
		Frame and Roof Construction	Depending on the design of the building or the infrastructure facility, after the foundation, the frame is designed. It provides the structural support to the building. Based on material, it can be a timber frame, concrete or a metallic frame (generally steel) depending on the project or a composite frame. Based on arrangements, it can be a column beam, balloon frame, braces, portal frame with various kinds of roof systems.
		Cladding Installation	The cladding is the components of building like weather exposed outer layers, insulations, brackets, cavity barriers that are attached to the primary structural elements and help in transferring loads such as wind load, snow load and self-weight to the structural components of the building erected in the frame construction. They can be curtain walls, sandwich panels, rainscreen, timber or metal claddings, solar panels and more.
		Fitting Out	When the frame structure and cladding work is done in the building, the interior work also starts at that level of the building. Fitting out basically means installing the necessary lines and finishing the space for the occupant to occupy the space. The shell and core of the building that is frame, cladding and other communal areas are made fit by installing necessary components and furnishing the space. It results into non furnished, semi- furnished or furnished spaces based on the agreement between developer and client.
		Landscaping	The client if needed in the project then goes for landscaping the space around the building or the infrastructure. This work may include works on the landform, the built structures around the building, circulation routes, vegetation, water installations, furniture, lightning, drainage systems and signage.
4	Monitoring	Health and safety	A health and safety plan is necessary in the Netherlands for construction projects that involve several stakeholders, or construction projects that last longer than a month or having more than twenty workers are at work at the same time or those that require Sociale zaken en werkgelegenheid (SZW) inspection. It usually includes risk inventory and evaluation of planned project activities and emergency response measures(Nederland Rijksdienst voor Ondernemend, 2020).
		Construction Progress	During construction, work is inspected for compliance with the terms of the permit issued against the building decree and its violation is a punishable offence.
		Inventory	Monitoring inventory is crucial for avoiding unnecessary costs and proper planning of materials, labour and equipment is important for that purpose. Inventory maintenance task include monitoring tools and consumables with details of suppliers and RFID scanners. It also has a contingency plan and applications for better monitoring.
		Budget	It is essential to control costs in the project by proper planning and predicting probable future deviations. The scope for cost control is

			limited to make the project go according to the plan without any potential delays. However, without proper budget monitoring, it gets complicated.
		Waste Disposal	The construction and demolition waste in the Netherlands need to be recycled and reused. Hence, a waste disposal plan and proper monitoring is necessary for the waste outflow and inflow back to the site for reuse directly or after recycling.
5	Handover and Closeout	Handover and close out takes place after the construction has ended. In this phase payments are made by the client and the contractor during or after the preoccupancy evaluation. Some corrective measures are taken if necessary and the handover of information takes place.	
		Preoccupancy Evaluation	The contractor remains responsible for rectifying defects during a period known as the 'defects liability period' (or 'rectification period') which typically lasts six to twelve months. The contractor has to carry out inspections and prepare a detailed project information model if necessary in this stage to be reported to the client for further discussions on the corrective measures that the contractor is liable to fix based on the agreement the parties entered into and to verify against the client requirements.
		Corrective Measures	Based on the mutual agreement and legal actions taken if any by the parties, the contractor with other consultants do rectifying measures and prepare the final project information model and handover report.
		Payment	The client pays the contractor and other parties the payment on the work that was done. Cost and budget plans are revaluated, and profit and losses are evaluated in this phase.
		Site Handover	This is a last step when the site is handed over to the client. This is where the important reports for possible Maintenance and operation measures are reported, and the project information model is transferred for use by the operation and maintenance company and the clients.

13.4 Operation and Maintenance Stage

The operation and management stage of construction is a part of a broader term “facility management”. (Becker, 1990) defined it as *“the discipline responsible for coordinating all efforts related to planning, designing, and managing buildings and their systems, equipment and furniture to enhance the organization’s ability to compete successfully in a rapidly changing world”.*

A similar definition by (Moore & Finch, 2004) considered facility management as *"the development, coordination, and management of all of the non-core specialist services of an organization, together with the buildings and their systems, plant, IT equipment, fittings and furnishings, with the overall aim of assisting any given organization in achieving its strategic objectives".*

Facility management is based on an agreement between associated parties to maintain and develop services which support and improve the effectiveness of activities associated with a space which also include a building. Operation and Maintenance is a part of it as is seen in the Figure 136.

