Reuse potential in architecture

Developing a data-driven approach to implement reused material in new architectural circular buildings.

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I. Abstract

The construction sector is one of the most resource-intensive industries globally, contributing significantly to environmental degradation and greenhouse gas emissions. Transitioning towards a circular economy within the built environment offers a promising solution by emphasizing the reuse of building materials. This paper explores the potential of data-driven design methodologies to facilitate the integration of reclaimed materials into new architectural projects. A structured design tool is developed to assess the reuse potential of building materials, incorporating factors such as material quality, disassembly index and lifecycle performance. Through a case study involving materials sourced from the Megastores shopping mall in The Hague, the research demonstrates how data-driven approaches can a guide for deposition decisions of building materials for new circular buildings. Case studies of successful architectural projects like Biopartner 5, K.118, and Resource Rows give insights into design implementation with reclaimed building materials. This study highlights the critical need for architects to adopt innovative design tools and practices to meet sustainability targets while leveraging the untapped value of donor building.

II. Keywords:

Reuse Building Materials, Reuse Potential, Data-Driven Design Tool, Reuse practices in Architecture, Circular Building principles

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IV. INTRODUCTION

The world's population that will live in cities is rising and by 2030, three billion people need new housing. However, the construction sector in industrialized countries is currently the most resource intensive industry. It utilizes 50% of all materials consumed in Europe and generates 36% of the total waste in the European Union (EU). Additionally, it contributes to 39% of global energy-related greenhouse gas emissions. This impact is primarily due to the sector's linear model of dealing with building materials and resources: take (extract), make (produce), use, waste (dispose) (Çetin et al., 2021).

The Paris Agreement is an international agreement signed by 195 countries and the EU to limit global warming to 1.5 degrees. CO^2 budgets for the Dutch building industry are calculated to achieve these goals. To develop with a low carbon footprint, sustainable use of materials has three major pillars:

1. Prevent
2. Urban mining first
3. Renewable if possible
4. Choose the most sustainable producer

(Ellen Macarthur Foundation, n.d.-a)

4.01 Circular Building Indicators

The challenge for all stakeholders in the built environment is to respond to global housing needs while minimising environmental impacts and achieving the goals of the Paris Agreement. We need to change the building processes and our behaviour. Change is needed rapidly, and because of that, our processes, material, economic system and building norms need to be adjusted. Everything around construction and urban development is up for debate (de Architect, 2024). A transition to a circular model is needed to address the emissions, resource depletion and waste caused by this industry. The concept and model of a Circular Economy (CE) is a system thinking we cannot escape from nowadays. Organisations like the Ellen MacArthur Foundation popularised the vision where the Earth' is seen as a closed system. The circular economy is based on three principles: eliminate waste and pollution, circulate products and materials (at the highest value), and regenerate nature (Ellen Macarthur Foundation, n.d.-b).

Building circulars is a hot topic in the Netherlands. The Dutch Green Building Council (DGBC) is the national civil society organisation dedicated to rapidly making the built environment future-proof with in mind that the built environment greatly influences climate change. Their definition of a circular building is:

> *"A circular building is a building that is developed, used and reused without unnecessary depletion of resources, environmental pollution and degradation of ecosystems. It is built in an economically sound manner and contributes to the well-being of people and the biosphere. Here and there, now and later. Technical elements are demountable and reusable, and biological elements can be returned to their biological cycle."*
>
> - (Framework Voor Circulaire Gebouwen - Nieuwbouw - Dutch Green Building Council, n.d.)

To pursue this, building design becomes not only an examination of the role in the present, but also the role in future from materials to use. Architects and developers will be required to include future scenarios in the design.

4.02 Circular Material Flows

Several organisations like New Horizon are mining the physical building components. Urban mining is a key player in the field that makes the reuse of building components possible. Mining leads not only to conserving resources but also to developing new business models and creating environmental, technical, and social value. Formed by a multistakeholder consortium, the Buildings as Material Bank (BAMB) project has been a pioneer in developing and testing circular strategies and tools to recover value from buildings (BAMB - Buildings as Material Banks (BAMB2020) - BAMB, 2019). However, addressing the lack of cross-sector communication and coordination tools is crucial to enable the broad implementation of a feasible circular design strategy in current construction practice. Digitalisation could provide some of the necessary tools (Çetin et al., 2021).

4.03 Architectural Design Process in Transition

Architects are partly able to enable the shift to a circular economy. A different approach to architectural practices is needed to make the proper design steps to let development happen. For that, we must be critical of the design steps we already know and re-envision architectural outputs when old and new materials are combined. 'Architects and designers are redefining their roles as assemblers of existing materials into forms that are as open and flexible as possible.' ('Ter Steege et al., 2023, p.12)

4.04 Challenge: Reuse of building materials demands a different approach to be successful

The industry is changing to enable the reuse of building materials, and assembly is being reviewed to enable the reuse of building systems. Buildings are being demolished because of different needs, but the building materials, in some cases, are not end-of-life yet. A different design approach is needed to implement these reclaimed building materials in new designs. Other stakeholders within the building industry also need to work together to make reuse implementation happen.

4.05 Experiment: How data can be the backbone of your circular design decision (Design Tool: Data-Driven Design)

To be effective in our actions against climate change, we must be able to measure them. Tools in the building sector, such as the Environmental Cost Indicator (ECI), Life Cycle Analyses, and Embodied Carbon are crucial. Measuring the outcomes allows us to steer our initiatives towards reducing our carbon footprint.

Digital datasets from material banks and donor buildings give insights into the availability of building materials and give insights into circular deposition decisions. More and more buildings are getting Material Passports (MP). BAMB gives this definition to these MP's: "A passport for construction is a digital dataset that records an object in the B&U or GWW sector. It documents what an object consists of (both qualitatively and quantitatively), how it was built and where it is located. It documents the ownership of the whole and/or parts" (What Is Materials Passports - BAMB, 2017). The availability of building materials in digital form like this makes it possible to plan with them, closing the gap between the existing material stock and new ideas for their use (Felix Heisel et al., n.d.). From existing older buildings this data is lacking. To plan with these building materials another approach is necessary to collect this data.

When designing with reused and reclaimed materials becomes a necessity, we need to address that fact in our contemporary design tools. In recent decades, designing with computation-based approaches has emerged rapidly. A script can control raw data. The output of this combination is a data-driven design that gives guidance on design decisions.

A form of data-driven design is Parametric Design (PD) or Algorithm Design (AD). Both terms describe a set of mathematical instructions to help calculate a design output. In PD, geometric constraints and dimensional relationships play a bigger role. Generative Design (GD) focuses on finding solutions to complex problems by algorithms (problem-solving) (Caetano et al., n.d.).

The use of Parametric Design in architecture tends to customize parts for singular projects overly (Felix Heisel et al., n.d.).On the other hand, we have the increased flow of material databases (Honic et al., 2021). Finding a way as architects to translate this data into new design solutions with reclaimed materials is a step forward to the new normal of designing with reclaimed materials.

V. Research Questions

Main question:

What data-driven design method is needed for a design tool with reclaimed materials to make deposition decisions for a new circular residential building?

Sub-questions:

1. What information and methods are needed to facilitate the reuse of building materials to extend the life cycle?
2. How to make the reuse potential measurable to develop a design tool?
3. What constraints does a new circular residential building impose on implementing reclaimed materials into design?
4. What can we learn from architectural projects with reclaimed materials implemented in their design? What characterises the design process of these projects? What design guidelines can be concluded from that to implement reclaimed materials in a building?
5. When availability defines the form of your design, how does it influence your design process?
6. When availability defines the form of your design, how does it influence your design process?

VI. Methodology & reading guide

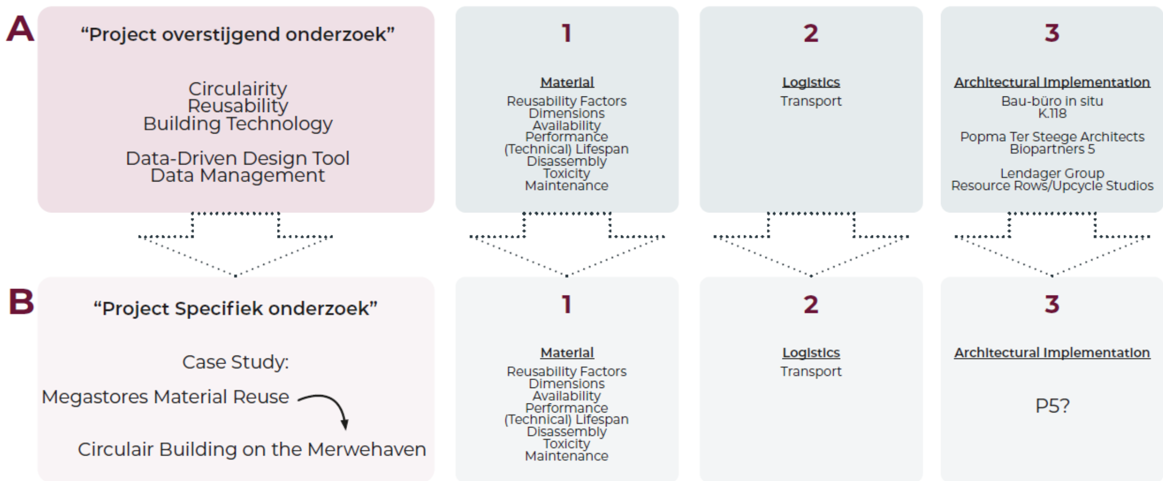


Figure 1 Scheme methodology research (made by author)

To develop a method to design with reused materials and experiment with a data-driven approach, this paper starts with cross-project research. Research into what information is needed to enable the reuse of building materials. Several reports from organisations in the Netherlands that are involved in putting circular construction on the agenda and offering tools to make circular construction measurable are examined. The factors affecting the reuse potential of materials are outlined. Themes that are involved in the reuse potential and the new implementation of the building materials are: measurements, availability, performance, logistics, (technical) lifespan, disassembly, quality, toxicity, and maintenance. The data-driven factors will be included in the calculation for the reuse potential. This score is a number between 0 and 1. The various Value Retention Processes are put in ascending order to set the R-ladder between 0 and 1 as well. The two values correspond to each other and will guide whether or not a material is suitable for reuse. Microsoft Excel will be used as the interface to set up the design tool.

The total set of factors influences the deposition decision for sustainable reuse. This choice will be different for each case and product. This thematic paper is part of a graduation project design brief in which materials from a donor building are applied to a transformation project in Rotterdam's Merwehaven. The donor building is the Megastores in The Hague. Only 24 years after opening, this Shopping Mall from 2000 is already on the demolition list to make way for more housing. This building is far from being in the end-of-life state and therefore represents a source of good materials that can still last quite some time. But as mentioned earlier, direct reuse has its risks and good trade-offs have to be made. Therefore, part of this paper is an experimental study in which the case of the Megastores is used as a case study to test the design tool with reclaimed materials to make deposition decisions for a new circular residential building.

In case studies about architectural projects with reclaimed materials. The cases selected for this research are Biopartner 5, K.118 and Resource Rows. Information for these cases is from literature studies (books, websites, academic papers). The themes that are set out are CO_2 savings with reuse applications, design process, why using reclaimed materials was successful and architectural application. Design guidelines for reuse implementations in architectural design can be taken from these studies.

At the end of this research, I hope to provide a realistic overview of what to look out for when reusing, what design guidelines should be applied and how the data from the Megastores project can guide your design possibilities.

VII. Materials

7.01 Building Layers

A building is composed of multiple layers, as described by the Steward Brand's theory of Shearing layers, which addresses the varying lifespan of the different building layers. In a circular building, it is important to keep these layers separate from each other to extend lifespans of the building.
When doing a material inventory of a building those layers consist of multiple materials and building systems with al different properties and performance requirements.

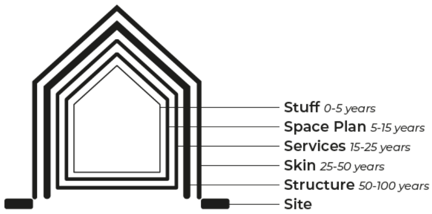


Figure 2 Shearing Layers of Steward Brand (made by author)

These building parts can be broken up into different levels: from building part to building system to product to component and raw material.

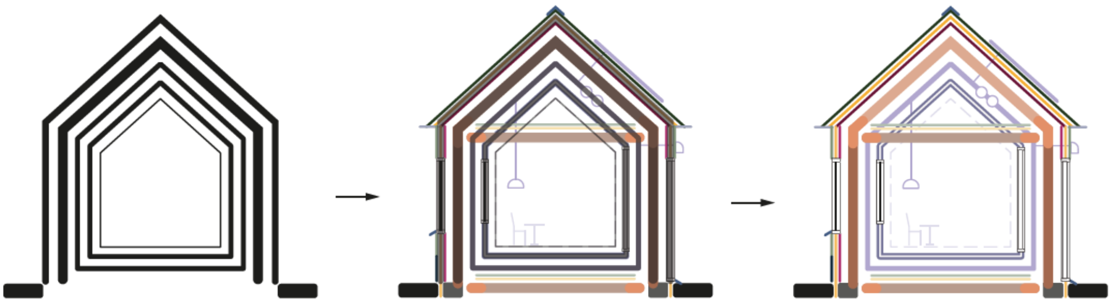


Figure 3 Scheme transition building layers to materials inventory

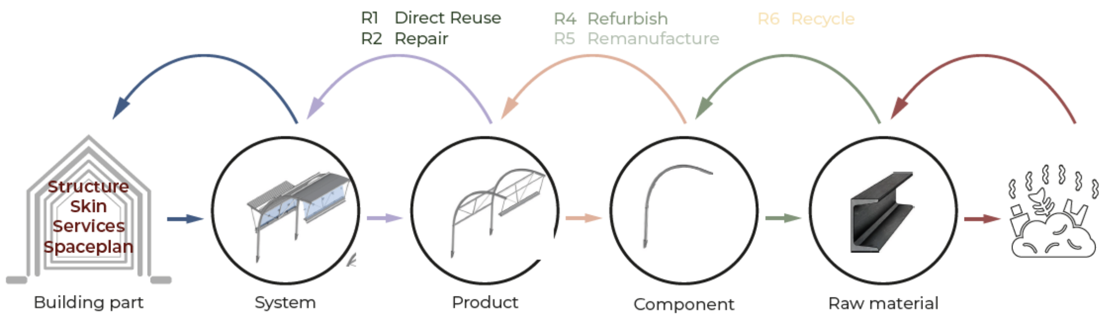
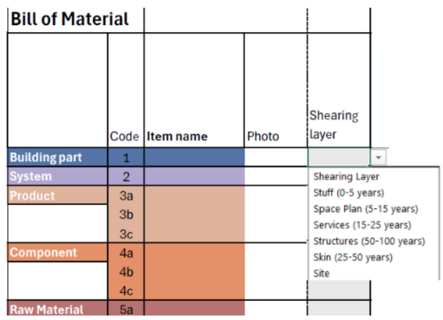


Figure 4 Different scales of building materials (made by author)

7.02 Tool 1/5: Bill of Material

All these layers come together in the inventory, 'the bill of materials'. This documentation needs to be structured well. In the design tool made for this research 'the bill of material' is structured in a vertical column.



