Research Plan / aE Studio

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TITLE

FROM DEMOLITION TO DISASSEMBLY

The potential of CNC milling enabled disassemble-able infill systems for a circular economy

HAKA gebouw – inside the former office part of the buidling
photographed by the author

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Choice of Studio

I chose the Architectural Engineering graduation studio because of its technical, practical and solution-oriented approach to design and planning. Also the very open project brief that allows students to pick their topic of fascination was a key argument of choosing the studio. The strong focus on current problems in architecture and the building industry and the thematic orientation towards topics like circular design, energy efficient design, sustainability, manufacturing, prototyping and material flows were amongst the strongest arguments for me as I want to focus on circular design and advanced manufacturing in my graduation project.

Keywords

A selection of the most relevant keywords – Detailed definitions can be found in the 'Glossary of Keywords' section at the end of this document.

Circular Economy | **Ease of Disassembly** | **CNC Milling** | **Waste Minimisation** | **Building Infill System**

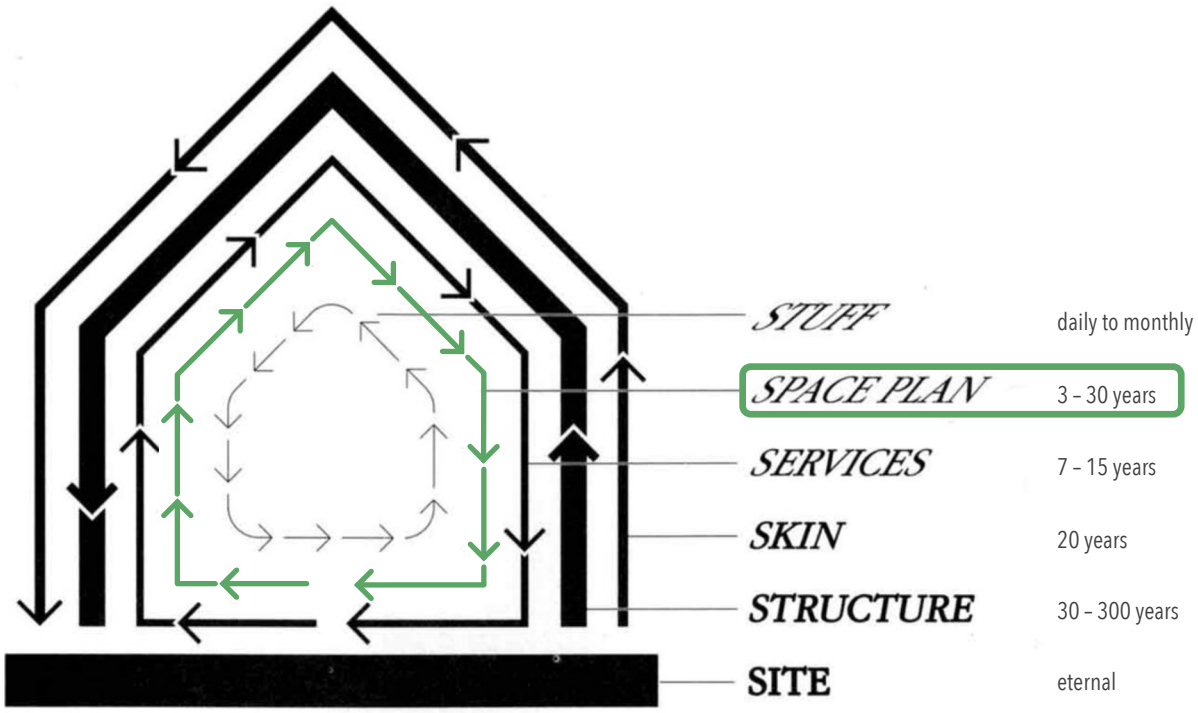
Relevant Keywords | Source: Wordart.com (2022)

Introduction

The shearing layers model introduced by Stewart Brand in his book ‚How Buildings Learn: What Happens After They're Built' describes six distinct layers of a building and differentiates them regarding their life span. The model divides a building in the layers site, structure, skin, services, space plan and stuff, assigning each an estimated life span depending on type of building and its use (Brand, 1994).