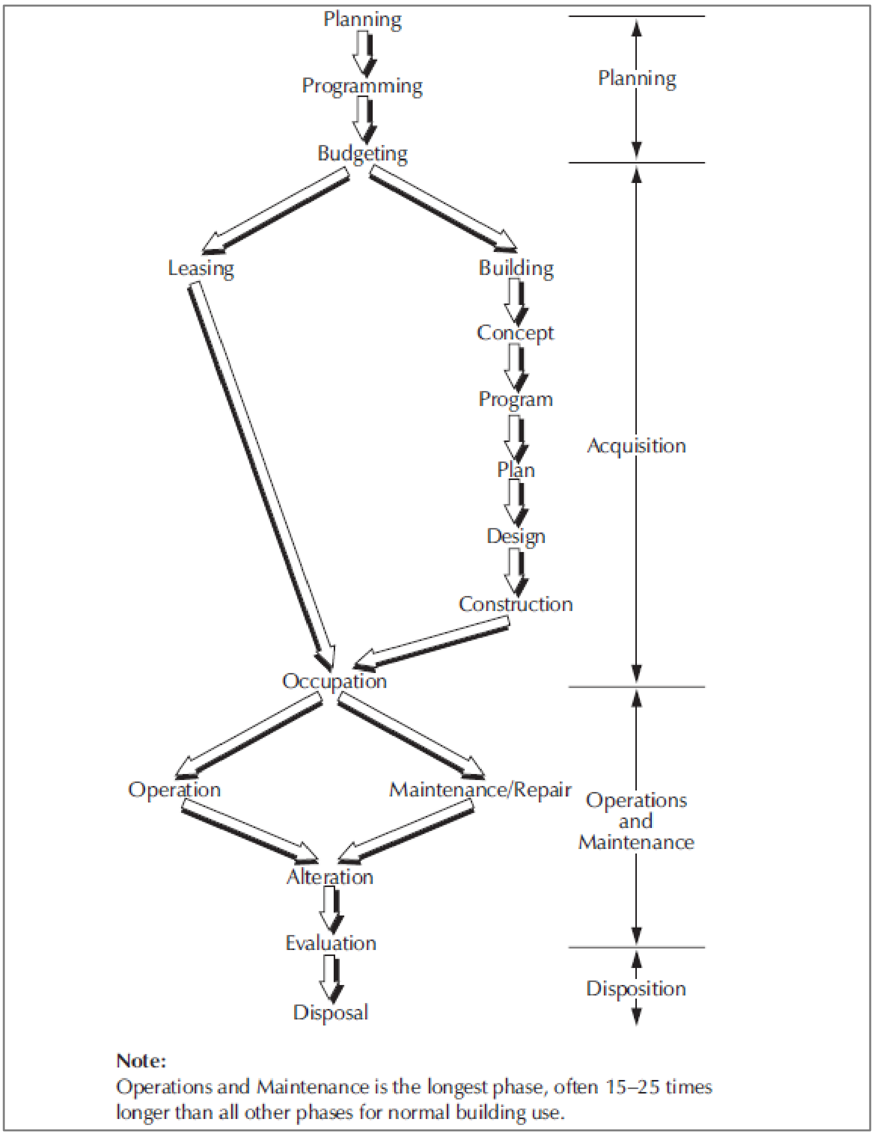

FIGURE 136 FACILITY MANAGEMENT LIFECYCLE (COTTS ET AL., 2010A)

The operation and maintenance stage comprise of occupying the building, its operation and maintenance, its alteration if needed and further monitoring and evaluation before entering the demolition stage of the building lifecycle or a facility lifecycle. These are explained in Table 43.

TABLE 43 PHASES AND PROCESSES IN O&M STAGE

S. NO	PHASE	PROCESSES	DESCRIPTION
1	Requirements Management	Requirement Planning	This phase of operation and maintenance stage has a focus of defining requirements based on five elements, namely people involved in management; location of the key asset in the facility to be managed; the time to coordinate, operate and maintain an asset or family of assets; the tools, equipment and materials required; and the information needed. Based on the requirements, the policies are made, and further activities are carried out.
		Contracting and Outsourcing	As stated before the operation and maintenance services are performed partially by the client's associate or outsourced. Factors such as owner and building's user goals and vision, selection of vendor, type of contract, communication

			structure, executive support, presence of outside experts, personnel issues, near term financial justification are the most important factors that influence this process (Cotts et al., 2010b).
2	Commissioning	Planning	Based on the requirements defined in the previous phase, it is important to create Mantainence plan and capital plan which helps owner helps control what happens at each lifecycle stage by ensuring that adequate maintenance is performed to achieve the full service life from the assets and reserve a budget for proper Mantainence of assets. The Mantainence plans can be reactive like replacing damaged inventory, or preventive maintenance or replacing or repairing machinery before it breaks or predictive maintenance where the failure time is predicted, and maintenance schedule is defined based on the prediction or a combination of those.
		Cordination	The coordination team with a work centre is set up for receiving requests and requirements from and for the various stakeholders and users of a building. These requests or requirements are based on whether a work is needed to protect assets or is detrimental to operations or is a routine work. The work can be preventive, reactive, or predictive. It also include service orders, alteration projects or revenue based work and evaluation projects(Cotts et al., 2010b).
4	Operation	The operation process is the most expensive part of the building lifecycle which is a multifaceted process with an increasing need for automation and if not done properly cost a lot of additional time and money.	
		Asset Operation	Heating, ventilation, and air-conditioning (HVAC), mechanical and electrical vertical and horizontal transportation. major electrical and emergency power and plumbing system are some of the assets whose operation and management in the phase is a critical routine work.
		Energy Management	It is a process that spans every asset operation. A detailed energy consumption baseline is established for each asset operation to evaluate annual performance of the different systems. The stakeholders involve steering committee with a senior manager, budget director, facility manager, line managers and technical committee with a facility manager and energy manager(Cotts et al., 2010b).
		Hazardous Waste Management	This process involves managing waste such as asbestos, medical waste, nuclear waste. The first step is designing a waste management plan, appointing an abatement operation and Mantainence manager, hiring teams to do independent testing if required, maintaining records of abatement efforts, air quality reports and disposal records, laying down an awareness plan for managing waste.
		Recycling	Recycling plan of a building is the most crucial plan to manage waste that is not hazardous. General waste is usually segregated into paper, aluminium, glass bottles and jars, scrap metal, Styrofoam, electronic equipment, paint, clothes, oil, organic wastes and others. A proper recycling stream requires proper segregation plan, collection points, policies and associated market or subsidies for recycled products and pickup strategies.