Bill of Material	Code	Item name	Photo	Shearing layer
Building part	1			
System	2			
Product	3a			
	3b			
	3c			
Component	4a			
	4b			
	4c			
Raw Material	5a			

Figure 5 Bill of Material in Excel (part 1/5 of tool) (made by author)

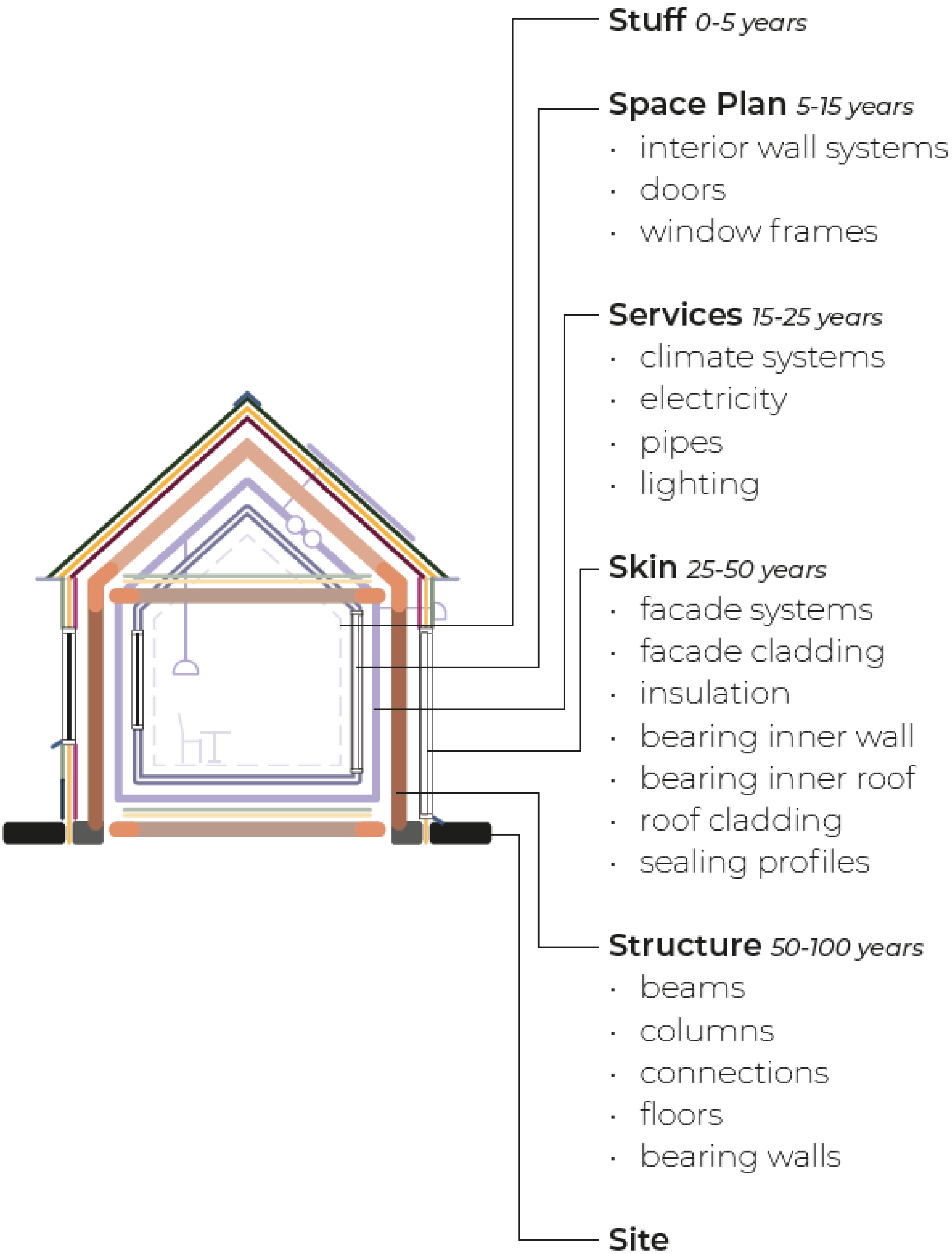


Figure 6 Building layers and systems (made by author)

7.03 Reuse Potential Building Materials and R-strategies

When buildings are going to be demolished, building materials in those buildings are often seen as waste. Urban Mining parties aim to take these building materials and find a new purpose for them. To label something as waste, it is often treated as such, and that is not what is aimed in a circular economy (Pongrácz & Pohjola, 2004). Therefore, building materials and components are better to be called used building materials because this definition is more open to different strategies (Van Hooff, 2021). It is important to know the difference between two stages of the lifetime of used products: End-of-Life (EoL) and End-of-Use (EoU).

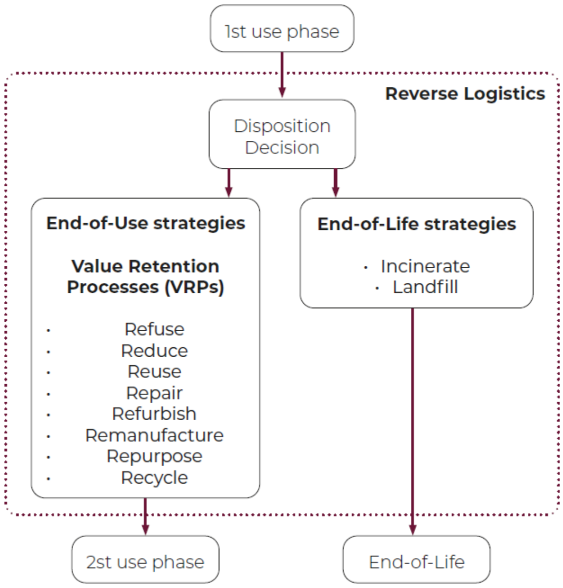


Figure 7 Reverse Logistics (based on the model of Van Hooff (2021))

7.04 R-ladder

The R-ladder illustrates the level of circularity, comprising six steps (R1 to R6) that represent varying circularity strategies. Strategies higher on the ladder conserve more raw materials, indicating greater circularity. R1, being the highest rung, signifies the most circular strategy (*R-ladder - Strategieën Van Circulariteit*, n.d.). The R-ladder can also be used to determine low-value and high-value reusability. However, Recycling (R5) and Recovery (R6) should not be part of low-value reusability. This is because Reuse is at the product level, and Recycling is at the material or resource level. Also, it is questionable whether Repurpose would be a high-value reuse type because of the product's function changes. In addition, the right R-strategy depends on the type of product, which makes it is difficult to make a generalised statement about what is better (Kentie, 2021, p.57).

Disposition Decision is a set of options for a used building product. As a result, contractors can impact both the Disposition Decision regarding a product's End-of-Use strategy and its potential new application. This empowers contractors to promote the reuse of building products within the built environment (Van Hooff, 2021, p.16).

VRPs aim to retain a certain amount of value in a used product. However, they are not necessarily aimed at retaining the original amount of value of the product.

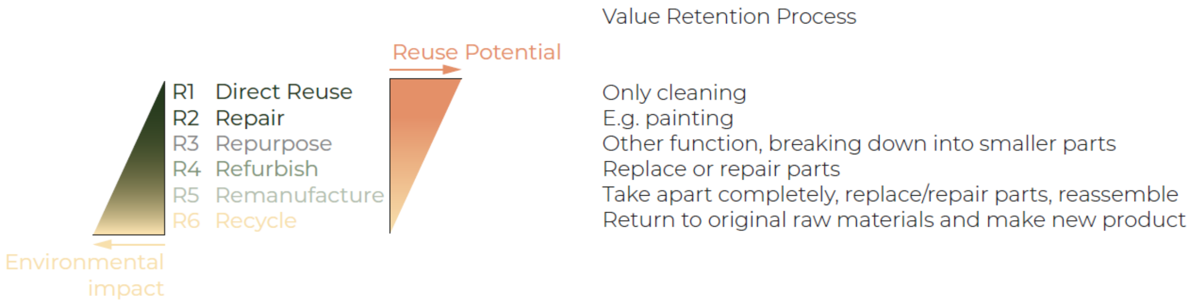


Figure 8 correlations reuse potential and environmental impact with description VRP's (made by author)

7.05 Consequences lack of Data management

The more data is available about the products' history, such as repair work and maintenance, the more this will affect the assessment and also the willingness to apply reclaimed materials.
As mentioned earlier, data on used building materials is lacking. Estimates and analysis of the materials are necessary to enable reuse. Without accurate data on the materials, there are risks, making the choice of Deposition Decision more difficult (Circulair Beheer En Onderhoud, n.d.).

7.06 Making the 'Reuse Potential' measurable

An assessment must determine if a used building product is suitable for direct reuse. In this assessment, the 'Reuse Potential' of individual building products needs to be measured (Kentie, 2021). This research's assessment tool is intended for the early design stage and makes the assessment of suitable materials for a new design comprehensible.

The 'Reuse Potential' is the potential for a building product to be reused at the end of its lifespan. In more detail, the 'Reuse Potential' is the possibility of reusing a building product. To make the 'Reuse Potential' measurable, it is expressed in a score between 0 and 1. For this study, it is assumed that the Reuse Potential works both for used and new building materials. This makes it possible to measure the same factors to test and scale reuse. Besides that, to enable the following user lifecycle, you should also increase the reuse potential of a used product.

The products must be reused at the highest value possible, as high as possible on the R-ladder (Kentie, 2021). Therefore, This ladder can also be translated to a score between 0 and 1. By assigning normalization values (0 to 1) to these strategies, comparisons can be made to assess their effectiveness. In figure 9 the relation between these factors is demonstrated.

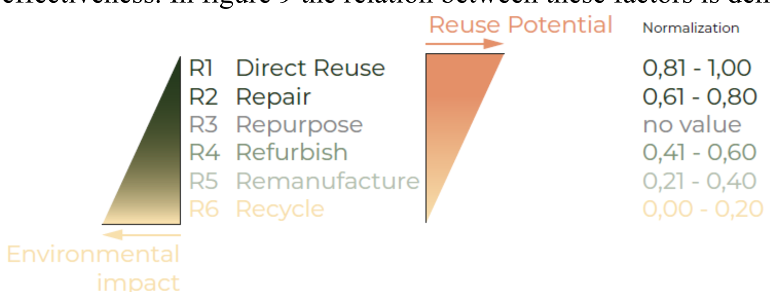


Figure 9 correlations reuse potential and environmental impact with normalization factor (made by author)

For reuse, several factors are pre-conditional, and other factors are non-pre-conditional. Some factors are technical, some process, and some financial. Not all factors are measurable and data-related; however, the reusability of products is generally influenced by all these factors.
This suggests that while the reusability potential may be high, a product might ultimately not bereused if any of the following factors are insufficient.

- *"Measurable: A measurable factor is already measurable, or expected to be measurable, or it might be possible to make it measurable or assessable." (Kentie, N., 2021).*
- *"Discrete measurable: A discrete measurable factor is expected to be measurable only on a yes or no basis." (Kentie, N., 2021).*
- *"Not measurable: A non-measurable factor cannot be measured at all. The reason for this is that the factor can only be determined for products that are currently going to be reuse, or that it is a general factor and cannot be predicted or assessed." (Kentie, N., 2021).*

In the table below the criteria for reuse are categorized under the different types of measurability.

Measurable	***Discrete measurable***	***Not measurable***
Disassembly	*Toxicity*	*Time*
Logistics	*Standardisation*	*Supply and demand*
Financial value	*Contracting*	*Willingness*
Data management		*Design*
Material quality		*Law and regulations*
Maintenance		*Certification*
Over-dimensioning		*Aesthetic*
		Taxes
		Adaptivity

Figure 10 Criteria 'Reuse Potential'

At an early design stage, information gaps do not give insight into all factors. Determine what information is important for each application and material. Additionally, some factors are expected to have no direct impact on reusability potential but instead function as overarching general considerations.

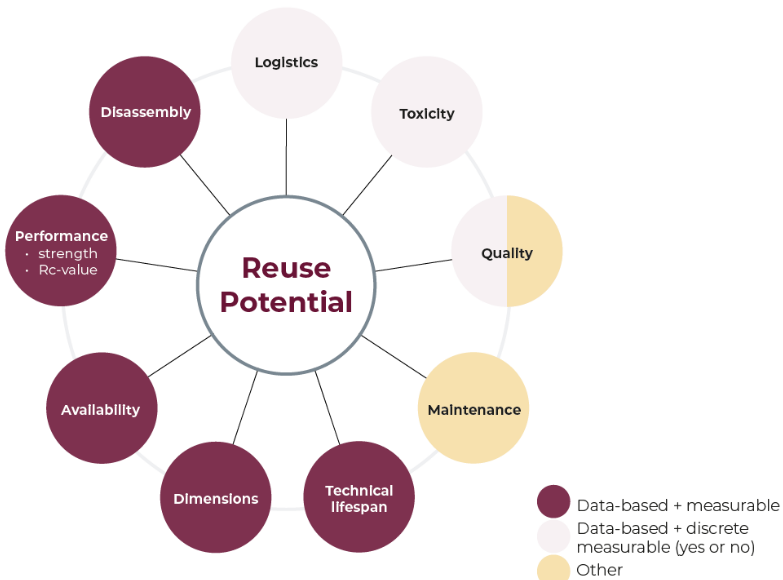


Figure 11 Criteria Reuse Potential overview (made by author)

7.07 Disassembly

Taking out a building component in the mining phase without any damage and losing quality is a significant factor in reusability. DGBC (Dutch Green Building Council), in cooperation with Alba Concepts, have written a whitepaper about the disassembly of building materials (Circulariteit in de praktijk losmaakbaarheid whitepaper dgbc.nl, n.d.). Alba Concepts has developed a measurement method linked to the DGBC (BREEAM-NL) methodology. They developed a formula to calculate the 'Disassembly index' (losmaakbaarheidsindex) (Circular buildings meetmethodiek losmaakbaarheid, n.d.). Appendix 14.06 outlines how this formula is conducted. All these factors are programmed in Excel format as dropdown menus and related to a score.

$$LIp_n = \frac{4}{\frac{1}{TV_n} + \frac{1}{ToV_n} + \frac{1}{DK_n} + \frac{1}{RO_n}}$$

Figure 12 Formula Disassembly index (Circular buildings meetmethodiek losmaakbaarheid, n.d.)

7.08 Tool 2/5: Criteria Reuse Potential

The themes discussed in this chapter can be summarized in the horizontal direction of the design tool. The figure 13 below shows how these criteria appear in the Excel format.

Figure 13 Criteria Reuse Potential (part 2/5 of tool) (made by author)

Case Study Part 1: Megastores

Assessing the reuse potential starts with visiting the building and taking photos of the visible building materials. Below are a number of images taken at the site.

Figure 14 Pictures Megastores, Den Haag (made by author)

The building plans were analysed afterwards to identify what other materials were implemented in this design. In an early design stage, looking at the larger building systems made of non-renewable resources is sensible, as that is where the most significant environmental gains can be made.

Construction	***Facade***	***Floorplans***
Precast hollow core slabs	*Curtain wall (Rc=2,5)*	*Railings*
Steel columns with concrete	*Steel for advertisement*	*Stairs*
Concrete beams	*Doors*	*Shop windows*
Concrete columns	*Spider curtain wall (Rc=2,5)*	*Paving*
Steel beams 'arches'	*Insulation*	*Prefab concrete elements (bridges, stairs)*
Steel beams	*Corrugated sheets*	
	Prefab concrete facade panels	
	Tourniquet door	

Figure 15 Overview most significant building materials in Megastores

Steel beams 'arches' from the roof system, precast hollow core slabs and spider curtain wall system were selected for this study. These building systems are drawn out using 3D modelling software (Rhino).

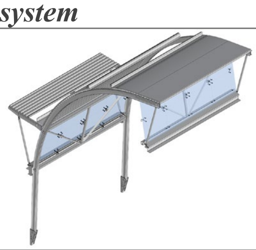
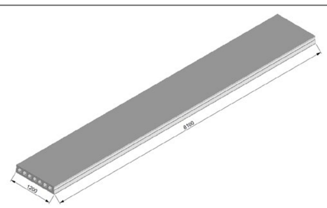
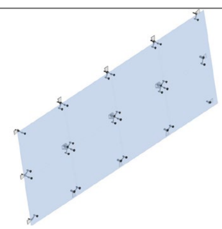
Steel beams 'arches' from the roof system	***Precast hollow core slabs***	***Spider curtain wall system (Rc=2,5)***
		

Figure 16 Overview selected building materials =

The next step is to enter the relevant data into the Excel sheet: the shearing layer, dimensions, material types, amount, performance, disassembly index and quality description. The technical lifespan of the material can be extracted from the supplier or (Milieu) databases like Granta Edupack. If this information is not available, the shearing layer years can be used. For the disassembly index, you need information from the builders or detailed 1:5 drawings. When you lack this information, a possible scenario should be adopted.

VIII. LOGISTICS

To apply building materials to a new location in a new building, construction logistics, transport, and whether the building material will still be processed before the material functions for the new application must be considered.

Building materials are often transported by truck by road. Figure 17 shows an assessment of the options for normal and specific transport. The size and weight of the building material are the main factors in the choice.

