Figure 1:
Reference project, Work Space Basel,
designed by Stereo Architektur

Research Plan | aE Graduation Studio

Technical University Delft

Optimizing Building Infill Systems

A rating of digitally fabricated timber infills
on possibilities for wider applications in today's construction

2022-2023

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Key Terms

Circular Economy: *A model of consumption and production, which includes reusing, refurbishing and recycling materials and products as long as possible in order to keep them in the material loop. (EU, 2015)*

Digital Fabrication: *A type of production process in which the machine used is controlled by a computer. For example CNC - milling or 3d-printing. (IGI Global, 2022)*

Building Conversion: *A process where the function of a building is getting changed in order to increase funtionallity and use for future inhabitants.*

Building Requirements: *The goal of building requirements is to regulate the wellbeing and safety of the people in and around the building. It includes fire safety, acustic and structural requirements.*

Infills: *Timber infill in this context are prefabricated building components that are used to create rooms inside existing buildings or open building structures.*

Flexibility: *"The ability to change or to be changed easily according to the situation" (Cambirdge dict., 2022)*

Choice of the aE Studio?

The Architectural Engineering Studio caught my interest because it focuses on the technically oriented approach to solutions in the field of architecture. In addition, the tutor´s high level of expertise in different topics like circular economy and digital fabrication was a direction I wanted to explore further before joining the studio. I appreciate the freedom to follow personal interests and the possibility to choose my own site, which makes the studio unique among others. It also allows the students to find their direction as future architects and designers much more easily and provides a playground to explore with the help of experts from the field.

General Problem Statement

Layers of problem

The construction sector is causing too much waste due to the excessive use of resources. One of the reasons for that is the poor demountability of buildings and the lack for end of life scenarios for building components.
(Ghisellini, Ripa, & Ulgiati, 2018)

Global

Waste Problem

To cope with the climate crisis and adapt to higher sustainability standards, the problem of demolition and construction waste is becoming an essential topic for the construction industry. Although many precise calculations of project costs and estimates of the amounts of materials required, waste management is often neglected. The waste generated during demolitions also requires an ever-increasing financial investment for disposal, reuse, and recycling. Waste generation is a consequence of the material used. Unconsidered handling of materials and damage to components during delivery or deconstruction are some reasons for excessive waste production. Considering this, there are several influencing factors in the supply chain, planning, and contractors that have a contribution to waste generation. In the European Union, 33% of the total waste ending up in landfills is related to solid construction waste, while China's construction and demolition industry accounts for around 40% of the country's landfills. Estimations show that the environmental impact of demolition and construction waste will increase by 20.2 % by 2025. (Tahir, 2021)

Material

Material circularity

The main reason for this is the extreme amount of waste production, as the construction sector is mainly based on a linear economic model with a "take, make, use, dispose" approach. After using the resources for construction projects, they are often left in landfills without an end-of-life scenario. In recent decades, many different industries have tried to integrate the circular economy model into their product development to close the loop of materials by maintaining their maximum value. The construction industry is also trying to embrace this model, which offers great potential for reducing demolition and construction waste. (Benachio, Freitas, & Tavares, 2020)

Architecture

Layering

The awareness that building components have different longevity depending on their layering and material, and therefore need to be perceived as such, was originally described by Frank Duffy and later developed further by Stewart Brand (Brand, 1994). The "Spaceplan" only lasts between 3 and 30 years. Therefore it has a quite fast-changing and renovation frequency and produces, therefore, the most waste if it is not planned demountable.

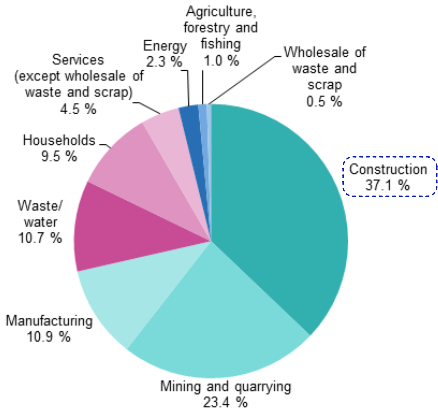


Figure 2: Waste generation by economic activities and households, EU, 2020

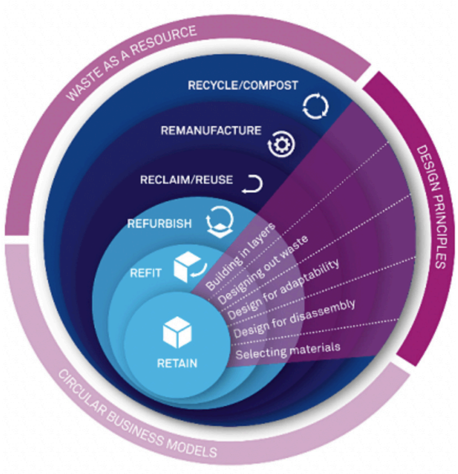


Figure 3:Building Revolutions (2016)
David Cheshire, RIBA Publishing.