		Indoor Air Quality	The contamination of various kinds of pathogens within the building is usually determined by indoor air quality. (International Labour Office, 2011) defines Indoor air quality in a building as a function of a series of variables which include the quality of the outdoor air, the design of the ventilation and air-conditioning system, the conditions in which this system operates and is serviced, the compartmentalization of the building and the presence of indoor sources of contaminants and their magnitude. Proper management procedures of indoor air quality is necessary in the operation process.
		Inventory Management	It is similar to procurement process in the construction phase and is dependent on policies and procedures set by various stakeholders. Some key parameters of inventory management are tracking the inventory and repairing and replacing it as governed by policies alongside monitoring its effective use during operation. A major part of inventory management is furniture installation and management.
		Communication Management	Communication systems in a building enable connectivity via platforms like facsimile, telephones, internet hotspots, fibre-optic runs, antennas, communication ducts , cable trays and more. The communication plans are user driven and usually contracted. To have an effective communication overlay, information such as room type, basic power requirements, heat output data and more.
		Alteration Management	Altering the living space in a building is common. Hence alteration management is necessary. Alteration budget and standards are laid before or during the operation phase to avoid diversion of management funds into alteration funds for effective operation of a building. Furthermore, requirements and budget driven restrictive policies is framed to deal with alteration. A control process for information interoperability between operation and alteration division is planned to coordinate ordered changes properly.
		Relocation	Relocation management in facility operations is not limited to management of departmental staff but also include movement to a more suitable space. Relocation budgets are part of maintenance budget. The maintenance manager employs a moving company to move furniture, equipment, and supplies within their facilities.
		Disaster Prevention and Recovery	Disasters, whether man made or natural can occur at any phase of the building lifecycle. It can be an earthquake, fire, robbery or a cyber security attack. A disaster during the operation phase of the building is the most disruptive. Hence a disaster prevention and recovery plan is necessary. It also covers simulations and safety runs for preparing and a disaster recovery budget.
5	Maintenance	Maintenance is the process of warranting building assets retain their aesthetic value and operation efficacy. If not done properly, the building assets can degrade in look and performance. It can affect health and safety of users. There are different maintenance strategies (Design Buildings Wiki, 2020) as listed below.	
		Planned maintenance	It is a scheduled maintenance that must be done on a regular basis such as replacing air filters in AHU units. It does not have a predictive aspect to the maintenance prospects.
		Preventive maintenance	This maintenance is carried out to extend life of assets such as fixing the roof tiles before a thunderstorm.

		Corrective maintenance	It is maintenance that is not planned and happens if an asset fails and get damaged and needs repair to restore functionality.
		Front-line maintenance	This involves maintaining something while it is still in use, such as repainting and decorating an occupied building.
		Predictive maintenance	Maintenance work that is undertaken to avoid failures and has a predictive element to identify defects that could lead to failure.
		Reliability centred maintenance	A combination of maintenance strategies used to ensure a physical asset continues to function correctly.
6	Post Occupancy Evaluation	Post-Occupancy Evaluation (POE) is the process of obtaining feedback on a building's performance in use by showcasing the problems that require immediate action, recognize blocks in operation of a building and act as an aid to compare across projects and over time and use that to improve efficiency. Some key areas for post occupancy evaluation are listed below.	
		Occupant and owner specific evaluation	An evaluation of parameters like environmental comfort and control over indoor environmental conditions, impact of a building’s performance on productivity and performance of facility managers amd occupant’s satisfaction may be considered under this evaluation scheme.
		Monitoring of building’s environment strategies	This evaluation includes indoor conditions such as temperature, noise, light, air quality, ventilation and relative humidity. This also include sustainability and utility audits.
		Assessment of design quality of building	This assessment caters to design quality and performance of a building against industry benchmarks and good practice.

13.5 Demolition Stage

In the building lifecycle the demolition has the most dangerous stage if not safely planned. It requires enough time for planning the works, carrying out essential audits and follow standards set nationally with effective information management. The demolition stage can be divided into the following phases as shown in the Figure 137.