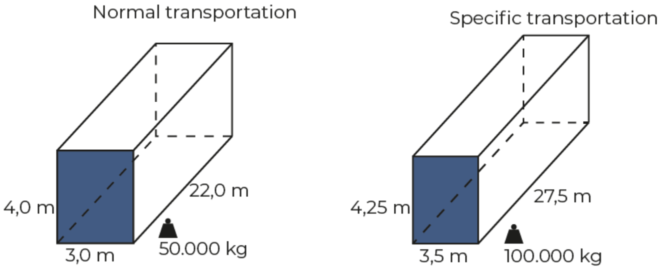


Figure 17 Transport Assesment (made by author)

The possibilities for transport by waterway in the Netherlands are quite extensive. The route determines which types of inland ships can be used.

Case Study Part 2: Logistics Megastores and Merwehaven

Location Megastores:
Van der Kunstraat 123, 2521 CD Den Haag

Location Merwehaven:
Marconistraat 80, 3029 AK Rotterdam

The location of Merwehaven and Megastores also allows for the delivery of building materials via water. For this, an inland ship with a CEMT class II is suitable. Appendix 14.09 shows the specifications of this ship.

For the selected building materials of the Megastores, there are no limitations in transport when taking the size of the material into consideration.

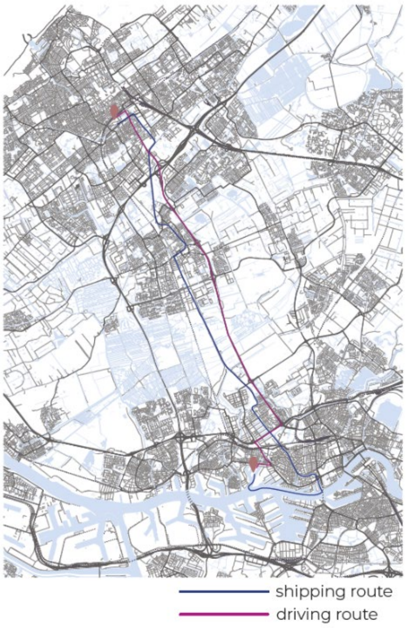


Figure 18 Routes Megastores to Merwehaven (made by author)

Building material	***Dimensions largest item***	***Normal transportation***	***Specific transportation***	***CEMT-class II***
Steel beams 'arches'	*19,257x4,1 x 0,3 x 0,1 m.*	*x*	*x*	*x*
Precast hollow core slabs	*8,1x1,2 m.*	*x*	*x*	*x*
Spider curtain wall (Rc=2,5)	*1,55x2 m.*	*x*	*x*	*x*

Figure 19 Overview options transport building material Megastores

IX. 1ST USE PHASE TO 2ND USE PHASE

The transition from the initial user phase to the subsequent phase involves many processes, many of which are related to the constraints of the new material implementation.

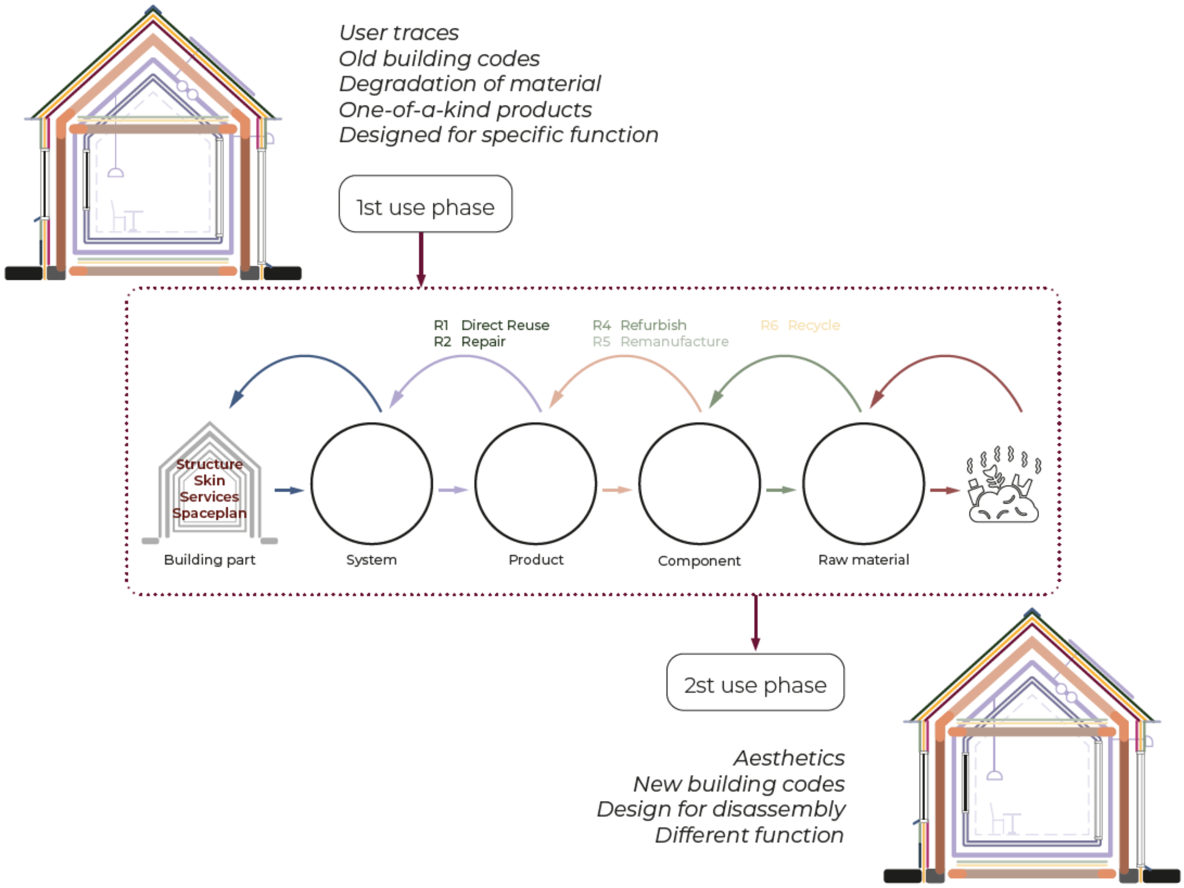


Figure 20 Scheme transition between user phases (made by author)

New circular buildings have different requirements than buildings of a year of construction a few years back. Topics such as energy use, insulation values, and mechanical requirements have often changed over the years, creating a gap between the requirements of the first and second use phases.

9.01 Tool 4/5: RP Value

The constraints on performance and lifespan can be translated into plus and minus trade-offs. The mean value is shown in the green columns in the figure 21 below. It is between 0 and 1 and represents the RP value (Reuse Potential).

Performance					
Strength	Strength aim	RP value	Rc-value	Rc-value aim	RP value
		1			1
		1			1
		1			1
		1			1
		1			1
		1			1
		1			1
		1			1
		1			1
		1			1
		1			1

Supplier				
Brand	Age (End-of-use) (months)	Technical lifespan End-of-life (months)	Estimated remaining lifespan	RP value
			0	0
			0	0
			0	0
			0	0
			0	0
			0	0
			0	0
			0	0
			0	0
			0	0
			0	0

Figure 21 Tool 4/5

9.02 Tool 5/5: R-strategy

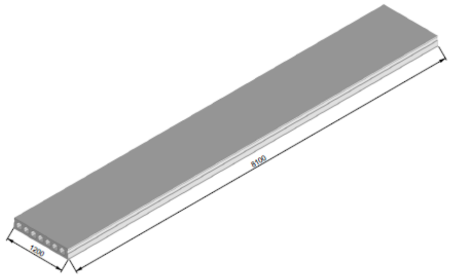
The RP value can be translated into R-strategies, suggesting a method for reusing this material in a new circular design.

Reuse Potential				Bill of Material				
RP-		RP	RP+		Code	Item name	Photo	Shearing layer
R4 Refurbi	0,33	R5 Remanufacture	R6 Recycle	Building part	1			
R4 Refurbi	0,33	R5 Remanufacture	R6 Recycle	System	2			
R4 Refurbi	0,33	R5 Remanufacture	R6 Recycle	Product	3a			
R4 Refurbi	0,33	R5 Remanufacture	R6 Recycle		3b			
R4 Refurbi	0,33	R5 Remanufacture	R6 Recycle		3c			
R4 Refurbi	0,33	R5 Remanufacture	R6 Recycle	Component	4a			
R4 Refurbi	0,33	R5 Remanufacture	R6 Recycle		4b			
R4 Refurbi	0,33	R5 Remanufacture	R6 Recycle		4c			
R4 Refurbi	0,33	R5 Remanufacture	R6 Recycle	Raw Material	5a			
R4 Refurbi	0,33	R5 Remanufacture	R6 Recycle		5b			
R4 Refurbi	0,33	R5 Remanufacture	R6 Recycle		5c			

Figure 22 Tool 5/5

Case Study Part 3: Reuse Potential Megastores

After entering all the criteria and factors into the Excel sheet, conclusions can be drawn about how to use the materials in a design.

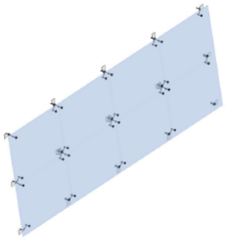


Reuse Potential				Bill of Material		
RP-		RP	RP+		Code	Item name
R2 Repair	0,54	R4 Refurbish	R5 Remanufacture	Building part	1.1	Floors
R2 Repair	0,54	R4 Refurbish	R5 Remanufacture	System	1.2	Floor packet
R1 Direct u	0,75	R2 Repair	R4 Refurbish	Product	1.3a	Precast hollow core slabs
R4 Refurbi	0,39	R5 Remanufacture	R6 Recycle		1.3b	50 mm Anhydrietvloer
R1 Direct u	0,75	R2 Repair	R4 Refurbish		1.3c	Finishing
R2 Repair	0,57	R4 Refurbish	R5 Remanufacture	Raw Material	1.5a	Concrete
R2 Repair	0,50	R4 Refurbish	R5 Remanufacture		1.5b	Concrete and gypsum mix
R2 Repair	0,57	R4 Refurbish	R5 Remanufacture		1.5c	Reinforcement steel

Figure 23 Reuse Potential precast hollow cast slabs

Reuse Potential				Bill of Material		
RP-		RP	RP+		Code	Item name
R2 Repair	0,54	R4 Refurbish	R5 Remanufacture	Building part	2.1	Roof
R2 Repair	0,54	R4 Refurbish	R5 Remanufacture	System	2.2	Loadbearing construction
#N/B	0,94	R1 Direct use	R2 Repair	Product	2.3a	Steel beam square
#N/B	0,95	R1 Direct use	R2 Repair		2.3b	Steel beam I
#N/B	0,95	R1 Direct use	R2 Repair		2.3c	Steel pipe
#N/B	0,95	R1 Direct use	R2 Repair	Component	2.4a	Pin + bolts
R1 Direct u	0,66	R2 Repair	R4 Refurbish		2.4b	Hanger curtain wall
R1 Direct u	0,69	R2 Repair	R4 Refurbish		2.4c	Profile connections
R2 Repair	0,57	R4 Refurbish	R5 Remanufacture	Raw Material	2.5a	Steel

Figure 24 Reuse Potential roof structure



Reuse Potential				Bill of Material		
RP-	RP		RP+		Code	Item name
R2 Repair	0,43	R4 Refurbish	R5 Remanufacture	Building part	2.1	Facade
R2 Repair	0,43	R4 Refurbish	R5 Remanufacture	System	2.2	Curtain wall spider
#N/B	0,81	R1 Direct use	R2 Repair	Product	2.3a	Glass panel
#N/B	0,98	R1 Direct use	R2 Repair		2.3b	Spider connections
R2 Repair	0,57	R4 Refurbish	R5 Remanufacture	Component	2.4a	Pin + bolts
R2 Repair	0,57	R4 Refurbish	R5 Remanufacture		2.4b	Spider 2 knots
R2 Repair	0,57	R4 Refurbish	R5 Remanufacture		2.4c	Spider 4 knots
R2 Repair	0,50	R4 Refurbish	R5 Remanufacture		2.4d	Plate
R2 Repair	0,57	R4 Refurbish	R5 Remanufacture	Raw Material	2.5a	Aluminium
R2 Repair	0,57	R4 Refurbish	R5 Remanufacture		2.5b	Glass
R2 Repair	0,57	R4 Refurbish	R5 Remanufacture		2.5c	Foil

Figure 25 Reuse Potential spider curtain wall system

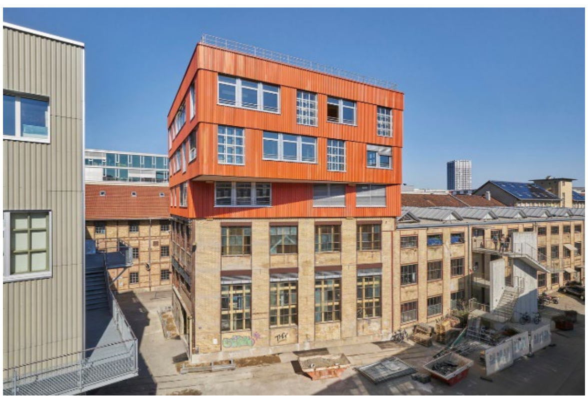
X. IMPLEMENTATION: DESIGNING WITH RECLAIMED MATERIALS

Applying reclaimed building materials in a new design demands a different approach. In this chapter, this approach is examined by case studies.

Do these projects consist entirely of reused materials? Full reuse in larger contemporary architecture projects is not possible yet. Used building materials are not designed and installed for reuse in other situations. In addition, new construction due to building regulations tends more often to be an application with new materials and new materials need to be applied to fit reused materials. These projects show that reuse is possible in different ways; in all projects, extra labour is involved, and a flexible design process is needed.

10.01 Case: K.118

The K.118 building in Winterthur, Switzerland is a remarkable example of circular and sustainable construction. Situated on the former Sulzer factory site, it represents an extension of an industrial corner building. The project was an experiment where the aim was to, wherever possible, reused components should be used. Besides that, the project team sourced building materials from demolition sites within a 90 km radius. As if this challenge wasn't already daunting, an additional requirement was imposed: the project's cost must not exceed that of a conventional building using new materials (Stricker et al., 2023).



Lightweight building materials are easier being reused. In this project that results in that only 14% of the weight is reused materials, but that is in volume 41%.

Project name: K.118 *Year: 2021*	*Firm: bau-büro in situ* *Location: Winterthur, Switzerland*
Reused components	- *steel supporting structure (supports and girders, profiled sheets of the composite ceilings)* - *parts of the building shell (e.g. insulating materials, sheet metal cladding, windows) to the interior fittings (e.g. various bricks, wall and floor coverings made of wood-based materials, doors, built-in furniture)* - *elements of the building services (e.g. radiators, sanitary appliances, photovoltaic systems).*

In the book 'Re-Use in Construction', Michel Massmünster wrote down how the design of this building came to life. In appendix 17.04 a summary of the key aspects of the design process are set out. The main is the iterations of design choices and material hunting and how that influences the design applications and the parameters and requirements of the next hunt. The building materials were searched and implemented in the design from large to small. Within the architecture firm, there were 'product hunters' who re-traced the objects in the inventory list on their computers. After that, the drawings were added to the design plan. Designers and drafters will add these drawings to the design plan. This will illustrate if and how the components fit together with the existing materials (in the design plan). If everything fits, disassembly will be organized. It is better to reuse an entire system than collect different parts one by one.

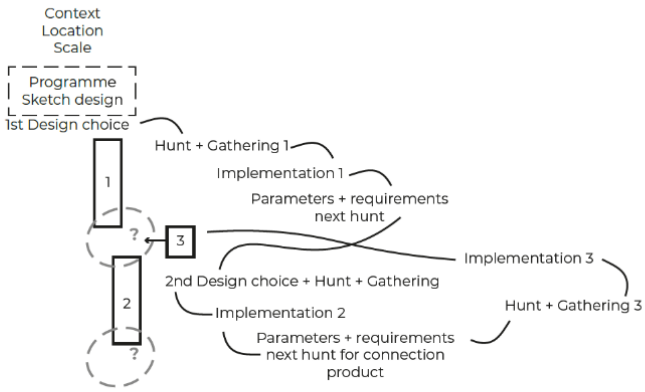


Figure 26 Design Process analyses K.118

The structure utilizes a steel skeleton, repurposed from a distribution centre in Basel, as the load-bearing frame. The height of the floors and windows where determined by this steel structure. The exterior appearance will not change much once the basic shape, the facades, and the exterior staircases have been put in place. However with regard to the details, the design of the building will keep developing as components are added.