Considering the greatly differing life spans of the layers, it is a model that could find more attention in the architectural design process and the planning and construction of the six layers to make them structurally more independent from each other. Not seeing a building as one rigid object but rather as a more complex system of layers with different life spans is an approach that aligns with circular design principles. Instead of demolishing a whole building because one of the above mentioned layers does not meet the users requirements anymore, it implies the possibility to replace, refurbish or repair elements of one layer without interfering with the others.

The space plan is amongst the layers with the shortest life spans, according to Brand between 3 and 30 years, strongly dependent on the function and intensity of use of the building (Brand, 1994). The space plan considers all internal elements like floors, walls and ceilings which define the interiour layout of a building and are not related to the (load-bearing) structure. To see these elements separated from a buildings' structure can open new possibilities for circular design approaches as it makes it considerably easier to repair or demount ‚space plan' elements.



Shearing Layers | Source: *How Buildings Learn*, Stewart Brand (1994)

Problem Statement

LAYERS OF THE PROBLEM

GLOBAL

Construction and demolition waste - A global problem

Throughout the process of construction and predominantly at the end-of-life of a building or building component, large amounts of waste are produced. The building and construction sector contributes an estimate of at least one third of all waste generated in the EU, on a state level, the figures align with that estimate, for instance with rates of 36.7% in Belgium, 41.5% in the UK and 41.6% in the Netherlands, posing a significant impact on the environment (Rajagopalan et al, 2021). The biggest part of construction waste results from demolition of structures that reached their end of life, yet also significant amounts of waste can be attributed to the construction process itself. Avoidable omissions namely lack of design detailing, choice of appropriate materials and dimensions of elements, to name a few, contribute to high waste production during the construction phase (Willmott Dixon, 2010). Current construction practices largely focus on the end goal being the production of a finished building, only rarely taking into account the deconstruction or adaption of a building or building component and the reuse or recycling of its related materials (Crowther, 2009).

INDUSTRY

Design for disassembly only rarely applied

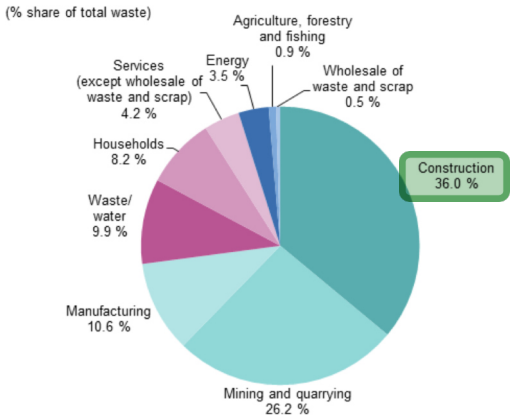
Design for disassembly is a main driver of circular building construction, yet the implementation of disassemble-able building components is still very limited due to a number of reasons, for example, it is often financially more feasible to demolish than to disassemble structures because current planning rarely involves the aspect of ease of disassembly. That makes it complex and inconvenient to take structures apart at the end of their life. The lack of a market for reusable building components in many countries is an additional reason why the disassembly of structures is not more widely practiced (O'Grady et al, 2021).

TECHNOLOGY

Applying state-of-the-art technology to move towards a circular economy

Our opportunity – With the advent of the information age, both the architectural design process and the manufacturing and construction processes have been digitised. The construction industry tends to lag behind when it comes to implementing new technologies and methods. Therefore, for designers it is important to apply state of the art technology, like the application of CNC milling, to design and planning processes and rethink current design and construction methods to address environmental issues and move towards a circular economy in the building industry.

Research Focus



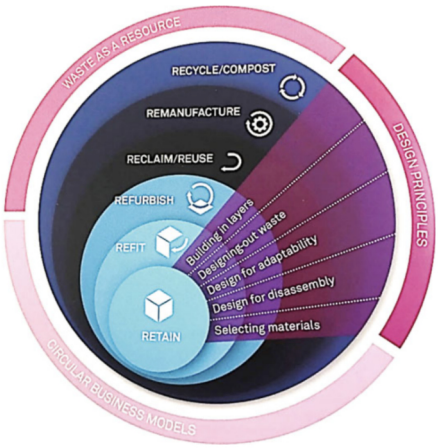
Waste generation by economic activities and households | Source: Eurostat (2018)

Design Objective

The goal of this graduation project is to design a circular strategy for the conversion of existing and vacant open structure buildings into mixed use housing, working & commercial function. The approach is to design a prefabricated infill system, making use of CNC-milling fabrication, that follows the principle of design for disassembly. Focussing on adequate choice of materials and the ability of the system to be disassembled or adapted to different needs reflects the strong focus on a circular design approach. Overall, the project is an attempt to tackle the problem of waste generation associated with conventional construction and demolition and should propose a holistic circular design strategy. The typology of open structure buildings as existing context was chosen because of the high degree of functional and spatial adaptability and potential of functional conversion, as it allows for a free floor plan arrangement and minimises the need for customised infill elements. Apart from partition walls between units, the infill should be designed to be structurally independent and decoupled from existing walls and ceilings.