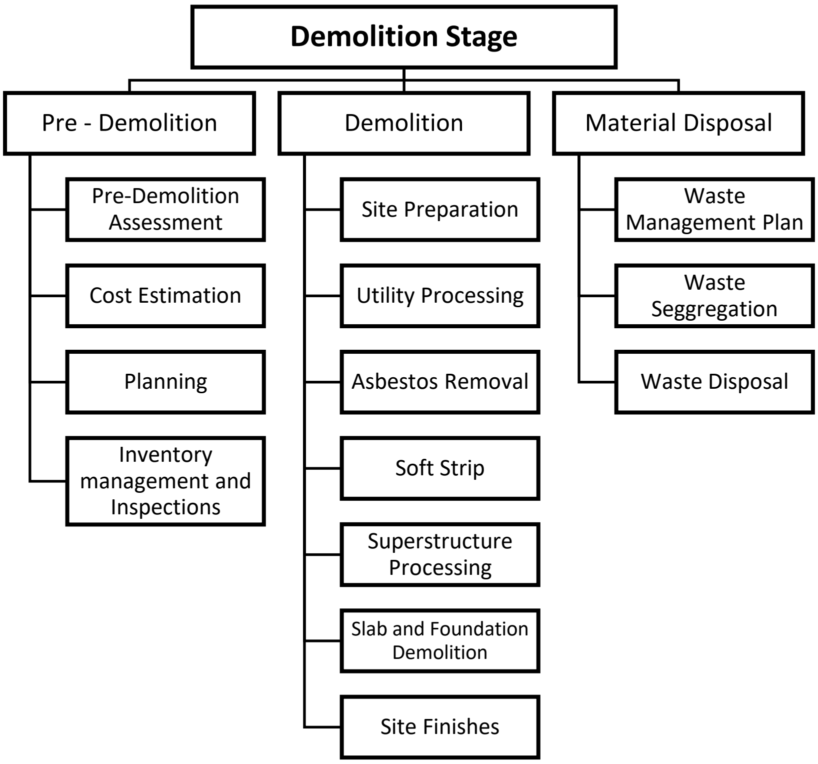

FIGURE 137 PHASES IN DEMOLITION STAGE

Table 44 elaborates the phases and the key processes involved in the demolition stage.

TABLE 44 PHASES AND PROCESSES IN DEMOLITION STAGE

S. NO	PHASE	PROCESS NAME	DESCRIPTION
1	Pre-Demolition	After the decision to demolish a building or a part of it is made, it is necessary to assess parameters and follow some processes before carrying out the actual demolition. The key parameters concerning the pre-demolition phase includes asbestos removal, utility analysis, structural hazards, possible presence of hazardous materials, building's historic use and land use regulations and more.	
		Pre-Demolition Assessment	Pre-Demolition Assessment includes conducting surveys and other necessary investigations to plan the demolition. This includes survey of the building and the surrounding areas, materials used in the building, built technique and presence of explosive material which may result in losing control of the demolition.
		Cost Estimation	After the assessment stage, an estimate of the cost that can be incurred in the whole phase including demolition procedures and waste management is presented.
		Planning	After the cost estimation presented to the client is approved, a demolition plan is made. The plan includes list of permits and rules that need to be obtained and complied with, a safety evacuation scheme, methodology to be followed for demolition along with waste management plan.

		Inventory management and Inspections	The client must survey the site to pick up inventory that can be used or donated. Also, a waste collection team must survey the building to collect the hazardous waste that is in the building.
2	Demolition	After the demolition plan is prepared and site assessed, the demolition phase may include combination of demolition processes like explosion, hand demolition, machine assisted demolition, gas expansion, hydraulic expansion, thermal reaction, drilling and more.	
		Site Preparation	The site is entirely cleaned and surveyed to remove unwanted people from the site before demolition.
		Utility Processing	The water, gas and electricity are cut off and rerouted to the grid. Pipelines and cables are guarded against the demolition. The MEP engineer and the municipal body are involved in the demolition utility processing.
		Asbestos Removal	The asbestos is removed before the building is blasted and stored separately to be disposed of.
		Soft Strip	The building is stripped of all the door and windows frames and returned to the core construction stage.
		Superstructure Processing	The superstructure is demolished with the methods mentioned above and proper care is taken of the adjacent structures or other restraints.
		Slab and Foundation Demolition	The slab, foundations and the risers are then removed, and the ground is refilled as per the local land refill regulations
		Site Finishes	The site is prepared to be sealed off so that it can be reused for other land use purposes that it is intended to.
3	Material Disposal	The last step of demolition stage is disposing the material. This consist of creating a waste management plan, segregating the waste and disposing the waste to the right centres.	
		Waste Management Plan	Building demolition involves dealing with hazardous waste, landfill and recyclable material. Hence the process of evaluating and enforcing waste management plan.
		Waste Segregation	The waste collected must be processed and segregated on site or transferred to waste management plants to be segregated.
		Waste Disposal	Waste is disposed of to landfill sites, waste management plants where it can be recycled, refurbished, crushed, incinerated.