When highly detailed versions of the design are created in the office and the availability of materials often lags behind them. A situation occurs where it is sometimes not clear yet which components can be used to implement the design. Although it is not yet clear which components can be used to implement the design, the team needs to at least have an idea of their role in order to be prepared for possible finds during the hunt for components. At the same time the components hunters will also be open to making unexpected finds. This means the detailed preplanning will usually end up with the design having to be reworked following each find.

This project embodies a circular approach to construction, demonstrating the importance of thinking in cycles. Beginning with the identification of available materials, the architectural process followed a continuous cycle of evaluation, verification, and decision-making.
(Institute of Constructive Design, 2022)

10.02 Biopartners 5

The Biopartners 5 building in Leiden, the Netherlands, is the first building in the Netherlands that met the CO2 budget necessary to comply with the Paris Agreement. To achieve this goal and keep the CO2 footprint low, sustainable use of materials has three major pillars:

2. Urban mining first - 20%
3. Renewable if possible - 40%
4. Choose the most sustainable producer – 40%

The aim was to have a lower budget value than 250 kg $CO_2/m^{2,}$ and it ended up with a footprint of 212 kg CO_2/m^2. An integral approach is crucial for large buildings like Partner 5. A building scale like this cannot be made from used materials in its entirety, so a mix of materials, old and new, will always be needed. Making the optimal choice for this is essential.

Project name: Biopartners 5 *Year:*	*Firm: Popma Ter Steege Architects* *Location: Leiden, Netherlands*
Reused components	- *Reused steel construction: 165 tonnes of steel* - *250 m3 of brick rubble* - *and 60 m2 of Alta Quartzite tiles*

In the book "Reuse to Reduce – Architecture within a Carbon Budget. The case of biopartner 5." the design process is described and Popma ter Steege Architects are trying to make a plea to embrace the circular transition as a chance for a more meaningful architecture. Just like the K.118 building the importance of gathering, searching for the next piece, and making the biggest impact with utilizing materials on the biggest building scale possible is found in this project.

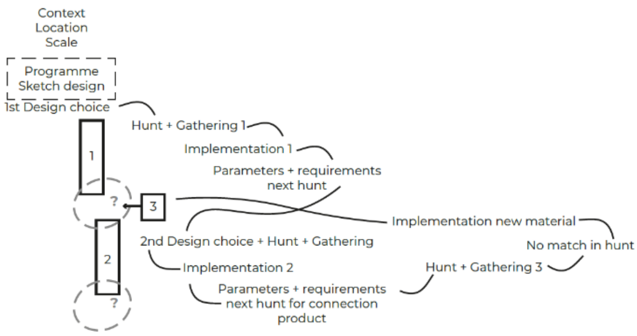


Figure 27 Design process analyses Biopartners 5

Besides that, they plea for the craftmanship to retain the quality of the donor elements when the buildings are dismantled piece by piece and put together again to make the new building. The post-war buildings (and before …) are not designed for dismantling. Buildings from these periods require a new craftsmanship. 'Knowing what materials have been used in a building and what qualities they have becomes increasingly important if we want to use these materials again. Currently, the potential for reusing elements is often not recognised.' (Ter Steege et al., 2023, p.41)
A building is a curated collection of materials. When reusing materials you get the history of earlier uses and the accompanying imperfections. To accept reuse, you have to accept these imperfections.

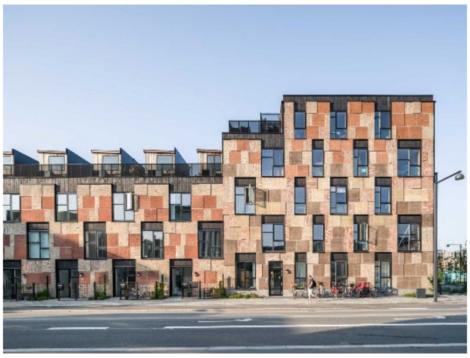
A decisive moment to go for the steel construction from the donor building was when the architectural firm found out the storey height was the same as required. Glass interior walls where extracted from a government building in Haarlem. They were simply considered as waste by the owners after new budget for interior became available after 15 years. Toilets where taken from a former office accounting firm in Amstelveen. Oak from second-hand furniture that will not sell is repurposed by cutting into panels for a new bar. Carpet flooring with production errors where used.

All these decisions have a core reason of accepting the imperfections, being the perfect fit, and the drive to first look at reuse options.

Another goal the designers where trying to achieve is increasing the reuse potential of the used materials for a next lifecycle. Fewer materials for the finishings and more attention for the joint between the really necessary materials. Leaving out materials that are not necessary and knowing what materials are needed to meet the strict requirements. A building with the smallest footprint is a chain of optimised material solutions. After 50 years of use, the constructions also deals with his distortions. Thus the structural components were processed step by step, so they complied with the technical requirements that new buildings have to meet in order to obtain a permit.
(Ter Steege et al., 2023)

10.03 Resource Rows - Lendager group

Project name: Resource Rows *Year: 2019*	*Firm: Lendager group* *Location: Oerestad Copenhagen*
Reused components	- *Brick* - *Bridge*



Upcycled bricks and waste wood (saved 29% of CO_2, with 10% of building materials). The 92 flats and rowhouses in the Resource Rows demonstrate that it is possible to reuse bricks from new buildings and waste wood without compromising on costs and aesthetics. The result is a project that saves CO_2 and materials and creates strong communities among the people living in it - and it doesn't cost more.

An example of making potential out of a problem: since the 1960s, new, harder, cement-based mortar has been used, so bricks cannot be recycled efficiently anymore. Cutting slabs of abandoned structures and using them as a collage technique on the facades not only saves waste but also creates a new aesthetic where the history of materials gets new higher values.

Lendager Group tries to make sustainability an added value without adding a cost factor. No matter how good a design is, sustainability will never be part of the solution unless it becomes cost-neutral, cheaper, or adds value to the project from day one. (*Resource Rows - Lendager*, 2024)

10.04 Design guidelines reuse in architecture

When deciding to do full reuse. You have to have a flexible design approach. Gathering, implementing and gathering again. This statement highlights the importance of considering interconnected details in a design process. It emphasises that deferring decisions on certain details is not feasible because other design aspects, which are already defined, depend on them. For instance, if the specifications for windows are already established, this affects what materials or methods can be used around them. The statement also notes that it is uncommon to have all elements predefined. Consequently, when introducing a new component, it often necessitates adjustments to the existing design, such as rearranging the windows to accommodate the new element. In summary, it underscores the iterative and interdependent nature of the design process, where decisions in one area impact multiple other areas, requiring continuous adaptation and refinement.

XI. CONCLUSION

To meet the CO2 budgets of the Paris Agreement the CO_2 impact of buildings must be drastically reduced. Emissions are emitted during construction, when building materials are produced, when the building is in use, and afterwards also during any demolition and disposal of building materials. Solutions must be sought inter-graphically to keep a building within a CO_2 budget. One approach is to stay within the CO2 budget is to get 20% of the building materials from Urban Mining, 40% from renewable materials and 40% from the most sustainable producer. Within a circular economy, waste is seen as a resource. There are different R-strategies to bring used materials back into the system. It is best to aim for high-value reuse, because that saves the most CO_2. These building materials must be used in a new architectural design, and how that is done is an architect's responsibility. The profession of architects is going to shift to assemblers, with the consequence of making sustainable solutions from reuse more valuable.

Main research question:

What data-driven design method is needed for a design tool with reclaimed materials to make deposition decisions for a new circular residential building?

For a design tool focused on using reclaimed materials to make deposition decisions for a new circular residential building, a data-driven design method that integrates multiple aspects of sustainability, material properties, and circular economy principles is essential. Setting the constraints of the new design implementation is one of the inputs of the tool. The argumentation of the deposition decisions is in this research based on a data-driven approach. The reuse potential of building materials corresponds with the high- to low-value reuse of materials.

Sub-questions:

1. **What information and methods are needed to facilitate the reuse of building materials to extend the life cycle?**

To extend the lifespan of building materials, an inventory of the building materials must be done to decide the most suitable Value Retention Process (VRP). These processes are based on the R-strategies (R1 to R6). R1 'reuse' is the highest reuse value. R3 is 'repurpose', which refers to when building materials are given another function or broken down into smaller parts. The 'Reuse Potential' summarizes technical, logistical, and qualitative factors. These factors include dates, descriptions and calculations. Therefore, there is a distinction between measurable, discrete measurable and unmeasurable factors.

The method needs to be characterized with a user-friendly interface, e.g. excel. A concise overview of the information input and methods is provided below:

1. INPUT: Material inventory and Data Management.
    a. Data from existing building is hardly available, this results in:
        i. Manual analyses of digital building plans.
        ii. Visual examination
        iii. Taking photos
        iv. Measuring building materials
    b. Create a comprehensive database, including:
        i. Brand name
        ii. Type of System
        iii. Dimensions
        iv. Weight
        v. Quantities
        vi. Physical properties
        vii. Description of previous usage history and visual quality assessment

c. Structure the building parts based on the building anatomy and Stewart Brand's Shearing Layers, with the following categories: system, product, component, and material.
d. Gather data from suppliers: performance (Rc, strength) + technical lifespan + toxicity.

2. INPUT: Inventory the connection type and disassembly ability.
   a. OUTPUT: Calculate the disassembly index
3. INPUT: Setting the demands/goals, constraints, parameters and requirements for new design application. These parameters should be between certain ranges to increase sourcing of suitable building materials via urban mining. The importance of type constraints varies for each product. Examples may include structural requirements, insulation needs, or size specifications.
4. OUTPUT: Calculate the data-based outputs with the constraints of the new design application.
5. Evaluate the most suitable VRP for the design application.

2. How to make the reuse potential measurable to develop a design tool?

In the context of building material reuse, the goal is to achieve the highest level of reuse (direct reuse), whenever the material's application permits. If direct reuse is not possible, alternative strategies can be employed to recover the materials. This leads to a distinction between End-of-Use and End-of-Life. For End-of-Use, several Value Retention Processes (VRPs), also referred to as R-strategies, are available. These strategies can be scaled based on their level of material recovery. Six R-strategies have been examined, with 'Repurpose' omitted due to its overarching nature and the involvement of functional modifications to the material. High-level reuse is closely associated with 'Direct Reuse,' as it involves no modifications and, consequently, results in minimal environmental impact. By assigning normalization values (0 to 1) to these strategies, comparisons can be made to assess their effectiveness.

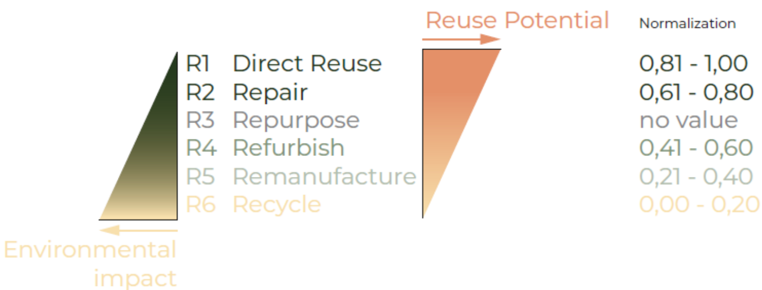


Figure 28 correlations reuse potential and environmental impact with normalization factor

3. What constraints does a new circular residential building impose on implementing reclaimed materials into design?

To reuse old used building materials in a circular design, three steps must be taken:

1. Reuse potential must be analysed
2. Once a product is suitable or partially suitable for reuse, a reverse logistic should be applied.
3. The product must be modified in such a way as to promote reuse in subsequent use cycles.

The constraints are mainly technical constraints by differences in building codes and sustainability objectives. New circular buildings, for instance, have targets in detachability and energy use (Nearly Zero Energy Building (NZEB).

4. What can we learn from architectural projects with reclaimed materials implemented in their design? What characterizes the design process of these projects? What design guidelines can be concluded from that to implement reclaimed materials in a building?

Designing with reclaimed materials from the start results in a design process where iterations of design choices and material hunting influence the design applications, and the parameters and requirements of the next hunt. This results in a "Material Driven Design". This design approach starts with mapping the building materials. Start local and expand the search area if needed.
To make the biggest impact with reuse in an architectural design. The building is designed with a donor structure. The approach is to start from big to smaller elements. Start with the structures and floors, and later take a look at the other systems and building materials.
A flexible design approach, allows buildings to accommodate variations in reclaimed materials, dimensions and properties. This also correlates with anatomy and Stewart Brand's Shearing Layers. A tool to bring the different materials architecturally together is to use collaging techniques.
Another approach to stay within the CO_2 budget of a building is to work with the following guideline in mind: get 20% of the building materials from Urban Mining, 40% from renewable materials and 40% from the most sustainable producer.

5. When availability defines the form of your design, how does it influence your design process?

This research paper is part of the graduation project for the graduation studio Architectural Engineering. The general design question of this project is:

How can a circular multilevel building in the Merwehaven, Rotterdam, take shape for a mixed target group with a design approach where reclaimed materials and reuse practices play a leading role?

In this project, the process began with identifying and prioritizing the use of reclaimed materials from the Megastores, treating the "pile of materials" as the foundation for both construction and materialization. This parallel exploration of material inventory and design principles reshaped the design process, requiring adaptability to the constraints and opportunities posed by available donor materials.

Starting with the bigger building materials and grid size of the donor building was the base for the final design. This ensured that many other building materials could be directly reused.

In this graduation studio, students are required to determine the Plan of Requirements for their final project. The open-ended Plan of Requirements enabled greater flexibility, fostering innovation in the reuse of materials. In practice, tender requests are drafted in great detail, which creates a significant degree of steering within the design process. This steering can potentially limit the design options available, particularly when there is a preference for reuse. In order to promote reuse, it is essential to conduct a critical assessment of the current tender specifications to ascertain whether they are aligned with more sustainable trends, like reuse.

Constraints imposed by materials encouraged creativity in finding new applications and maximizing their potential, striking a balance between architectural, technical, and logical considerations. It is crucial to leverage the potential of materials and navigate around their limitations. If a particular material is unsuitable for a specific application, there are still numerous other possibilities. While materials impose constraints on the design process, they also encourage designers to explore different applications to achieve the highest potential of reuse.

A recurring theme during this design process was that you always need extra material to complete your design. These materials were sought in biobased options when these could not be found within the donor building. This accelerates the development of the design, but can be seen as the easier way to bypass reuse. On the other hand, these design infills can also be seen as temporary implementations and set the parameters for the next hunt. These moments of compromise underscore the need for iterative processes and continual refinement as part of a circular and resource-conscious design approach.

XII. Discussion

This method is mainly focused as steps that can be taken in an early design stage. To assess the reuse potential and structure your data. For further stages in the building development, different barriers need to be overcome.
To enable reuse on the highest level and largest scale possible, there are still many enablers, barriers and potentials today. All these factors are linked to availability, lifespan, or application. Reuse applications are often project-specific, yet the next use cycles also need to be considered.
Existing buildings are not designed for easy and efficient demolition, resulting in a low efficiency of the recovery process. Incorporating detailed design considerations for recovery in new constructions ensures the possibility of future reclamation of raw materials and products (Sobotka & Czaja, 2015).

Barriers:

- Data is lacking on buildings that are now being demolished. Whereby reuse first requires hunting, and surveying before new applications can be done.
- Extra labour costs more money, because of that new materials are often chosen over reclaimed materials
- The performance of used building materials is outdated compared to new materials, resulting in facade applications not meeting contemporary requirements.
- Building codes, certification
- Logistics and supply chain
- Skills and knowledge
- Design requirements should be more free because the material is leading.
- Availability of materials

Enables:

- When reuse can be applied at the same price as new. In many cases, sustainability will generate more value, because reuse will add to the architectural value.
- CO2 excesses will cost clients more money, because CO2 taxes will be introduced. Reuse is one way to avoid these taxes.

Potentials:

- New construction parts are already being designed with dry bonding, promoting reuse.
- Sustainability
- Cost saving
- Unique aesthetics, historical value

This setup can be the backbone for further innovative experiments, like parametric design, that need to be done to promote the use of reused materials today. In design studies, data-driven design is used to bring new design solutions to life and provide insights into the ecological footprint, quantities, usage, costs, logistics, etc.

XIII. REFERENCES

Literature:

Caetano, I., Santos, L., & Leitão, A. (n.d.). *Computational design in architecture: Defining parametric, generative, and algorithmic design*. https://doi.org/10.1016/j.foar.2019.12.008

Çetin, S., De Wolf, C., & Bocken, N. (2021). Circular digital built environment: An emerging framework. *Sustainability (Switzerland)*, *13*(11). https://doi.org/10.3390/su13116348

Circulair beheer en onderhoud. (n.d.).