The project is set to be within the context of the HAKA gebouw in Rotterdam which is located in the so called „Makers District" in M4H (Merwe-Vierhaven). The area is to be developed to facilitate housing and working space for creatives, craftsmen, entrepreneurs, start-ups and growing businesses by 2035. To contribute to these ambitious plans, the goal of this project is to design a circular infill system that allows for an environmentally sustainable conversion of the HAKA gebouw and to offer the „makers" working in the M4H area a communicative and inspiring living and working environment.

To conclude, with this project I want to create new housing, working and commercial spaces in the existing building context of the HAKA gebouw by designing a fully circular infill system that provides the inhabitants with all the required facilities while preserving the original state of the existing structure.



Principles of circular economy applied in the construction industry | Design for Disassembly plays a key role the circular economy
Source: *Building Revolutions*, D. Cheshire (2017)

HAKA gebouw, Rotterdam
photographed by the author

Overall Design Question

How can the **implementation of digital manufacturing tools** and **methods for design for disassembly** inform the design of a **circular building infill system** that allows for an **environmentally sustainable and circular design strategy** for the **functional conversion of existing open structure buildings**?

The vision of **future-proof conversions of monumental existing buildings** is based on a focussed study of the HAKA gebouw in Rotterdam and its urban context.

Research Focus

HAKA gebouw – inside the former office part of the buidling
photographed by the author

Thematic Research Question

How can the **implementation of CNC milling** improve the **ease of assembly and disassembly** of **circular building infills?**

Sub-Questions:

What are the principles of design for disassembly and how is it related to circular design?

What CNC milling enabled infill systems do already exist and are suitable for disassembly and future reassembly?

How can ease of disassembly be quantified?

What technical and material aspects have to be considered for a system to be easy to assemble and disassemble?

What are the limitations of existing infill systems regarding building regulations and how can these be implemented?

Research Hypothesis:

By combining the technical advantages of CNC milling and the knowledge about methods of design for disassembly and physical characteristics of disassemble-able systems with principles of circular design and bio-based and waste-based material sourcing it will be possible to develop a building infill system that follows the guidelines of environmentally sustainable and circular design.

The application of CNC milling technology to the fabrication of a building infill system allows for ease of assembly and disassembly at the end of life or when there is need for spacial reconfiguration.

The Circular Building – fully designed for disassembly
ARUP

Research Methodologies

PHASE 1:

1. Literature Study on Design for Disassembly

This initial part of the research is meant to gain a fundamental understanding of design for disassembly and its relevance in the framework of circular design and construction. Furthermore, the literature study should provide profound theoretical knowledge about the aspects and characteristics of ease of assembly and disassembly of non-load bearing structures and the potential relevance of CNC milling for the production of such structures.