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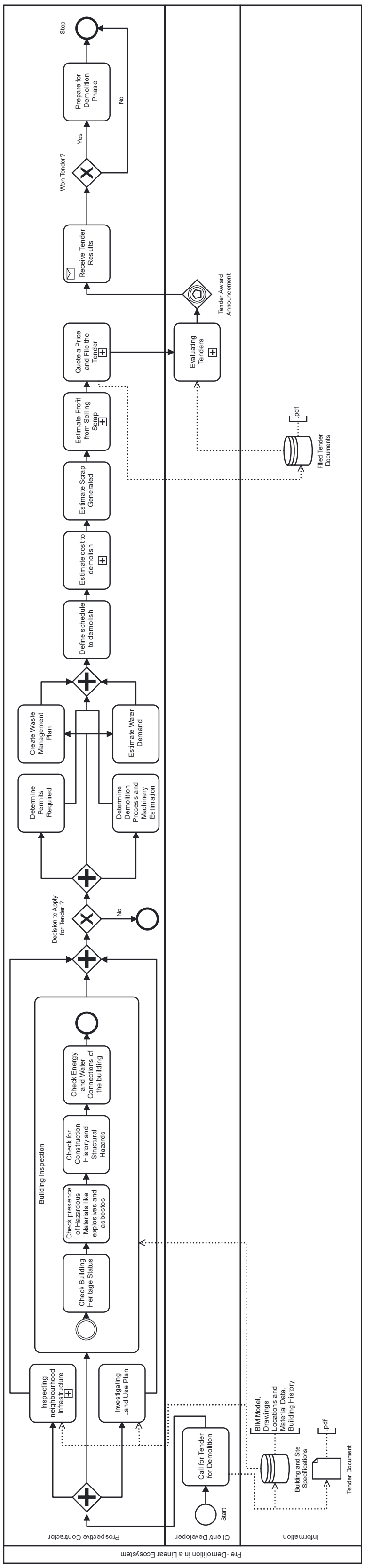
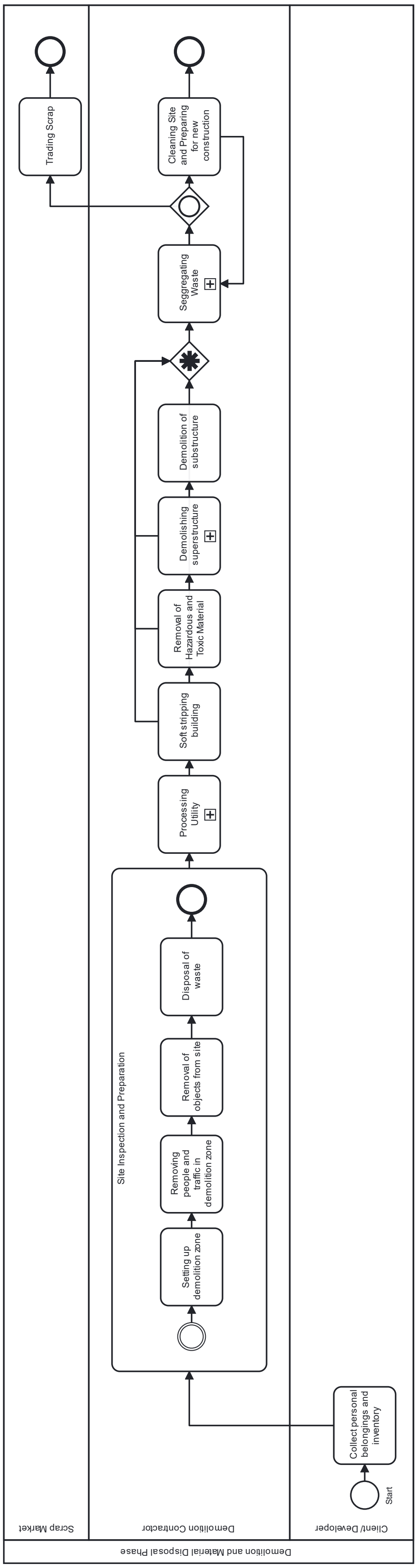
14. Appendix G: BPMN Diagrams

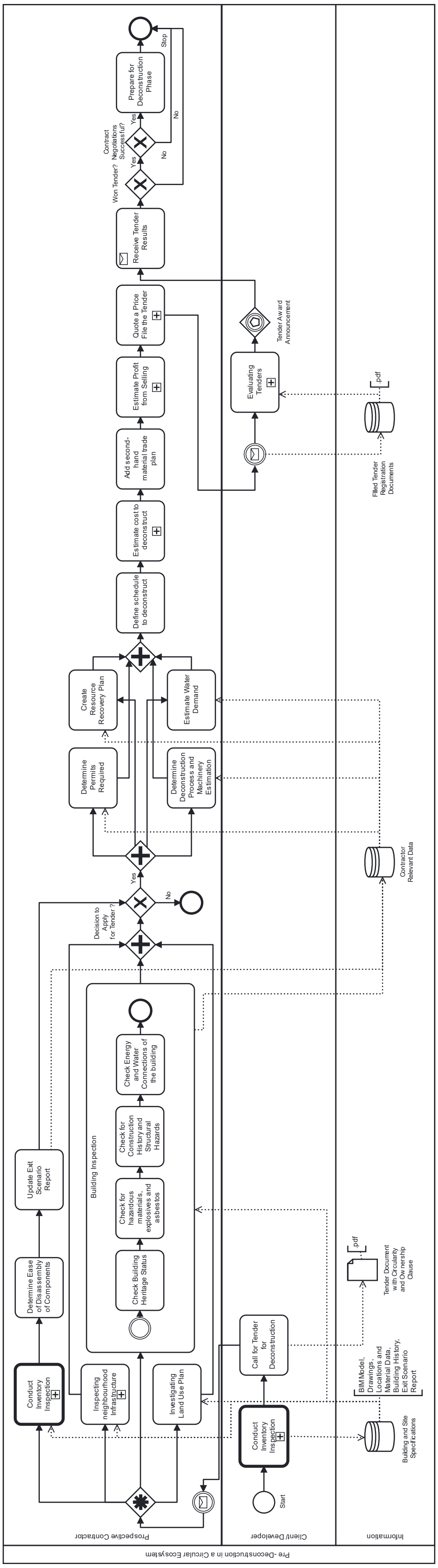
14.1 Figure 39 Pre-Demolition Phase in Linear Ecosystem