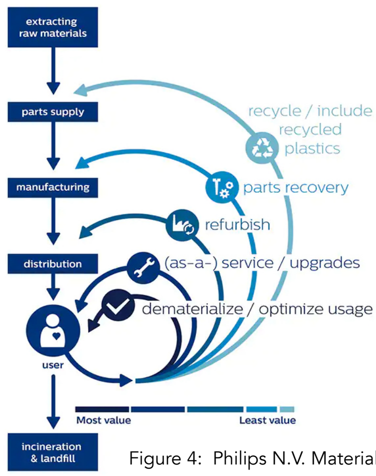


Figure 4: Philips N.V. Material Flows

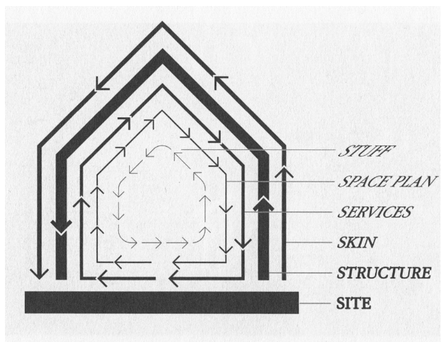


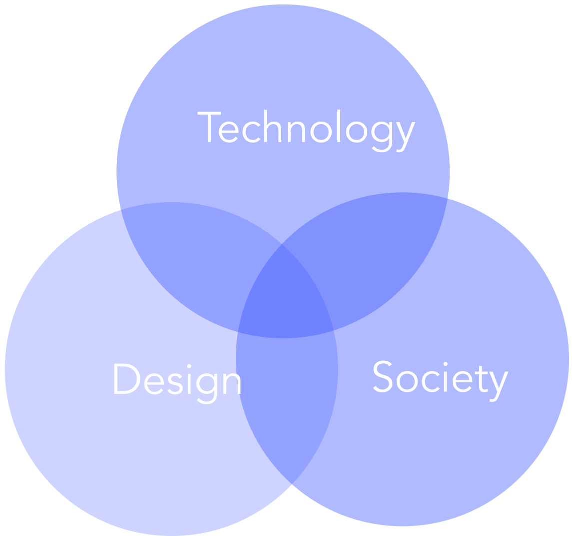
Figure 5: Shearing Layers, Brands

Project Objective

Reuse or program conversions of underused existing structures is another effective alternative to the demolition of buildings to save resources. Adaptive reuse is already widely known as a tool for circularity since it reduces the raw material use, waste generation, and energy consumption by extending the lifespan of a structure.
(Ikiz Kaya, Dane, Pintossi, & Koot, 2021)
Because of the reasons of lacking circularity for building components and the necessity to reuse existing structures the graduation project is aiming to create a First Aid Kit with tools for a fast, affordable, and circular framework to enable various uses in existing structures. Besides the essential needs for the housing of the users just as dryness, heating, sanitary rooms, and a kitchen, housing needs to meet more requirements like for example acoustic insulation, and fire safety that needs to be addressed properly to give the needed comfort and safety to the inhabitants.
While this graduation project is aiming to reduce construction waste by offering a framework for the flexible use of existing structures, it also aims to tackle the housing crisis with a "building reuse mining" approach. The "First Aid Kit" should enable the use of potential spaces in the city center. For this task, the Hofbogen structure in Rotterdam was chosen. The Hofbogen project is currently underdeveloped and so is the area around the structure. The Hofbogenpark on the former railway on top of the structure is scheduled for redevelopment in 2023, therefore it offers an interesting outlook to work on a site that is about to explore its full potential in the near future. On the other hand, the existing 200 mixed-use units below the structure between the bridge piers are evolving inconsistently, the former Bergweg station was converted into a restaurant and the two former platforms on top of the station with 250 sqm each are currently vacant.
Depending on the outcome of the site research, the program of the infill will either host commercial use, housing, or a public program and will be designed with a demountable framework of the wooden infill system to fit the neighborhoods and future user demands within the nearly 120-year-old structure.