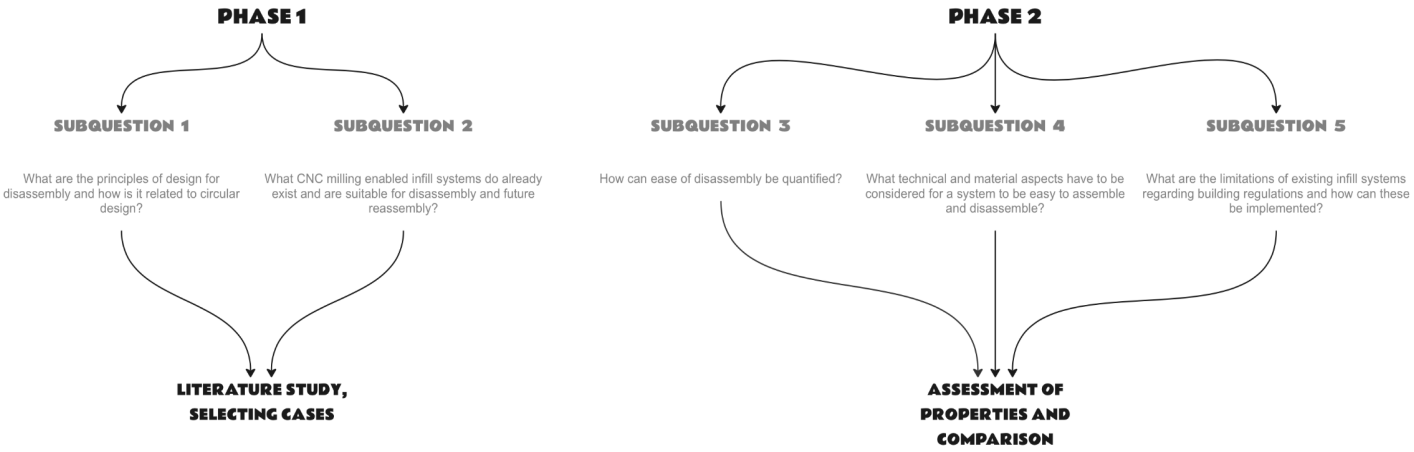
2. Selecting Cases for Assessment and Comparison

A number of existing disassemble-able wall systems and prototypes from studies will be selected for assessment based on specific aspects like bio-based material use, acoustic performance, CNC milling fabrication, etc.

PHASE 2:

3. Assessing and Comparing

This will be the main part of the research. First, the chosen cases of existing disassemble-able wall systems will be re-drawn and re-modelled using 3D-modelling tools to understand connections, layering and material properties of each system and subsequently will be assessed on the ease of disassembly and the potential advantages of CNC milling by applying existing assessment methods.



Research Structure

DESIGN | RESEARCH

CONTEXT, SITE & BUILDING ANALYSIS

URBAN CONTEXT

climate
culture
communities

SITE

location
buildings
functions/typologies

BUILDING

technical condition
orientation
dimensions

PHASE 1: STUDY

Principles of Design for Disassembly

Disassembly and Circular Economy

Characteristics of Ease of Disassembly

Technical Application of CNC Milling

research method: literature study

Identify a Number of Cases to Assess

Select Assessment Method for Ease of Disassembly

research methods: market analysis, case studies, literature study

PHASE 2: ASSESSMENT & COMPARISON

DIGITAL RECONSTRUCTION

3D modelling, Schematic drawings

ASSESSMENT AND COMPARISON

Applying existing assessment methods for ease of disassembly, Evaluation, Comparison

research methods: re-modelling, assessing

Msc 3

DESIGN INTEGRATION

TARGET GROUP
PROGRAMME
TECHNICAL ADAPTATIONS

CONCEPT DESIGN

INFILL SYSTEM
TECHNICAL SOLUTIONS
MATERIAL CHOICES

CIRCULAR STRATEGY FOR BUILDING CONVERSIONS

Msc 4

Argument on Relevance

OVERALL DESIGN

The graduation project aims to contribute value within the overall technological, architectural and social framework with the goal of developing a circular strategy to convert underused open structure buildings by applying state of the art technology and principles of circular design. – To move towards a circular economy in the building industry, the value of existing structures as capital for future-proof developments needs to be acknowledged. Especially in the urban context, land to build on is scarce and demolition and new reconstruction poses severe environmental issues. Although this graduation project focusses specifically on one building, it aims to develop a conversion strategy that is replicable and can be applied to open structure buildings in general.

THEMATIC RESEARCH

The thematic research will explore design for disassembly principles and their relevance in the context of circular design. Assessing deconstructable wall systems on the criteria of ease of disassembly will give an understanding of technical, constructive and material prerequisites and the relevance of CNC milling in the fabrication process. – Design for disassembly represents one of the key aspects of circular design and its implementation in today's design and planning processes and construction processes is of crucial importance to face current problems of a linear economy, namely large amounts of waste generated by construction and demolition and the depletion of finite ressources. Ease of disassembly and the application of cutting-edge technology therefore plays a key role in the minimisation of construction and demolition related waste and represents an important step towards a circular economy.