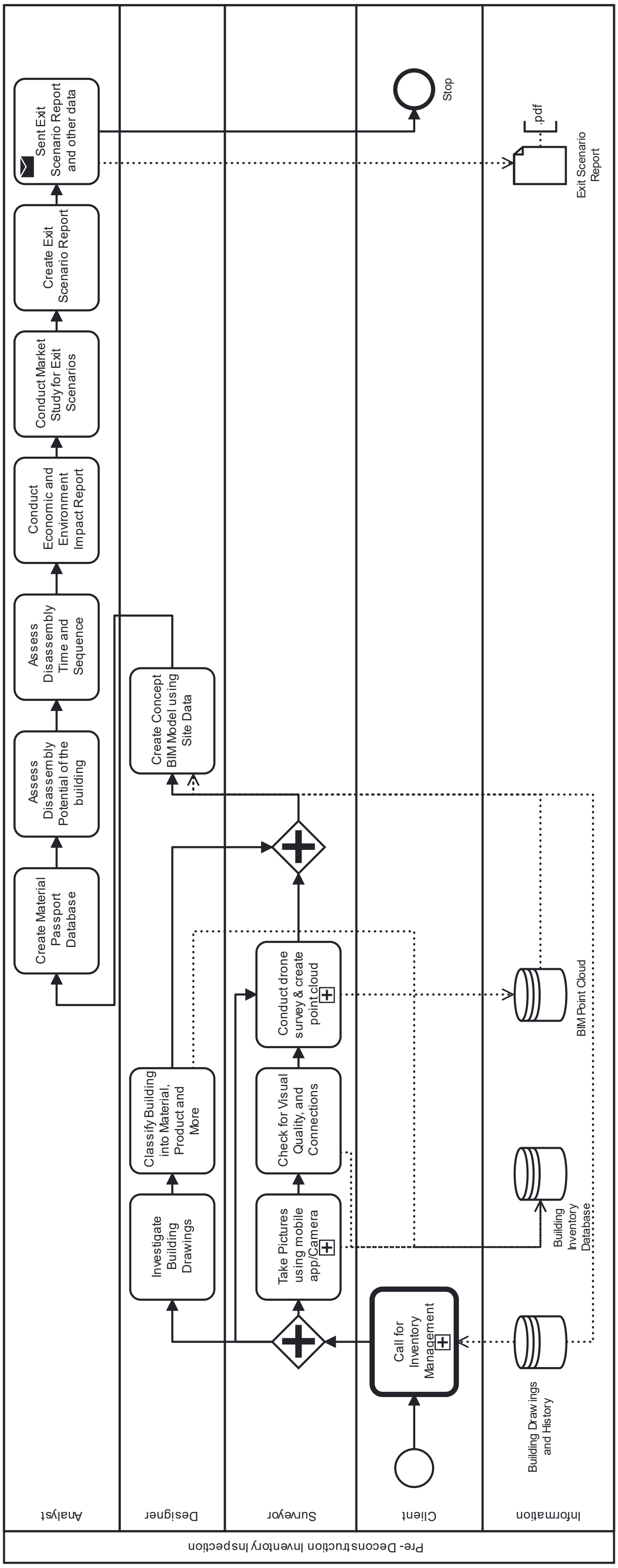
14.2 Figure 40 Demolition and Material Disposal in Linear Ecosystem



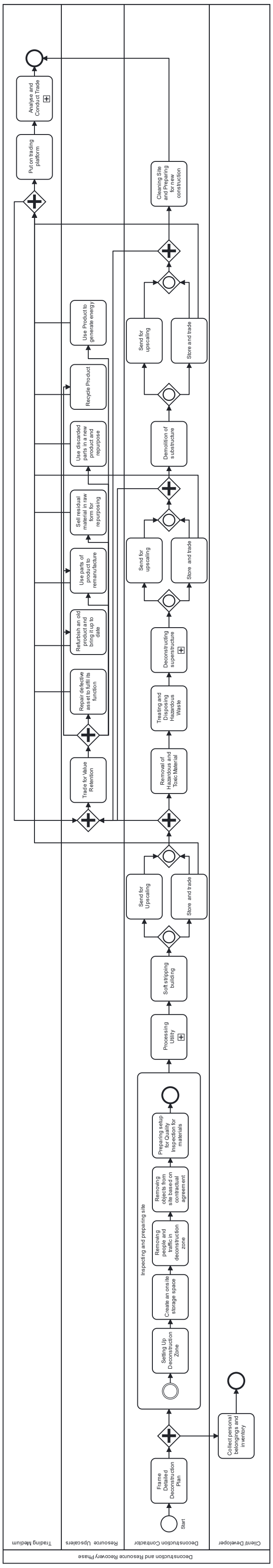
14.3 Figure 45 Pre-Deconstruction Phase in a Circular Ecosystem