Circulaire, E. N., & Voor Breeam, I. (n.d.). *FRAMEWORK VOOR CIRCULAIRE GEBOUWEN*. www.sgssearch.nl

CIRCULAR BUILDINGS MEETMETHODIEK LOSMAAKBAARHEID. (n.d.).

CIRCULAR BUILDINGS MEETMETHODIEK LOSMAAKBAARHEID VERSIE 2.0. (n.d.).

CIRCULARITEIT IN DE PRAKTIJK LOSMAAKBAARHEID WHITEPAPER DGBC.nl. (n.d.).

de Architect. (2024). Bouwen met wat er is. *1*. https://www.dearchitect.nl/289629/de-architect-1-2024-bouwen-met-wat-er-is

Ellen Macarthur Foundation. (n.d.-a). *The butterfly diagram: visualising the circular economy*. Retrieved April 25, 2024, from https://www.ellenmacarthurfoundation.org/circular-economy-diagram

Ellen Macarthur Foundation. (n.d.-b). *What is a circular economy?* Retrieved April 25, 2024, from https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

Felix Heisel, Dirk E. Hebel, Andreas Wagner, & Moritz Dörstelmann. (n.d.). *blz.128_Clean Energy Transition and digital transformation_Book 25 Mar 2024*. Retrieved March 25, 2024, from https://birkhauser.com/books/9783035621174

Goddin, J., Marshall, K., Pereira, A., Design, G., Herrmann, S., Ds, S., Sam, J., Dupont, T., Krieger, C., Lenges, E., Ben, C., Pierce, J., Susan, E., Gispen, I.-J., Veenendaal, R., Per, I., Natureworks, S., Ford, L., Goodman, T., … Cockburn, D. (n.d.). *Ellen MacArthur Foundation Project Team (in alphabetical order)*. http://www.ellenmacarthurfoundation.org/circularity-indicators/.

Honic, M., Kovacic, I., Aschenbrenner, P., & Ragossnig, A. (2021). Material Passports for the end-of-life stage of buildings: Challenges and potentials. *Journal of Cleaner Production*, *319*, 128702. https://doi.org/10.1016/j.jclepro.2021.128702

Institute of Constructive Design. (2022). *Reuse in Construction* (IKE Institut Konstruktives, Ed.). PARK BOOKS.

Kentie, N. (2021). *Reusability potential in the Building Circularity - An assessment tool to assess the reusability potential of individual building products in an early design stage in order to support circular decision-making in the Built Environment*.

Leidraad Circulair Ontwerpen | Hoofdstuk 4 | Ontwerpstrategieën. (2023).

Leidraad_Toekomstig-Hergebruik-1. (n.d.).

Pongrácz, E., & Pohjola, V. J. (2004). Re-defining waste, the concept of ownership and the role of waste management. *Resources, Conservation and Recycling*, *40*(2), 141–153. https://doi.org/10.1016/S0921-3449(03)00057-0

Sobotka, A., & Czaja, J. (2015). Analysis of the Factors Stimulating and Conditioning Application of Reverse Logistics in Construction. *Procedia Engineering*, *122*, 11–18. https://doi.org/10.1016/j.proeng.2015.10.002

Stricker, E., Angst, M., Brandi, G., Buser, B., & Sonderegger, A. (2023). Case Study K.118 - The Reuse of Building Components in Winterthur, Switzerland. *Journal of Physics: Conference Series*, *2600*(19). https://doi.org/10.1088/1742-6596/2600/19/192008

'Ter Steege, J. W., 'Van Leeuwen, M., 'Popma, J., & 'Betsky, A. (2023). *Reuse to Reduce - Architecture within a Carbon Budget. The Case of BioPartner 5* (1st ed.). Jap Sam Books.

Van Hooff, S. (2021). *The Reuse of Building Products*.

Websites:

R-ladder - Strategieën van circulariteit. (n.d.). RVO.nl. https://www.rvo.nl/onderwerpen/r-ladder

Resource Rows - Lendager (Door Lendager). (2024, 22 november). Lendager. https://lendager.com/project/resource-rows/

Other websites used as background information:

https://www.superuse-studios.com/nl/publication/oogsten-verzamelen-hergebruiken/

https://albaconcepts.nl/

https://themasites.pbl.nl/o/circulariteit-in-de-bouw/alkondor/#:~:text=Samen%20met%20TU%2DDelft%2C%20brancheorganisatie,gevel%20en%20de%20exploitatie%20daarvan.

https://www.cirkelstad.nl/circulaire-productencatalogus-2-0/

https://www.materialepyramiden.dk/

https://www.afvalcirculair.nl/vaste-onderdelen/zoeken/?zoeken_term=productie+en+verwerking+van+afval+per+doelgroep https://www.crow.nl/blog/september-2018/mooi-die-materiaalpaspoorten,-maar-hoe-zit-het-met

https://www.rvo.nl/onderwerpen/wetten-en-regels-gebouwen/beng#energieprestatie-indicatoren---beng

https://rijksoverheid.bouwbesluit.com/Inhoud/docs/wet/bb2012/hfd2/afd2-4/par2-4-1

XIV. APPENDIX

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14.01 Definitions and Terms

The list of terms and definitions below has been compiled with information from various references. If the definition comes from one specific reference, this is listed with the definition itself. The other references used are numbered below:

[1] Goddin, J., Marshall, K., Pereira, A., Sven Herrmann, Ellen MacArthur Foundation, ANSYS Granta, Circular Economy 100 (CE100) network, DS Smith, DuPont, Eastman, Essity, Gispen, IKEA, Natureworks, Oregon Dept. of Environmental Quality, Scion, StopWaste, TetraPak, UPM Raflatac, & US Green Building Council. (n.d.). *Circularity Indicators Project Methodology*. (Goddin et al., n.d.)

[2] Spitsbaard, M., Van Leeuwen, M., & NIBE B.V. (2022). Rekenprotocol Paris proof materiaalgebonden. In DGBC, *DGBC | Paris Proof Materiaalgebonden - Rekenprotocol* (p. v1.1) [Rekenprotocol]. https://DGBC.nl (Original work published 2021)

[3] Van Vliet, M., Van Grinsven, J., Teunizen, J., Alba Concepts, Dutch Green Building Council, Rijksdienst voor Ondernemend Nederland, W/E Adviseurs, Ministerie van Binnenlandse Zaken, & Transitieagenda Circulaire Bouweconomie. (2021). Circular Buildings - een meetmethodiek voor losmaakbaarheid 2.0. In *Circular Buildings - Een Meetmethodiek Voor Losmaakbaarheid 2.0* [Report]. Rijksdienst voor Ondernemend Nederland.

Bill of materials	A bill of materials (BoM) is a list of the parts or components that are required to build a product. For each of the components the precise type and amount of material is listed. [1]
Biological cycles	In circular economy, bio-based materials are used, consumed, and cycled in ways that regenerate natural systems and can be transformed using treatment types that generate cascades of value. [1]
Building flexibility	'The adaptive capacity of a building includes all the properties, which enable the building to maintain its functionality in a sustainable and economically viable manner during its technical lifetime, in the face of changing needs and conditions.' [3]
Circular economy	A circular economy is a global economic model that decouples economic growth and development from the consumption of finite resources. It relies on three principles: designing out waste and pollution; keeping products and materials in use; and regenerating natural systems. [1]
Climate impact	The environmental impact of greenhouse gases, expressed in CO_2-eq. [2]

Closed loop	In a closed loop, used products come back to the manufacturer and components or materials are used again to produce new products of the same type. [1]
Component	A component is part of a product.
Cradle to Cradle Certified®	The Cradle to Cradle Certified® products program assesses a product's overall sustainability throughout its entire life cycle. It broadens the concept of design quality to encompass positive impacts on economic, ecological, and social well-being. To achieve certification, a product must adhere to rigorous standards across five categories related to health and environmental protection: Material Health, Product Circularity, Clean Air & Climate Protection, Water & Soil Stewardship, and Social Fairness. https://www.agc-glass.eu/en/sustainability/glass-sustainable-architecture/cradle-to-cradle
Detachability	"The detachability of a building is the degree in which objects are demountable at all scales, without compromising the function of the object or surrounding objects so as to protect the existing value protect." [3]
Determination method (Bepalingsmethode)	The determination method states how we perform life-cycle assessment for building materials and products in the Netherlands and what environmental impacts we calculate. [2]
Downcycling	Downcycling is a process converting materials into new materials of lesser quality and reduced functionality.[1]
EN15804	EN 15804 is the EPD standard for the sustainability of construction works and services. This standard harmonises the design of EPDs in the construction sector, making the information transparent and comparable. The first version was published in 2012, known as EN 15804+A1 'Sustainability of construction works - Environmental declarations of products - Basic rules for

	the building products product group'. However, a second version of standard EN 15804+A2 was published in 2019, with the main aim of aligning standards-based EPDs with the Product Environmental Footprint (PEF) classification. https://www.ecomatters.nl/nl/services/lca-epd/milieuproductverklaring-epd/en-15804-epd/
Energy Recovery	The act of recovering the energy content of materials through means such as incineration or gasification. This term specifically excludes energy conversion where the energy content is not usefully recovered. [1]
Environmental impact	A change in the environment resulting from an activity. There are several environmental impacts, such as: climate impact, acidification and toxicity. Each describes a different effect with its own unit. [2]
EPC Energy Performance Coefficient	EPC stands for Energy Performance Coefficient and says something about how economical a building is. The more economical a building is, the lower its EPC value. The EPC norm is set using the energy efficiency of a typical 1990 residential house. This 'model house' was given an EPC value of 1.0 and has been used as a reference ever since. https://www.klimaatexpert.com/blog/wat-is-de-energie-prestatie-coefficient-epc
EPD	Environmental Product Declaration. A presentable and concise representation of an LCA with results such as environmental impacts and EQI (MKI in Dutch).
Feedstock	Feedstock is anything used to produce a new product. This in particular includes raw materials (from either virgin, bio-based, or recycled sources) but can also include components from old products reused in a new product. [1]
Functional unit	A functional unit is a measure of the product's use. For example, it could be

	one kilometre driven for a car, or one wash cycle for a washing machine. [1]
Fully linear product	A product is called fully linear if it is made purely from virgin material and it completely goes into landfill or energy recovery after its use, that is, LFI = 1 [1]
GWP	Global Warming Potential. See ‘Climate impact’ [2]
kg CO2-eq.	The unit in which climate change is expressed: kilograms of CO2 equivalents. This unit allows the effect of different greenhouse gases to be expressed in one number can be expressed. For example, the effect of 1 kg methane is equivalent to 25 kg CO2-eq. [2]
Life cycle assessment (LCA)	LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service. It is derived by compiling an inventory of relevant energy and material inputs and environmental releases and evaluating the potential environmental impacts associated with identified inputs and releases. [1] Longevity is defined by life stages, denoted by the numbering A1 to D. A1-A3 concerns the production phase, B the use phase, C1-4 the demolition and waste phase and D the recovery phase. [2]
Lifetime	The lifetime is the total amount of time a product is in use, including potential reuse of the whole product. The lifetime can be increased by repair or maintenance. [1]
Linear economy	A linear economy consists of ‘take, make, dispose’ industrial processes and associated lifestyles resulting in a depletion of finite reserves. Virgin materials are used to create products that end up in landfills or incinerators. [1]
Linear flow	The linear part of the material flow of a product is the part that comes from virgin materials and ends up as landfill (or energy recovery). [1]

Material Circularity Indicator	The main indicator developed by the 'Ellen MacArthur Foundation' and 'ANSYS Granta' in the methodology of Circularity Indicators. "It assigns a score between 0 and 1 to a product (or company) assessing how linear or restorative the flow of the materials for the product (or the company's products) and how long and intensely the product (or the company's products) is used compared to similar industryaverage products." [1]
Material-related emissions	CO2 impact of construction process and material use. [2]
MKI Milieukostenindicator	Environmental cost indicator. A life cycle analysis is used to calculate the environmental impact of a material, product or structure is calculated. These environmental impacts (several numbers with different units) can be converted into one integral number: the environmental cost, in euros. [1]
MPG MilieuPrestatie Gebouw	Environmental Performance Building. A sum of the shadow costs of all products and materials applied in the building divided by the period considered and the gross floor area. [2]
NMD Nationale MilieuDatabase	National Environmental Database. Database used to calculate the mi environmental performance of buildings and/or building products. The database contains a large number of profiles of materials and products commonly found in construction with their associated mi-lieu effects and shadow costs. [2]
Reference product	For a range of products with similar material composition, recycled and reused content, recycling and reuse at end-of-use, and utility, one of these products is selected to represent the whole product range in the aggregation on a department or company level. [1]
Recycling	Recycling is the process of recovering materials to feed back into the process as crude feedstock. Recycling excludes energy recovery. [1]

Refurbishment	Refurbishment is the process of returning a product to good working condition by replacing or repairing major components that are faulty or close to failure and making cosmetic changes to update the appearance of a product, such as changing fabric or painting. [1]
Remanufacture	Remanufacture denotes the process of disassembly and recovery at the sub-assembly or component level. Functioning, reusable parts are taken out of a used product and rebuilt into a new one. This process includes quality assurance and potential enhancements or changes to the components. [1]
Restorative flow	The restorative part of the material flow of a product is the proportion that comes from reused or recycled sources and is restored through reuse or recycling. [1]
Reuse	Reuse is the reintroduction of the same product for the same purpose and in its original form, following minimal maintenance and cosmetic cleaning. [1]
Service model	A business model in which customers pay for services instead of products. For example, this would include leasing, short-term hire or performance-based usage contracts. [1]
Sub-assembly	A unit assembled separately but designed to be incorporated with other units into a larger manufactured product. [1]
Sustained Production	In biological cycles, the extraction of natural materials at volumes and employing practices which aim to maximise the regeneration of natural systems in the indigenous ecosystems by for example supporting the development of healthy soils. Recognising that proving this can be challenging, as an intermediate step this definition includes extraction that does not reduce the capacity for future production of that material below its present capacity and also does not reduce the natural capital of the associated or dependent indigenous ecosystems [1]
Technical cycles	In technical cycles, products, components and materials are restored

	into the market at the highest possible quality and for as long as possible, through repair and maintenance, reuse, refurbishment, remanufacture, and ultimately recycling. [1]
Total mass flow	The total mass flow for a product is derived as the sum of the amounts of material flowing in a linear and a restorative fashion. [1]
Unrecovered waste	Unrecoverable waste includes waste going to landfill, waste to energy and any other type of process after the use of a product where the materials are no longer recoverable. [1]
Upcycling	Upcycling denotes a process of converting materials into new materials of higher quality and increased functionality. [1]
Use phase	The use phase of a product starts when it reaches its first users and ends when it is not reused any more as a whole. After the use phase, components can be reused and the rest of the product can go into recycling, energy recovery or landfill. [1]
Utility	The utility of a product measures how long and intensely it is used compared to an average product of the same type. The utility is derived from the lifetime and functional units of a product (compared to an industry-average product of the same type). [1]
Virgin material	Material that is not from reuse, recycling or, for the purposes of this methodology, biological materials from Sustained Production. [1]

14.02 Paris-Proof Embodied Carbon

Limits CO_2 budget

To meet Paris Proof material-specific CO2-eq. the building must have a material-specific CO2-eq. value per m2 GFA (BVO in Dutch) that is lower than or equal to the limits for the relevant year specified in Table 1 for new buildings and Table 2 for renovations the relevant year.

<u>Limit values for new buildings</u>

Table 1. Limit values for Paris-Proof buildings. Limit value is data in 'material-related emissions' per m2 structure.

Paris Proof grenswaarden	materiaalgebonden kg CO_2-eq. per m^2			
	2021	2030	2040	2050
Woning (eengezinswoning)	200	126	75	45
Woning (meergezinswoning)	220	139	83	50
Kantoor	250	158	94	56
Retail vastgoed	260	164	98	59
Industrie[5]	240	151	91	54

<u>Limit values for renovation</u>

Table 2. Limit values for Paris-Proof buildings. The limit value is data in 'material-related emissions' per m^2 structure.