Time Planning

MSc 3

	MSc 3																				
WEEKS	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4	5
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	2.1	2.2	2.3	2.4	2.5	2.6	–	–	2.7	2.8	2.9	2.10
DATES	05.09.22 - 11.09.22	12.09.22 - 18.09.22	19.09.22 - 25.09.22	26.09.22 - 02.10.22	03.10.22 - 09.10.22	10.10.22 - 16.10.22	17.10.22 - 23.10.22	24.10.22 - 30.10.22	31.10.22 - 06.11.22	07.11.22 - 13.11.22	14.11.22 - 20.11.22	21.11.22 - 27.11.22	28.11.22 - 04.12.22	05.12.22 - 11.12.22	12.12.22 - 18.12.22	19.12.22 - 25.12.22	26.12.22 - 01.01.23	02.01.23 - 08.01.23	09.01.23 - 15.01.23	16.01.23 - 22.01.23	23.01.23 - 29.01.23	30.01.23 - 05.02.23
										P1											P2	
RESEARCH				SETTING UP RESEARCH PLAN																		
								PHASE 1: LITERATURE STUDY					CONCLUSIONS ON FINDINGS									
											MARKET ANALYSIS FOR EXISTING SYSTEMS												
														PHASE 2: ASSESSMENT EXISTING SYSTEMS					EVALUATING RESULTS			
																	CHRISTMAS PERIOD			FINALISING & SUMMARISING		
DESIGN			PROBLEM STATEMENT, DESIGN OBJECTIVE, LOCATION												DEVELOP DESIGN CONCEPT				DEVELOP DESIGN CONCEPT			
							COLLECTING INFORMATION (CONTEXT, SITE, BUILDING)							DOCUMENT CONDITION OF BUILDING								
							SITE VISIT: CONTEXT					SITE VISIT: BUILDING										

MSc 4

	MSc 4																				
WEEKS	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	–	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.10	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.10
DATES	06.02.23 - 12.02.23	13.02.23 - 19.02.23	20.02.23 - 26.02.23	27.02.23 - 05.03.23	06.03.23 - 12.03.23	13.03.23 - 19.03.23	20.03.23 - 26.03.23	27.03.23 - 02.04.23	03.04.23 - 09.04.23	10.04.23 - 16.04.23	17.04.23 - 23.04.23	24.04.23 - 30.04.23	01.05.23 - 07.05.23	08.05.23 - 14.05.23	15.05.23 - 21.05.23	22.05.23 - 28.05.23	29.05.23 - 04.06.23	05.06.23 - 11.06.23	12.06.23 - 18.06.23	19.06.23 - 25.06.23	26.06.23 - 02.07.23
										P3							P4			P5	
RESEARCH		Reference Projects																			
		Technical upgrading of outdated buildings																			
		Bio-based and waste-based materials																			
DESIGN		BT Tutor joins									Finalising Design							Model making			
		Elaborating on concept design – implementation of research findings and further planning																Final drawings & presentation			

Glossary of Keywords

Circular Economy

As defined by the European Parliament: *The circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended. In practice, it implies reducing waste to a minimum. When a product reaches the end of its life, its materials are kept within the economy wherever possible. These can be productively used again and again, thereby creating further value.*

(Retrieved from: https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits)

Ease of Disassembly

Circular Economy Practitioner Guide describes Design for Disassembly as follows: *Design principle that calls for the end-of-life options of how the product, components and materials can be deconstructed.*

(Retrieved from: https://www.ceguide.org/Strategies-and-examples/Design/Design-for-disassembly-deconstruction)

Ease of disassembly therefore describes the time and work effort that is required to partially or fully disassemble an object.

CNC Milling

It is a computer-controlled process involving using a cutting tool to remove part of a workpiece. The basic setup involves placing the workpiece on the machine's table while the cutting tool/s attached to the spindle rotates and moves to shape the workpiece into a finished product.

(Retrieved from: https://www.rapiddirect.com/blog/what-is-cnc-milling/#What_is_CNC_Milling)

Waste Minimisation

Waste minimization techniques focus on preventing waste from ever being created, otherwise known as source reduction, and recycling. These techniques can be practiced at several stages in most waste generating processes, but require careful planning, creative problem solving, changes in attitude, sometimes capital investment, a d genuine commitment.

(Retrieved from: https://www.eiu.edu/environ/doc123/Waste%20Minimization.pdf)

Building Infill System

'Infill is defined as a product of industry and as a matter of individual decision-making.' This definition follows John Habraken's understanding of Infill and its structural independence from the 'Support', an anonymous structure that allows users to create their individual space within the structure.

(Retrieved from: https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/110607/eth-48493-01.pdf)

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