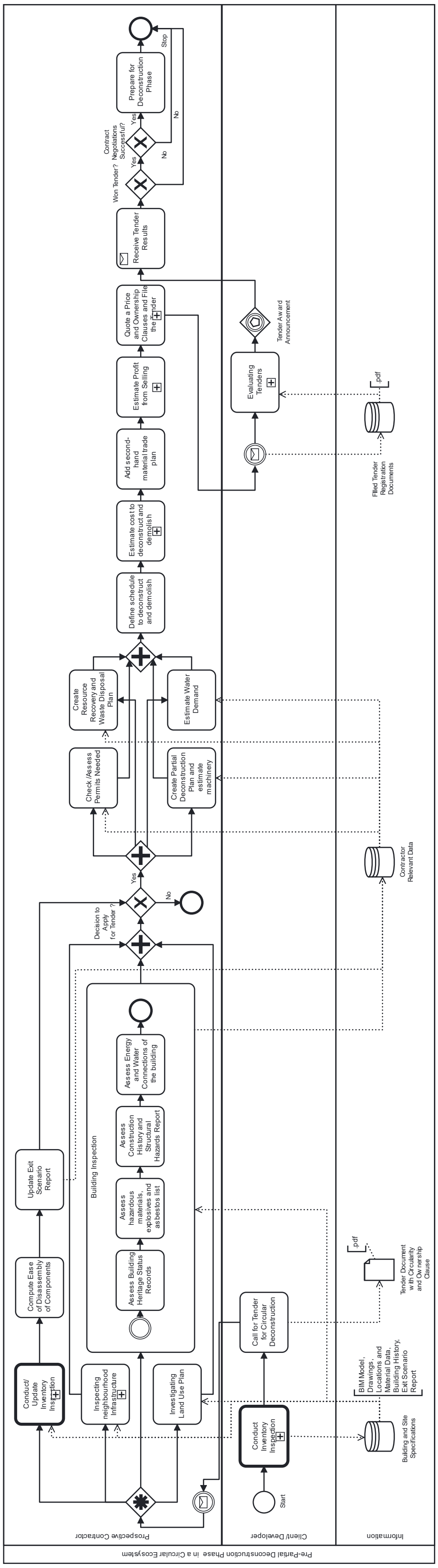
14.4 Figure 46 Pre-Deconstruction Inventory Inspection



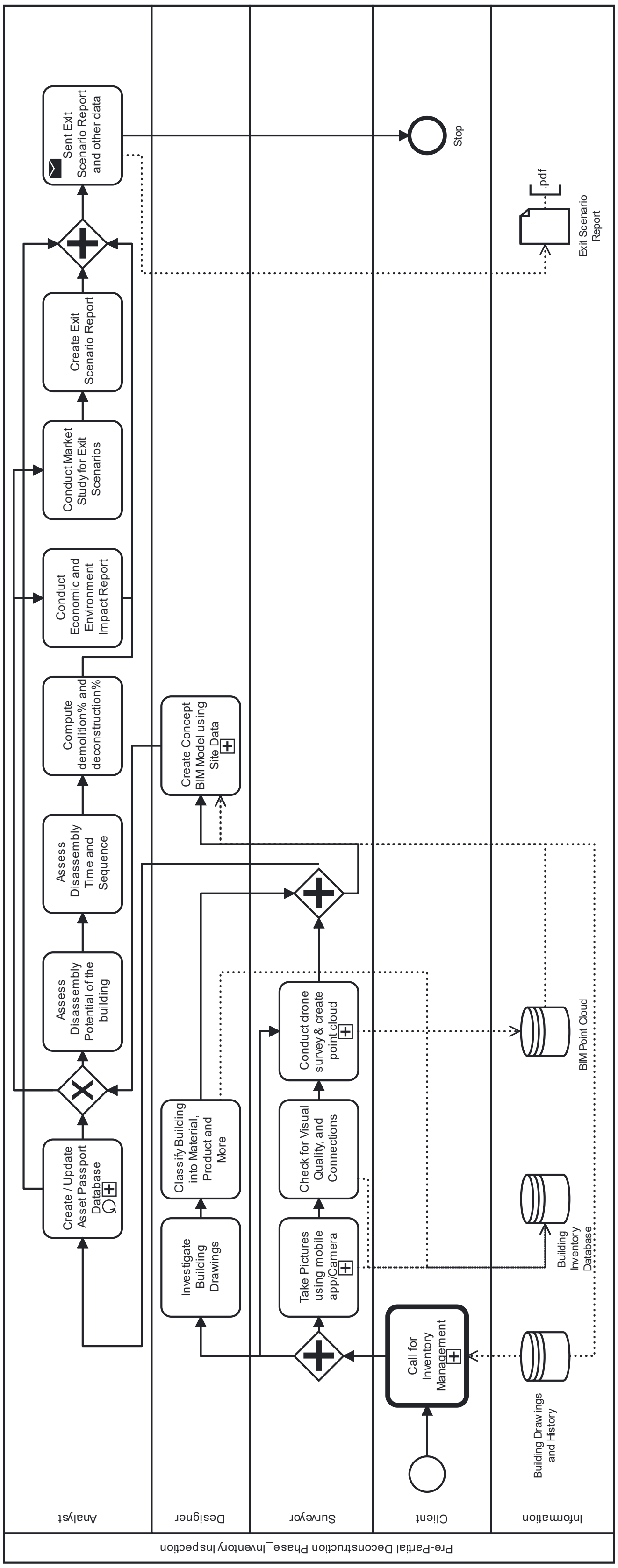
14.5 Figure 47 Deconstruction and Resource Recovery Phase