Paris Proof grenswaarden	materiaalgebonden kg CO_2-eq. per m^2			
	2021	2030	2040	2050
Woning (eengezinswoning)	100	63	38	23
Woning (meergezinswoning)	100	63	38	23
Kantoor	125	79	47	28
Retail vastgoed	125	79	47	28
Industrie	100	63	38	23

Spitsbaard, M., Van Leeuwen, M., & NIBE B.V. (2022). Rekenprotocol Paris proof materiaalgebonden. In DGBC, *DGBC | Paris Proof Materiaalgebonden - Rekenprotocol* (p. v1.1) [Rekenprotocol]. https://DGBC.nl (Original work published 2021)

14.03 Databases

https://milieudatabase.nl/nl/

https://www.bcigebouw.nl/

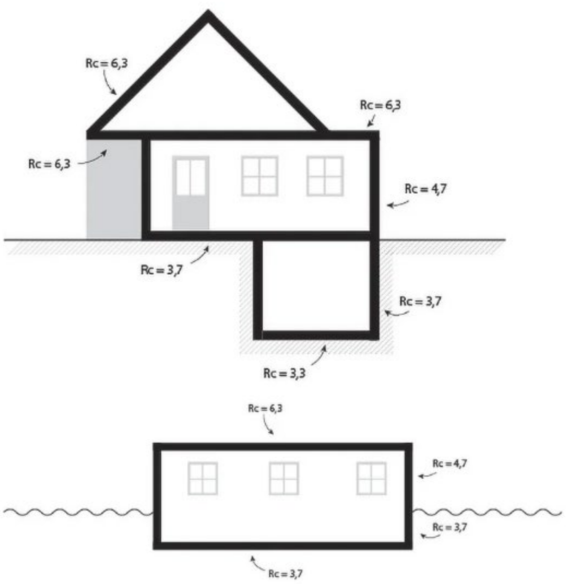
https://albaconcepts.nl/circulairbouwen/

14.04 New construction building codes

Insulation values

Rc-values new construction (since 2021)*		
Type construction	Boundary of the structure	Rc-value
Floor	Ground / crawl space / water	3,7
Basement wall	Ground / water	3,7
Basement wall	Outside air	4,7
Basement floor	Ground / water	3,7
Floor	Outside air / highly ventilated room	6,3
Facade	Outside air	4,7
Roof	Outside air	6,3

* The values as presented in table 1.1 apply to all use functions except for a:
- The residential caravan has a minimum RC requirement of 2.6 for both the floor, façade and roof.
- Floating structure that has an existing mooring location on or before 1 January 2018. This is subject to an Rc value of 3.7 for the floor and façade, and 4.5 for the roof.



https://www.handelbouwadvies.nl/rc-isolatie-waarde-bouwbesluit/

SCHEIDINGSCONSTRUCTIE	BOUWJAARKLASSE	RC [M2·K/W]
Vloer boven kruipruimte of direct op ondergrond; onder maaiveld gelegen uitwendige scheidingsconstructies die de verwarmde binnenruimte scheiden van de grond of een AOR	Van 1965 tot 1975	0,17
	Van 1975 tot 1983	0,52

	Van 1983 tot 1992	1,30
	Van 1992 tot 2014	2,50
	Van 2014 tot 2021	3,50
	Vanaf 2021	3,70
Gevels	Van 1965 tot 1975	0,43
	Van 1975 tot 1988	1,30
	Van 1988 tot 1992	2,00
	Van 1992 tot 2014	2,50
	Van 2014 tot 2015	3,50
	Van 2015 tot 2021	4,50
	Vanaf 2021	4,70
Daken en vloeren grenzend aan buitenlucht	Van 1965 tot 1975	0,86
	Van 1975 tot 1988	1,30
	Van 1988 tot 1992	2,00
	Van 1992 tot 2014	2,50
	Van 2014 tot 2015	3,50
	Van 2015 tot 2021	6,00
	Vanaf 2021	6,30

14.05 Profitability and business plan suggestions for reuse of building materials

Resale and Use Period Extension

Reselling a product in its entirety or extending its lifespan preserves its integrity and complexity, offering the greatest economic benefits compared to a linear model. Increased profitability often arises from tapping into new markets, such as providing a cost-effective option for a high-performing product. In cases where product quality and pricing change only slightly, this can function as a cost-saving strategy. Repair and maintenance activities help sustain the product's optimal performance for as long as possible, and when offered as services, they generate additional revenue streams. Moreover, design adjustments or more substantial innovations can further enhance benefits by prolonging the product's lifecycle. (circularity indicators)

ESG

ESG stands for Environmental, Social and Governance. ESG involves integrating environmental considerations, social impact and good governance into property management and investment. The growing focus on ESG has led to an increase in funds and strategies that integrate (ethical) considerations into the investment process.

The scope of ESG is broad. Besides focusing on energy consumption, ESG also considers broader environmental issues, such as (material-related) CO2 emissions and reduction and the availability and reuse of building materials. It also looks at the liveability of the environment, the promotion of a healthy indoor climate and the pursuit of transparent decision-making and good corporate governance within organisations.

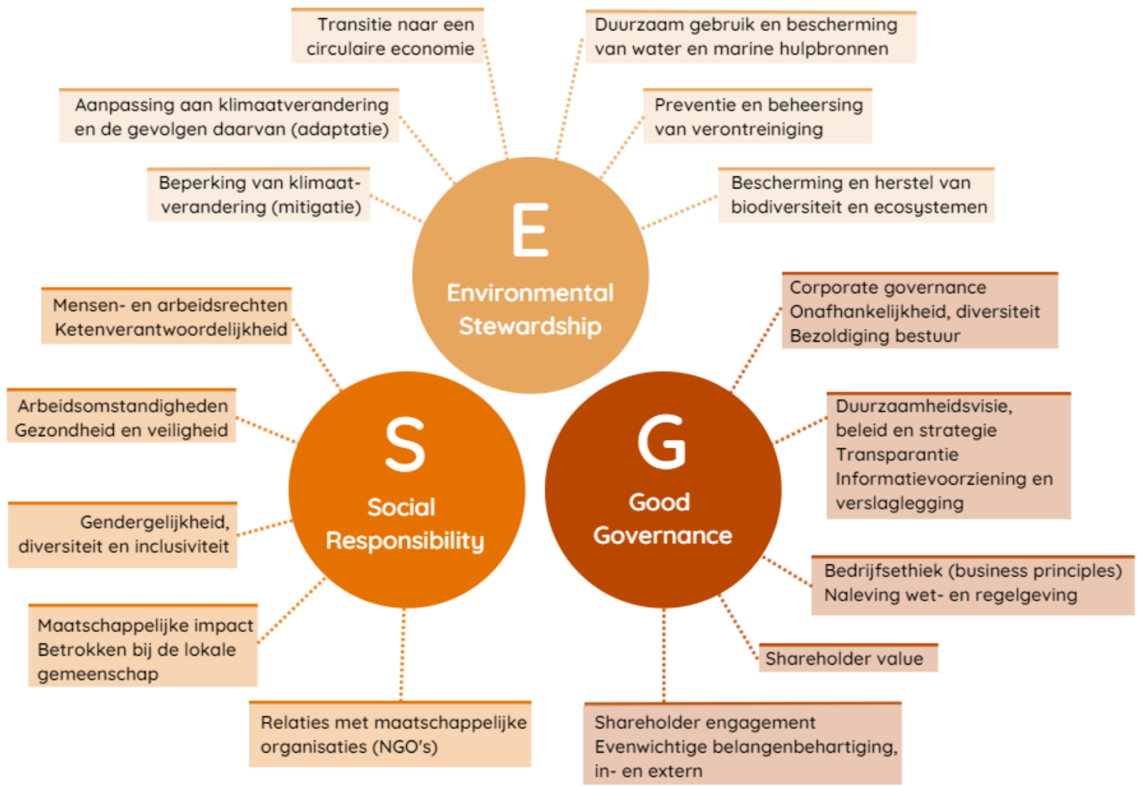
ESG thus creates a comprehensive set of values and standards for a company's behaviour. Various ways have been devised to understand how economic activities fit within ESG objectives. In the context of residential real estate investments, environmental objectives (E) refer to the ecological impact of real estate investments, such as energy efficiency, water consumption, waste management and the integration of green technologies. Social objectives (S) include issues such as housing affordability, occupant safety and health, social inclusion and promoting liveable communities. Governance objectives (G) focus on transparency, accountability and effective decision-making processes in real estate investments. The figure below summarises the various economic activities at play in the areas of environment, social and good governance.

https://research.capitalvalue.nl/pages/esg

More and more owners agree, according to our 2021 Global Investor Intentions Survey. In it, 60% of respondents said they were already including ESG criteria in their investment strategy. They are aware of the need, but also the potential: social and sustainability considerations contribute to the value of their properties. ESG can play a positive role in every life phase of a real estate investment: from due diligence to purchase, from leasing to management.

https://www.cbre.nl/insights/esg/esg-nodig-voor-behoud-van-goed-rendement

Reikwijdte van ESG



Bron: van de Griendt, B. (2022). Het ABC van ESG voor vastgoedprofessionals. SPRYG Real Estate Academy. Bewerking door Capital Value

Refurbishment and Remanufacturing

Refurbishment involves restoring a product to proper working condition by repairing or replacing major faulty components and may also include cosmetic updates to enhance its appearance. Remanufacturing, by contrast, focuses on the component level: reusable parts are extracted from a used product, potentially repaired, and reassembled into a new product. This process often includes rigorous quality assurance, enabling the product to be sold as "like-new." Both approaches retain much of a product's original integrity and complexity, leading to significant material and energy savings. To fully unlock the potential of these strategies, rethinking product designs is essential and can be key to creating viable business opportunities.
(circularity indicators)

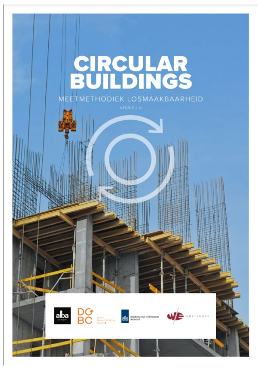
Recycling

If reuse, refurbishment, or remanufacture is not an option, the materials within a product can still be recycled. Although this process results in the loss of the product's integrity and complexity, it preserves the value of the materials. A company may choose to sell the recyclable components to a third-party treatment facility, creating a new revenue stream, or reuse the recycled materials in its own production, leading to material cost savings and ensuring a reliable supply of materials. Enhancing design can significantly boost the model's profitability by facilitating easier disassembly or by incorporating pure, easily recyclable materials, thereby optimizing revenue or cost savings as appropriate. (circularity indicators)

Service and Performance Models

Service and performance models enable companies to retain ownership of their products and facilitate their recovery after use. Examples include rental models (such as clothing rental), pay-per-use models (like a pay-per-wash model for washing machines), and service offerings that include maintenance, repair, and upgrades. These models can be integrated with other strategies mentioned earlier, aiding in product collection while generating new revenue streams (e.g., through service offerings) and capturing a larger market share (e.g., by offering products with a low initial investment).

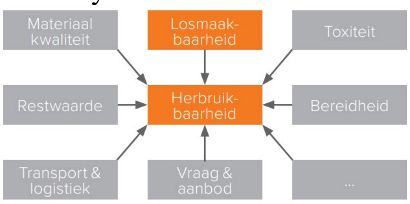
14.06 Losmaakbaarheidsindex.



Van Vliet, M., Van Grinsven, J., Teunizen, J., Alba Concepts, Dutch Green Building Council, Rijksdienst voor Ondernemend Nederland, W/E Adviseurs, Ministerie van Binnenlandse Zaken, & Transitieagenda Circulaire Bouweconomie. (2021). Circular Buildings - een meetmethodiek voor losmaakbaarheid 2.0. In *Circular Buildings - Een Meetmethodiek Voor Losmaakbaarheid 2.0* [Report]. Rijksdienst voor Ondernemend Nederland.
(CIRCULAR BUILDINGS MEETMETHODIEK LOSMAAKBAARHEID VERSIE 2.0, n.d.)

01.01. Definition Detachability
The extent to which these connections can be broken can be broken so that an object can retain its function and high-quality reuse is achievable, determines the degree of detachability.
"The detachability of a building is the degree in which objects are demountable at all scales, without compromising the function of the object or surrounding objects so as to protect the existing value protect."
In this, objects are all materials, products, elements, etc., independent of a defined scale level.

01.02. Detachability for reuse of building materials
In relation to a building, we should harvest products. If products are inseparable, you cannot harvest them, making demolition the only option. The more a building is detachable, the easier it is to harvest products and the more natural this is. Therefore, detachability underlies enabling a circular building economy. This therefore shows that detachability is not an end, but a means to enable reuse.



Figuur 2: **Losmaakbaarheid als factor voor herbruikbaarheid** uit Disassembling the steps towards Building Circularity door van Vliet, M., 2018, Technische Universiteit Eindhoven, Eindhoven

To express high-quality reuse, the 10-R model is used. This emphasises the goal of reusing products as much as possible in their original state, resulting in lower energy consumption. The final step is to recycle products into raw material for a new product. Higher detachability leads to a more favourable future scenario.

01.03. Detachability for building flexibility
'The adaptive capacity of a building includes all the properties, which enable the building to maintain its functionality in a sustainable and economically viable manner during its technical lifetime, in the face of changing needs and conditions.'

01.04. Detachability for management and maintenance

A building is maintained during its lifetime to ensure the quality of the products used - and therefore the building. Detachable products are easier to maintain, reducing maintenance costs. This has a positive effect on a structure's operating costs.

03.Scope van de meetmethode

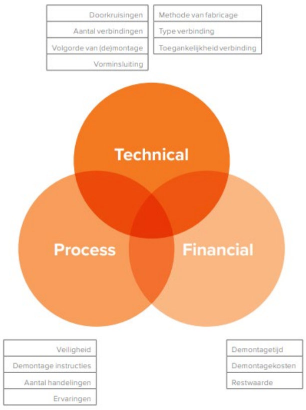
03.01. Building levels
1. Product = A component that arrives at the construction site and is further processed into a building.
2. Element = A component consisting of several products, which arrive at the construction site.
3. Sealant material = A material or product that provides a seal between different products or elements
4. Fixing material = Een materiaal of product dat zorgt voor de (constructieve) verbinding tussen verschillende producten of elementen.

03.02. Assess elements

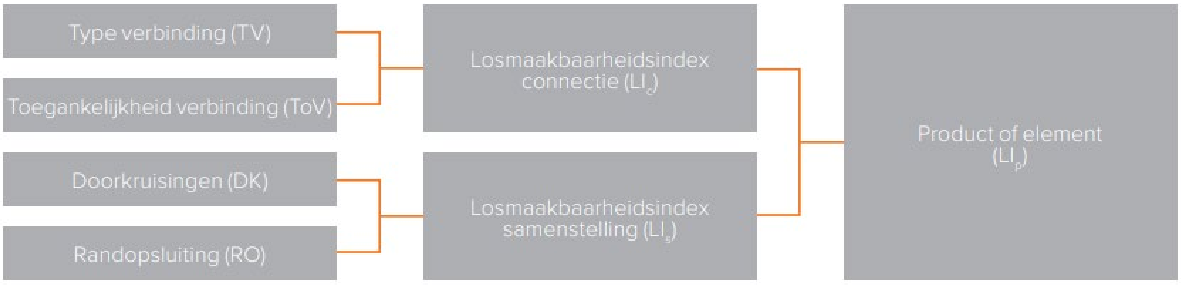
Figuur 4: **Losmaakbaarheid binnen de Layers of Brand**. Aangepast overgenomen uit 'How building learn' door Brand, S., 1994.

"One of the characteristics of the Layers of Brand is that products have different lifespans. Structural products (products under the 'Structure' layer) usually last the entire life of a building, while finishes are replaced several times. Products with lifespans shorter than that of the building in which they are applied are of extra interest to be detachable."

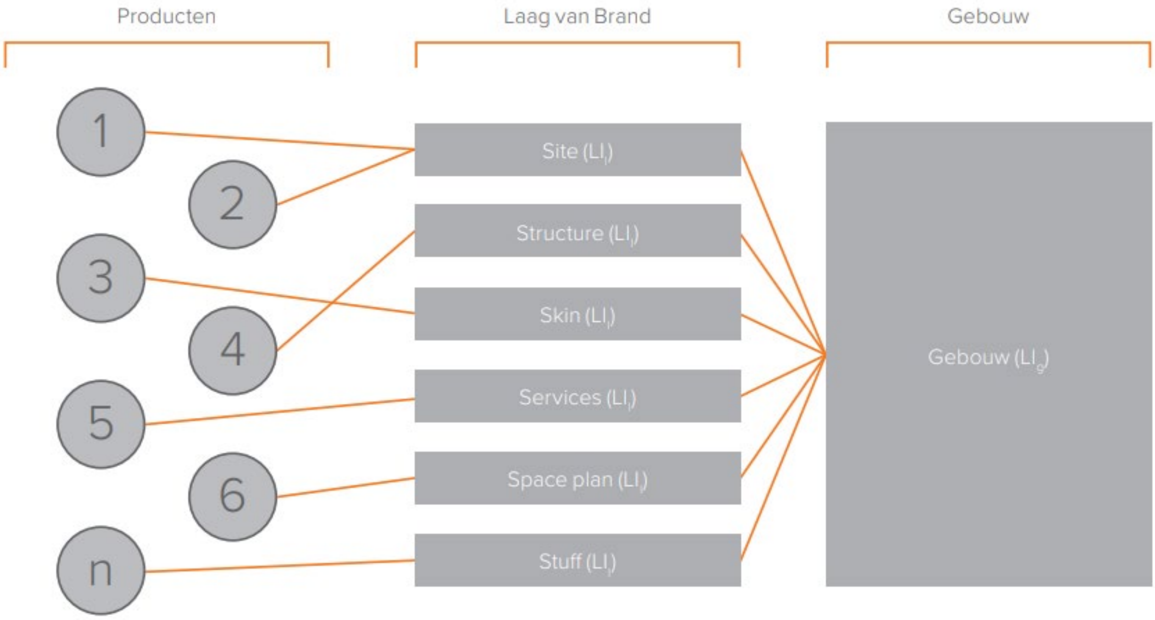
04. Measurement method



Figuur 5: **Overzicht losmaakbaarheidsaspecten** overgenomen uit Disassembling the steps towards Building Circularity door van Vliet, M., 2018, Technische Universiteit Eindhoven, Eindhoven.



Figuur 6: **Stappenplan beoordelen Losmaakbaarheidsindex van een product.**



Figuur 7: **Stappenplan beoordelen losmaakbaarheidsindex van een gebouw.**

04.03 Losmaakbaarheidsindex van de connectie (LIc)

De formule voor het bepalen van de losmaakbaarheidsindex van de connectie is:

$$LIc_n = \frac{2}{\frac{1}{TV_n} + \frac{1}{ToV_n}}$$

Waarbij:

LIc_n = losmaakbaarheidsindex van de connectie van product of element *n*:
TV_n = type verbinding van product of element *n*;
ToV_n = toegankelijkheid verbinding van product of element *n*.

04.06 Losmaakbaarheidsindex van de samenstelling (LIs)

De formule voor het bepalen van de Losmaakbaarheidsindex van de connectie is:

$$LIc_n = \frac{2}{\frac{1}{DK_n} + \frac{1}{RO_n}}$$

Waarbij:

LIc_n = losmaakbaarheidsindex van de samenstelling van element *n*:
DK_n = doorkruisingen van product of element *n*;
RO_n = randopsluiting van product element *n*.

04.07 Losmaakbaarheidsindex van het product of element

De formule voor het bepalen van de losmaakbaarheidsindex van het product of element is:

$$LIp_n = \frac{2}{\frac{1}{LIc_n} + \frac{1}{LIs_n}}$$

Waarbij:

LIp_n = losmaakbaarheidsindex van product of element *n*.
LIc_n = losmaakbaarheidsindex van de connectie van product of element *n*.
LIs_n = losmaakbaarheidsindex van de samenstelling van product of element *n*.

Of :

$$LIp_n = \frac{4}{\frac{1}{TV_n} + \frac{1}{ToV_n} + \frac{1}{DK_n} + \frac{1}{RO_n}}$$

Waarbij:

LIp_n = losmaakbaarheidsindex van product of element *n*.
TV_n = type verbinding van product of element *n*.
ToV_n = toegankelijkheid van de verbinding van product of element *n*.
DK_n = doorkruisingen van product of element *n*.
RO_n = randopsluiting van product of element *n*.

Bijlage 1 licht de totstandkoming van deze herziene formule toe voor de losmaakbaarheidsindex van het product of element. Beide formules leiden tot hetzelfde resultaat voor de losmaakbaarheidsindex van het product.

(Tv) Type joint

Dry joint	1-Loose (no fixing material)	1
	1-Click connection	1
	1-Velcro connection	1
	1-Magnetic connection	1
Connection with added elements*	0,8-Bolt and nut connection	0,8
	0,8-Spring connection	0,8
	0,8-Corner joints	0,8
	0,8-Screw joint	0,8
	0,8-Joints with additional connection elements**	0,8
Direct integral connection	0,6-Pin connectors***	0,6
	0,6-Nail connection	0,6
Soft chemical joint	0,2-Sealant compound	0,2
	0,2-Foam compound (PUR)	0,2
Hard chemical compound	0,1-Adhesive bonding	0,1
	0,1-Landfill joint	0,1
	0,1-Welded joint	0,1
	0,1-Cementitious joint	0,1
	0,1-Chemical anchors	0,1
	0,1-Hard chemical compound	0,1

Accessibility link (ToV)

1-Freely accessible without additional actions	1
0,8-Accessible with additional actions that do not cause damage	0,8
0,6-Accessible with additional operations causing fully repairable damage	0,6
0,4-Accessible with additional operations with partially repairable damage	0,4
0,1-Not accessible - irreparable damage to the product or surrounding products	0,1

Intersections (DK)

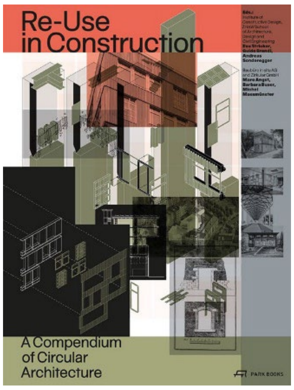
1-No intersections - modular zoning of products or elements from different layers.	1
0,4-Occasional crossing of products or elements from different layers.	0,4
0,1-Full integration of products or elements from different layers.	0,1

Edging (RO)

1-Open, no impediment to (intermediate) removal of products or elements.	1
0,4-Overlapping, partial obstruction for (intermediate) removal of products or elements.	0,4
0,1-Closed, complete obstruction for (interim) removal of products or elements.	0,1

14.07 K.118

K.118 (text by Michel Massmünster)



“First comes the hunt, then the construction: if you want to reuse building components, you first have to assemble them. This not only changes the usual processes and job descriptions but also alters our view of the city.”

“The architects from bau-büro in situ know that their search has to start in their personal surroundings because there is a lack of tools and information for a methodical search. They would love to have a map with planned demolition projects. Unfortunately, that doesn't exist.”

Hunt:

- Open for many possibilities for design
- Product hunters
  - The component hunter re-traces the remaining objects in the inventory list on her computer.
  - Ben, the designer, and Michele, the drafter, then add the drawings to the design plan. This will illustrate if and how the components fit together with the existing materials. 'If everything fits, we'll organize the disassembly.'
- Disassembly
- ‘it is better to reuse the entire system’

“while architects the architects design, plan and construct the building, they are always also developing the techniques, tools, and methods that are required for the project. The tools they use to contact the responsible parties once the architects become aware of a planned demolition have now been automated. There is a standard email an a project portfolio that the uses to contact the owners.”

Design process:

- The height of the floors and windows will be determined by the components they have already collected.
- The new façade is supposed to adopt the existing building rhythm. → limits design options.
- Sketches allow the team to explore different approaches further and specify the direction to take in the search for materials.
- Red aluminium trapezoidal sheeting. Material that is often found in industrial areas where reconstruction is taken place (location specific availability)
- Possiblitity to have the design of the dacae ready for the planning application submission.

- The exterior appearance will not change much once the basic shape, the facades, and the exterior staircases have been put in place. However with regard to the details, the design of the building will keep developing as components are added.
- The architect will move from large to small.
- Highly detailed versions of the design are created in the office and the availability of materials often lags behind them. Although it is not yet clear which components can be used to implement the design, the team needs to at least have and idea of their role in order to be prepared for possible finds during the hunt for components. At the same time the components hunters will also be open to making unexpected finds. This means the detailed preplanning will usually end up with the design having to be reworked following each find.
- In this design process, we can't just say, "Let's not worry about this detail now, we will define it later," because there are always other areas that are connected, where we already know and have defined the details. If, for example, we already have the windows and know how they are supposed to be attached and how much space there should be between them, then the instructions for the search team are very specific with regard to what can be used around the windows. But that is something we only find in rare cases. This means that, when we have found the next piece, we have to look at how we can adapt the arrangement of the windows as necessary.
- **The process is characterized by constantly having to backtrack, or rather by continuous circling. An idea that arises during a design is in most cases based on already existing materials or an ideal**. The process moves to the find and then to testing the material and reworking the design. , which then results in new ideas for what else is needed. It's a constant complication of a hypothetical image. That remains abstract at first and is only specified once that material has been found, but may also be revised if necessary.
- No standard solutions. Connections in field are necessary to find solutions. → experimenting, revising, and discarding are key methods: the project takes shape on the basis of decisions that in retrospect turn out the be suboptimal and then through a process of revision. → exploratory approach to develop its strategies for circular designing.

Concrete was sparingly used for necessary structural support, sound insulation, and fire protection. Three new floors were added atop the hall, accessible via an external steel staircase that was also reused.

This project embodies a circular approach to construction, demonstrating the importance of thinking in cycles. Beginning with the identification of available materials, the architectural process followed a continuous cycle of evaluation, verification, and decision-making. Biosourced materials were incorporated where necessary.

14.08 Biopartners

First project with reuse from start. Not because of sustainability but because of fascination for the materials or the existing buildings themselves. Utilising what already exists requires craftmanship and flexible thinking. Memories are stored in the used products, because of previous life.
CO2 budget for project to show how much smaller the footprint of the building would be. Working with a CO2 budget is an effective framework for buildings, because it makes sustainability concrete and transparent. The aim was to have a lower budget value than 250 kg CO_2/m^2 and it ended up with a footprint of 212 kg CO_2/m^2.

'CO_2 budget forces one to design, build and use differently. In his analyses, Martijn van Leeuwen gave us a hierarchy for thinking about the materialization of BioPartner 5. First aim for reuse solutions and, if these are not available, biobased solutions such as wood, and then, only in the last instance, for sustainable variants of prevalent materials.'

A integral approach is crucial for large buildings like Partner 5. A building scale like this cannot be made from used materials in its entirety, so a mix of materials old and new will always be needed. Making the optimal choice for this is essential.
The main actions that lowered the CO_2 footprint:

- Reused steel construction: 165 tonnes of steel
- 250 m^3 of brick rubble
- and 60 m^2 of Alta Quartzite tiles

Gathering

Architects need to become gatherers again. Keep searching for the next missing piece in their collection. When the collection is complete the building can be built.
From the perspective of CO_2 reduction, it is more effective to utilise a used material on the largest scale possible. This is the structure of a building. Looking at the Shearing Layers of Steward Brand, the structure last the longest after the site.
Used materials often require processing before the quality of the materials is apparent.

Gathering used materials is a 'city-act'.

- Search for suitable buildings due for demolition (donor buildings)

Finding a donor building is indispensable (p.23). When finding a donor building, the owner needs to be willing to revise the planned demolition process, and demounting needs carefully be done. A systematic inventory of the potential of the elements that can be used needs to be made. 'in an intended donor building, an inventory of its potential in terms of reuse can be made layer by layer.' These layers represent a hierarchy in terms of the lifespan of the elements. The largest CO_2 reduction is achieved with elements that still have a long lifespan.

- Challenge reusing on the largest scale possible

Reusing structural elements is the biggest environmental gain. On the building level this means a CO_2 reduction of 20% compared to new buildings. → In the Paris agreement a 40% is required, so half of it can be realized by doing this.

Post-war buildings (and before …) are not designed for dismantling. Buildings from these periods require a new craftsmanship to retain the quality of the donor elements when the buildings are dismantled piece by piece.

- Irrational aversion to reuse

'Knowing what materials have been used in a building and what qualities they have becomes increasingly important if we want to use these materials again. Currently, the potential for reusing elements is often not recognised.' (P.41) → material passports

- High-quality residual flows that now go to waste

- History of building materials. Building is a curated collection of materials. You get the history of earlier uses and the accompanying imperfections.

Accepting imperfections. ‘perfections is by no means always necessary, imperfections can give materials a past.’

The decision was fallen to demolish the Garlaeus Building on the same campus. A other campus building only 750 m away from the Biopartner 5 location. The steel construction and concrete flooring of this building became available and was the base of the new design (p. 22). A decisive moment was when the architectural firm found out the storey height was the same as required. Unfortunately, it later turned out that it was not possible to reuse the concrete floor elements, as they were stuck together with bitumen and for environmental reasons that was not allowed for reuse.
Glass interior walls where extracted from a government building in Haarlem. They where simply considered as waste by the owners after new budget for interior became available after 15 years.
Toilets where taken from a former office accounting firm in Amstelveen.
Oak from second-hand furniture that will not sell is repurposed by cutting into panels for a new bar.
Carpet flooring with production errors where used.

Collaging p.59

Assembly
Basics of buildings = joints + materials → clustering lifespans

Circularity revisited
Avoid wasting materials, every used material should be able to get a second life. Fewer materials for the finishings and more attention for the joint between the really necessary materials. Leaving out materials that are not necessary and knowing what materials are needed to meet the strict requirements. A building with the smallest footprint is a chain of optimised material solutions.

Assembly with used steel
Some parts were sawn too short with the disassembly. This had to be fixed with extension pieces. The order from the storeys was used again for the new design. So that the feet of the columns would fit when being reinstalled. After 50 years of use, the constructions also deals with his distortions.
Thus the structural components were processed step by step, so they complied with the technical requirements that new buildings have to meet in order to obtain a permit.
You can trace back the damages, inexplicable holes and structural additions. Aesthetically, we accepted the unique imperfections as a manifestation of the history of the material. They kept the structure visible in as many places as possible in order to show this story.

Assessing, testing, convincing and processing
‘The assessing, extending and questioning of the technical variants is an aesthetic exercise.’ ‘the various materials used come together.

Assembly new architecture p.91
In the new hybrid building, automation and craftsmanship will have to complement each other somehow or other.

14.09 Construction Logistics

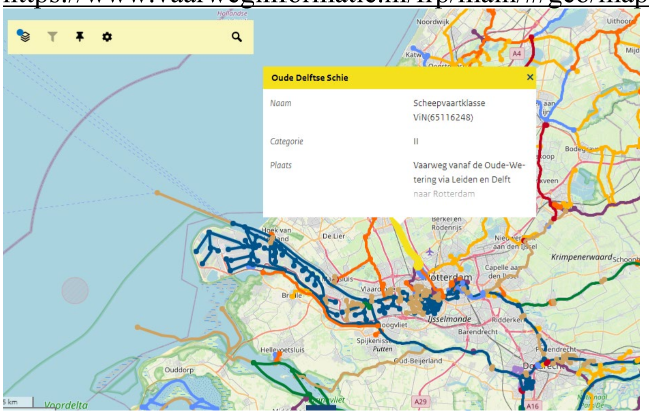
A barge measuring 15 by 3 metres fits at least 60 pallets (maximum 90). A truck fits 10 to 20 pallets. The barge can lift a weight of 80 tonnes. At the quay, only 10 tonnes of weight is allowed.
Sailing brings unexpected advantages: longer prefab elements fit on such a barge. But you are limited in height: the stuff has to fit under the bridge (3.5 metres high).