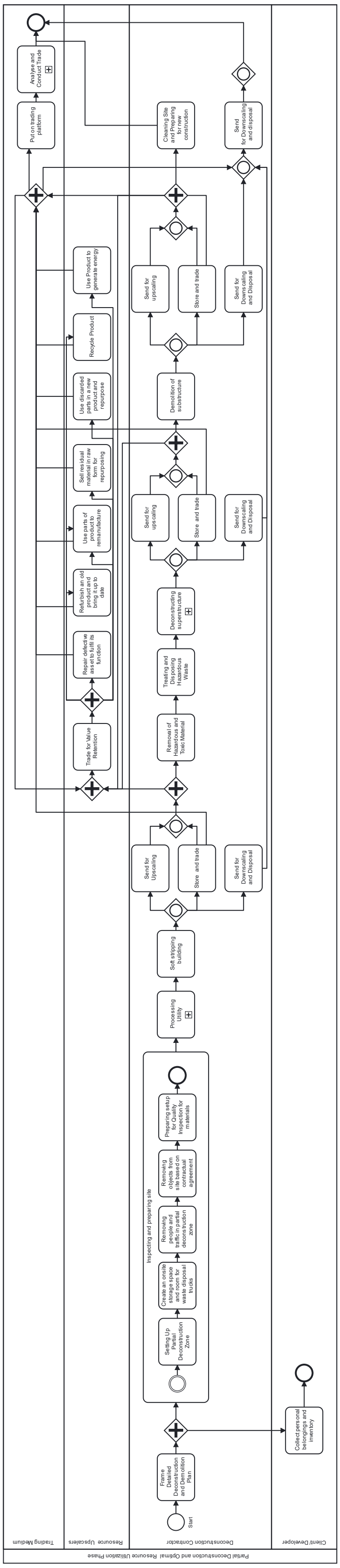
14.6 Figure 48 Pre-Partial Deconstruction Phase in a Circular Ecosystem



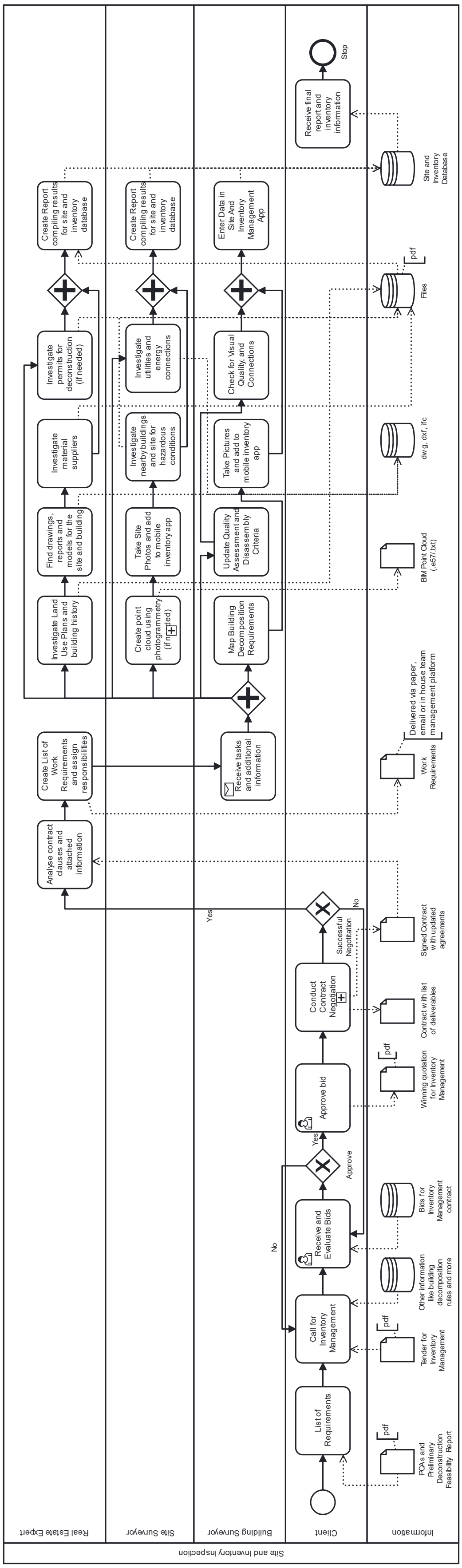
14.7 Figure 49 Pre-Partial Deconstruction Phase - Inventory Inspection



14.8 Figure 50 Partial Deconstruction and Optimal Resource Utilization Phase



14.9 Figure 62 Site and Inventory Inspection Information Exchange



“It is essential to redesign institutes and align them with the cycles of the living world to create an economy that regenerates when the wealth is distributive rather than concentrated without any compromise.”

- Kate Raworth