Specialist transport
PK Waterbouw works with large traditionally powered diesel engines but for the inner city also with special, electrically powered tugs. It also runs an innovation project testing how hydrogen propulsion can be used in hydraulic engineering.https://pkwaterbouw.nl/binnenstedelijk-bouwtransport/
https://www.mcs-bv.nl/diensten/watertransport/

https://www.zuid-holland.nl/onderwerpen/verkeer-vervoer/goederen-over-water/

https://pure.tue.nl/ws/portalfiles/portal/47004522/696932-1.pdf

https://www.vaarweginformatie.nl/frp/main/#/geo/map

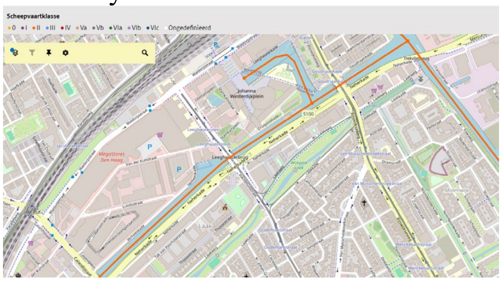


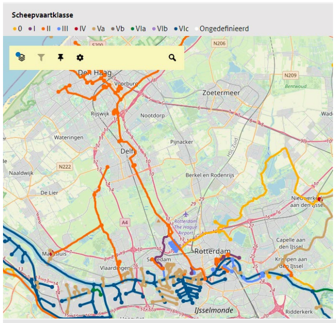
https://wereldvandebinnenvaart.nl/schepen/10/kempenaar

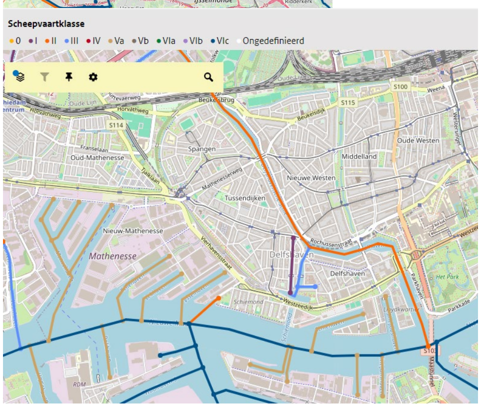
CEMT-klasse	*RWS-klasse*	*Type*	*Lengte*	*Breedte*	*Diepgang geladen*	*Strijkhoogte leeg/geladen*	*Laadvermogen (ton)*
II	*M2*	*Kempenaar*	*50-55*	*6,6*	*2,6*	*5,8/4,6*	*401-650*

https://nl.wikipedia.org/wiki/CEMT-klasse

Waterway:







14.10 Leidraad toekomstig hergebruik

(*Leidraad_Toekomstig-Hergebruik-1*, n.d.)

Building materials, building elements and building installations of an
existing structure go through several phases until the reuse application. The type of material and the application determines which specific (public and private) laws and regulations apply or are lacking.

The reuse of products from existing structures and the equipping new structures and products for reuse, are not yet sufficiently addressed in current building regulations. The result of this guide is an action list to adapt or develop technical regulations where necessary. (blz. 49)

and environmental gains to be achieved, such as steel and concrete, and o elaboration of the Eurocodes for reuse of structural products;
- substantive elaboration of building materials inventories and assessment for reuse, and linking to rules for inspections and demolition;
- a quality assurance system for the process from building materials inventory to product reuse, partly based on generic and specific technical rules;
- expansion of the Building Decree to include the 'reuse' situation (in addition to new construction and existing construction) to provide more clarity on possible exemptions and quality assessments;
- further facilitating the MPG calculation of structures with reused products. This can be done partly by offering for inclusion in the NMD product maps of materials to be reused in the future or by generic implementation of the H-factor in the NMD to value reusable materials. And by facilitating the MPG calculation tools for application of reused products. This can include those product maps together with the application of the generic H-factor. The aim is to transparently display reusable products for low-threshold application.

Page 23
Determining the (residual) quality of products to be reused is now basically done on the basis of requirements for new products (step 3) and material-specific aspects (steps 4 to 8). This is often costly, difficult to implement or unclear. Certification is not yet possible and it often cannot be guaranteed.

Currently, many recycled materials and products are used in 'non-Building Decree constructions'. Given also the material flows released, an assessment method for steel structures and structural concrete elements deserves priority. Product standards for newly marketed products should also define how to determine performance of reused products, taking safety factors into account. For example, by providing default values for certain post-use performance. The Eurocodes should develop this in an annex, for example

14.11 Design Tool

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Reuse Potential				Bill of Material					Measurements				
RP-		RP	RP+		Code	Item name	Photo	Shearing layer	Height (mm)	Width (mm)	Thickness (mm)	Weight (gram)	Volume (m^3)
#######	####	#DELING.DOOR.0!	########	Building part	1								0
#######	####	#DELING.DOOR.0!	########	System	2								0
#######	####	#DELING.DOOR.0!	########	Product	3a								0
#######	####	#DELING.DOOR.0!	########		3b								0
#######	####	#DELING.DOOR.0!	########		3c								0
#######	####	#DELING.DOOR.0!	########	Component	4a								0
#######	####	#DELING.DOOR.0!	########		4b								0
#######	####	#DELING.DOOR.0!	########		4c								0
#######	####	#DELING.DOOR.0!	########	Raw Material	5a								0
#######	####	#DELING.DOOR.0!	########		5b								0
#######	####	#DELING.DOOR.0!	########		5c								0

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Availability	Performance						Logistics		Supplier				
Amount	Strength	Strength aim	RP value	Rc-value	Rc-value aim	RP value	Building close to waterway ?	Transport options	Brand	Age (End-of-use) (months)	Technical lifespan End-of-life (months)	Estimated remaining lifespan	RP value
			0			0						0	0
			0			0						0	0
			0			0						0	0
			0			0						0	0
			0			0						0	0
			0			0						0	0
			0			0						0	0
			0			0						0	0
			0			0						0	0
			0			0						0	0
			0			0						0	0

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Disassembly index											
(Tv) Type joint		Accessibility link (ToV)		Intersections (DK)		Edging (RO)		Disassembly index	LIcn = losmaakbaarheidsindex van de connectie van product of element n:	LIcn = losmaakbaarheidsindex van de samenstelling van element n:	Assembly
								#DELING.DOOR.0!	#DELING.DOOR.0!	#DELING.DOOR.0!	
								#DELING.DOOR.0!	#DELING.DOOR.0!	#DELING.DOOR.0!	
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4/4

			Quality				Toxicity		Maintenance			LCA
Construction method	Deconstruction method	Risks of deconstruction	Condition	Aesthetics	Standardisation / Authenticity	Flexibility	Toxicity range	index toxicity	Data management	Financial value	Contracting	LCA Embodied Carbon

14.12 Reflection P4

REFLECTION PAPER - P4

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Second mentor: Paddy Tomesen
Third mentor: Dafne Swank

I. INTRODUCTION

My graduation project focuses on designing a circular multi-level building with dwellings and a public function in Merwehaven, Rotterdam, with reused materials as a core principle. Research has been done about setting up a data-driven tool to assess the reuse potential of building materials for a new architectural implementation. The context and scope of the project combines the challenges of the housing crisis and climate change by using existing materials from a donor building. The donor building for this project is the Megastores in The Hague. A vacant shopping mall that will be demolished.

In this reflection, I look back at the process, methodological choices, feedback and impact of my work, and give direction for the final phase.

I can say that my approach to my design worked, but it was a bumpy ride. In my research, it took some time to finally get the method straight and in a logical and user-friendly format. The solution ultimately lies in making the correct link between measurable and non-measurable factors, technical and architectural properties and process outcomes (deposition decisions). Linking it to a specific context (Merwehaven & Megastores) makes the research insightful and tests its applicability.

My architectural design is material-driven. Using donor materials was the starting point. This makes you face challenges different from those of traditional design research and process. In my design consultations, you are quickly pushed into this traditional corner, and looking back, I did so a lot. Distracted from my original purpose. However, through the research, material-driven design did become engrained in my intuition and allowed me to reasonably put myself back on the right path.

In your graduation project, you are your own project manager, but keeping yourself on your toes and addressing your design choices is something I found challenging and would like to be a lot better at. What did not help and what can be a significant factor in the continuity of an architectural design is the development from concept to technical design. On a personal note, I am actually very interested in the engineering detailing of buildings, and the concept has to stem mainly from certain logic. This prevents me as a designer from seeking or daring to push to the extreme extremes. The realism factor often pops up in my mind.

The feedback I mainly tried to incorporate in my design is the experience of the different spaces, the aspects that housing construction entails and that my research findings should support my story.

In the final phase of my graduation year (P5), I would like to revisit my design on use aspects and urban planning scale. I have developed a housing concept from materials, but this housing concept could be given some more attention in contextualisation. How does my design land on the Merwehaven? So, the process goes from the smallest puzzle piece to the bigger picture, from the material level to the urban planning scale.

II. RELATION BETWEEN GRADUATION PROJECT, STUDIO TOPIC, MASTER TRACK AND MSC-PROGRAMME

What is the relation between your graduation (project) topic, the studio topic, your master track (A, U,BT, LA,MBE), and your master programme (MSc AUBS)?

The connections between my graduation project, the Architectural Engineering studio, the Architecture track, and the MSc AUBS programme highlight the interdisciplinary and practical approach to design.

2.01 Relation Between Graduation Project and Studio Topic

The 'Circular Design and Reuse Practices' topic directly relates to circularity in the built environment, aligning closely with the master studio Architectural Engineering. The studio themes of 'Make, Flow, Stock' all emphasise aspects of circularity, aiming to develop architectural designs that are contextually relevant, user-focused, and technologically advanced.

2.02 Relation Between Graduation Project and Master Track

In the broader field, this topic relates to the Architecture track by emphasising creative and innovative design. The Architecture track fosters the use of design to address social, technical, and spatial challenges. My project showcases sustainable reuse practices that not only respond to environmental concerns but also enhance the social and spatial dynamics of the built environment.

2.03 Relation Between Graduation Project and Master Programme

Moreover, the MSc AUBS programme supports an interdisciplinary approach to solving complex built environment challenges. My project integrates principles from architecture, sustainability, and engineering, demonstrating the comprehensive and practical educational framework provided by the MSc AUBS programme.

In summary, my graduation project embodies the principles and objectives of the Architectural Engineering studio, the Architecture track, and the MSc AUBS programme. It illustrates how innovative design solutions can address contemporary challenges, preparing me for a career in the field of architecture.

III. INFLUENCE OF RESEARCH ON DESIGN

How did your research influence your design/recommendations and how did the design/recommendations influence your research?

The interplay between research and design was a defining feature of this project. My research concluded with the question, *"When availability defines the form of your design, how does it influence your design process?"* This question is related to the question above. The "Material-driven design approach" was guided in this project for the architectural and methodological approach of the graduation project. The architectural design of this graduation project is an experimental study in which the case of the Megastores is used to test reuse for a new project.

In this project, the process began with identifying and prioritising using reclaimed materials from the Megastores, treating the "pile of materials" as the foundation for construction and materialisation. This parallel exploration of material inventory and design principles reshaped the design process, requiring adaptability to the constraints and opportunities posed by available donor materials.

The base for the final design was starting with the bigger building materials and grid size of the donor building. This ensured that many other building materials could be directly reused.

In this graduation studio, students are required to determine the Plan of Requirements for their final project. The open-ended Plan of Requirements enabled greater flexibility, fostering innovation in the reuse of materials. In practice, tender requests are drafted in great detail, which creates a significant degree of steering within the design process. This steering can potentially limit the design options available, mainly when there is a preference for reuse. To promote reuse, it is essential to conduct a critical assessment of the current tender specifications to ascertain whether they are aligned with more sustainable trends, like reuse.

Constraints imposed by materials encouraged creativity in finding new applications and maximizing their potential, striking a balance between architectural, technical, and logical considerations. It is crucial to leverage the potential of materials and navigate around their limitations. If a particular material is unsuitable for a specific application, there are still numerous other possibilities. While materials impose constraints on the design process, they also encourage designers to explore different applications to achieve the highest potential of reuse.

A recurring theme during this design process was that you always need extra material to complete your design. These materials were sought in biobased options when these could not be found within the donor building. This accelerates the development of the design, but can be seen as the easier way to bypass reuse. On the other hand, these design infills can also be seen as temporary implementations and set the parameters for the next hunt. These moments of compromise underscore the need for iterative processes and continual refinement as part of a circular and resource-conscious design approach.

Ultimately, the research led to data-driven outcomes that valued the reuse potential of building materials for application in a new building. These outcomes guided the applications in the final design.

IV. ASSESSMENT OF METHOD

How do you assess the value of your way of working (your approach, your used methods, used methodology)?

As mentioned earlier, the data-driven approach was effective in identifying reusable materials and testing their potential. Due to missing data and complex logistics, constraints posed obstacles in realising the design. However, it also stimulated creative solutions. Resulting in the design outcome of my project.

V. ACADEMIC AND SOCIAL VALUE

How do you assess the academic and societal value, scope and implication of your graduation project, including ethical aspects?

This project contributes to knowledge development around circular design strategies and the reuse of materials in architecture. It shows how architects can actively contribute to sustainability and reducing CO_2 emissions with practical applications in future projects.

VI. *TRANSFERABILITY AND APPLICABILITY*

How do you assess the value of the transferability of your project results?

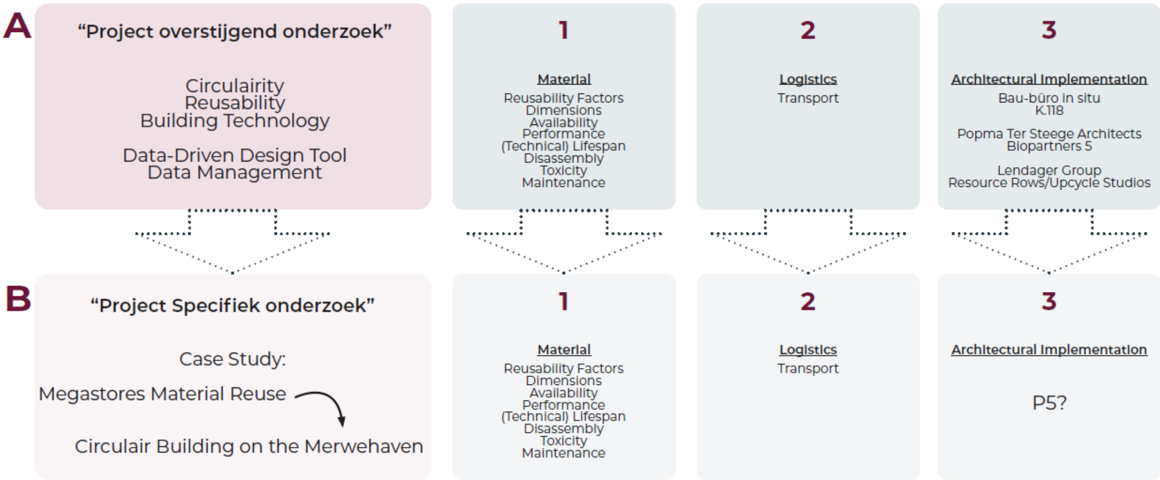

Figure 29 Scheme methodology research (made by author)

My thematic research consists of two parts. Part A is a cross-project study and part B is the part where I applied these results to the case of Merwehaven & Megastores. As seen in figure 1, the last part is part B3. This is the architectural implementation of the reclaimed materials in a new design as an experimental case study.
The results applied in the case of Merwehaven & Megastores can be seen as context-specific. The methodology developed in this project is cross-cutting with that relevant to different actors in the academic and professional fields.
The final design visually represents how complex technical and social challenges can come together. A showcase of how sustainable design principles can take shape.

VII. OWN REFLECTION QUESTIONS

I did my graduation project at the university itself. Other faculties and master tracks often offer an opportunity to do your graduation project at a company. I think for the subject of this graduation project, this would have been an interesting option. This leads me to the following question:

In what aspect will my research improve the realisability of the actual project?

My project is about data from building materials. There have been many developments on this in recent years. Material passports of buildings are created, building maintenance is tracked via databases, and with BIM no longer an indispensable part of the construction industry, there is a digital twin of every newly constructed building. My original idea was to do something with these topics. Still, I quickly ran into the problem that this information lies within companies and this information is not an open source. I approached several companies, but a collaboration was impossible because I was not doing a graduate internship with them.
How did this affect my research and project? The effect was that I eventually figured out all the important aspects for reuse and thus finally developed a method to grade the values of the reuse potential. The advantage was that I gained in-depth knowledge on the subject by

myself, and I feel that after this project, I could easily apply to New Horizon, BAMB, or DGBC.

Is the final design concept the best fit for answering the design question proposed at the beginning of this project?

My design question and objective were quite broad. In retrospect, there was quite a lot of design freedom despite the material-driven design. You always need more materials to complete your design, but you could also turn it around: if you don't have the materials, why design it that way? The requirements of my building programme did lead me to need additional materials.

Looking back, I think the reuse of building materials from vacant shopping malls is more attractive for public buildings than dwellings because you need a lot more extra material.