Figure 6: The Hofbogen, Rotterdam

Overall Design Question



How can advances in the digital fabrication process enhance the establishment of a new demountable prefabrication design language for the reuse of existing structures like the hofbogen?

The design goal is to find a position in each different direction of architectural problem solving.

Technology

Digital fabrication processes are workflows where a computer is controlling the executing machine. For example CNC-milling or 3D printers. These technologies have high precision and scalability in terms of production. They also make it possible to reduce manual labor.

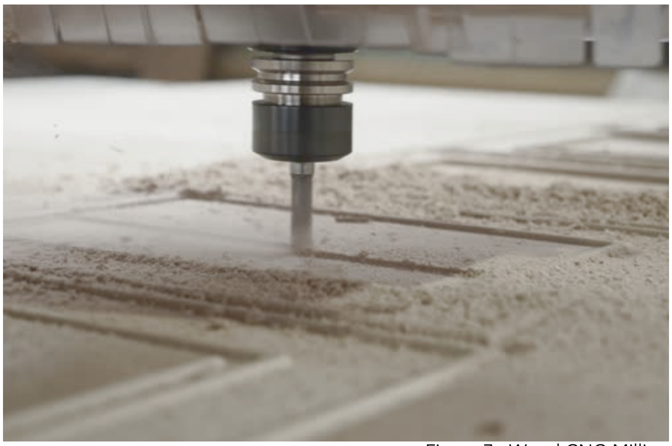


Figure 7: Wood CNC-Milling

Design

The design with digital fabrication can vary from very small scale to entire buildings or pavilions. Especially demountablilty can be improved with digital fabrication since a demountable connection that increases the ease of disassembly can be implemented. What impact will the demountability have on the design?

Figure 8: Las Setas, Seville

Society

Neither design nor the technology of the architecture will have a strong impact if it does not find a wide application in nowadays society. Therefore it is necessary to question where the possibilities and advantages of the technology can be placed the best to serve the users and inhabitants.

Figure 9: Reference project of SMS Arqitectos

Thematic Research Question

How can **existing demountable, biobased, and CNC-milled infill systems** be **rated** and **updated** on **fire, acoustic, affordability, structure, and flexibility** to be adopted in **housing projects**?

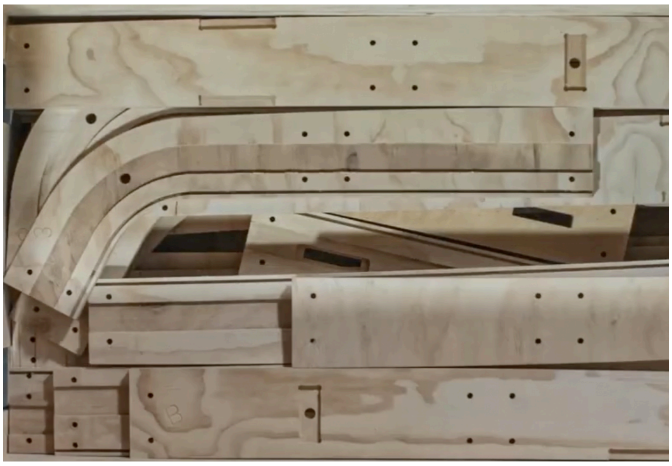


Figure 10: Wikkelhouse-System

Subquestions:

1.
What are the currently available wall systems
Case study

Wikklhouse
Netherlands
Exterior cabins

Respace
Netherlands
Interior

Wikihouse
Netherlands
Structural walls

Clip-Hut
Germany
Interior walls


Figure 11: Respace-System


Figure 12: Wikihouse-System

2.
What are the methods and parameters to assess the performance of existing wall systems?

3.
What are the current building code requirements?

4.
What is missing to fulfill the building requirements?

5.
What could makes the infill adaptable for a wider commercial sense? (PHASE II)


Figure 13: Cliphut-System

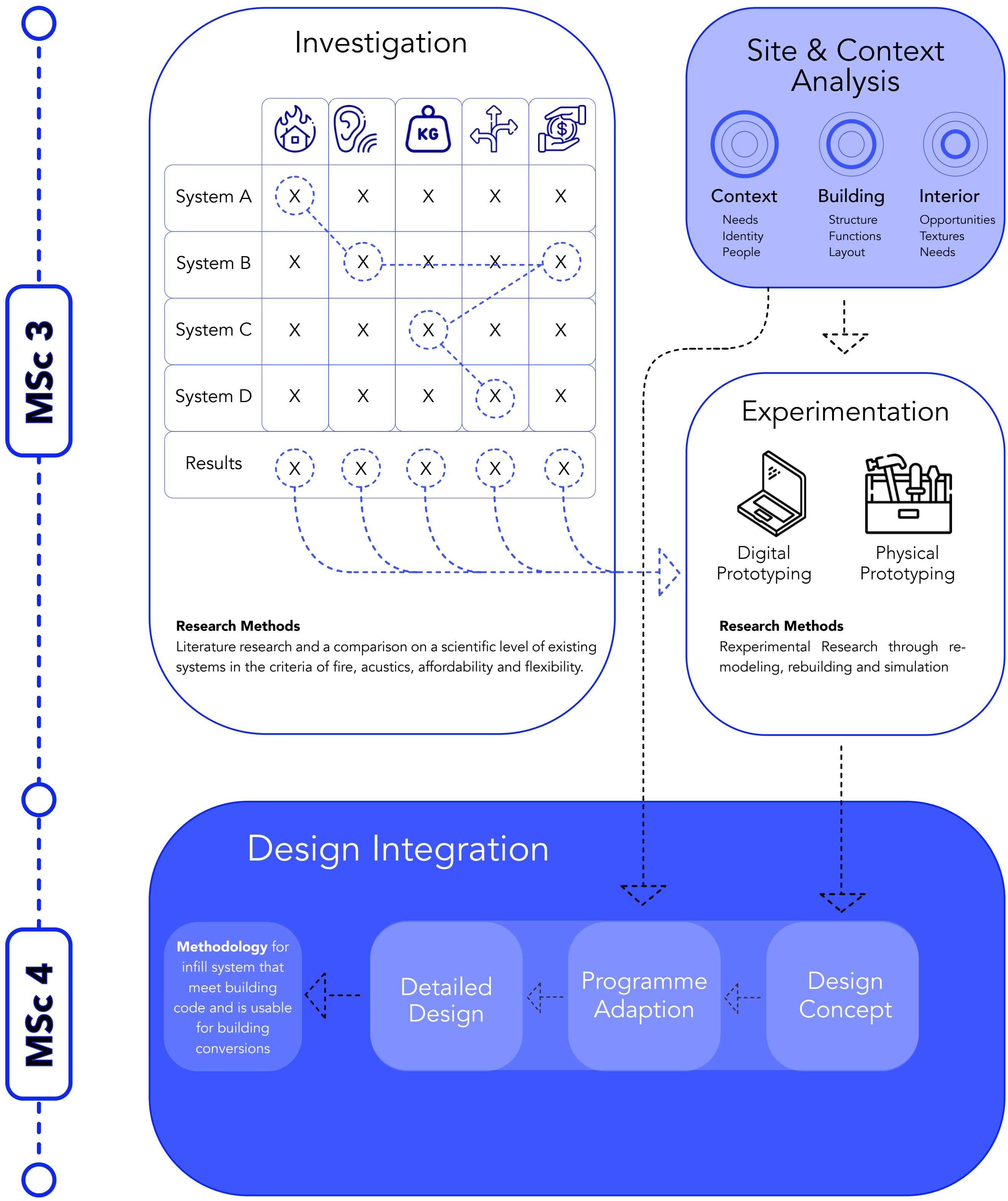
Research Sturcture

Design

Design Question:
How can advances in the **digital fabrication process** enhance the establishment of a new **demountable prefabrication design language** for the reuse of **existing structures?**

Research

Research Question:
How can **existing demountable, biobased and CNC-milled infill systems** be **rated** and **updated** on fire, accustics, affordability, structure and flexibility in order to be adopted in **housing projects**?



Methods 1

Master Thesis

Research | **Design**

Phase I
INVESTIGATION

Sudy:
CNC-Milling process & Advantages.

Case study:
Exploring and rating currently available systems for biobased, demountable, and CNC-fabricated infill systems. Finding out what is currently the state of the art and why they are successful. Investigating what the key components and advancements.

Phase II
EXPERIMENTATION

The aim is to use the experimentation phase to combine the advantages of the selected wall systems. Based on scientific background and empirical data.
The testing will consider new hybrid combinations of the existing systems.

Phase III
IMPLEMENTATION

The implementation requires conscious consideration. The knowledge from the investigation and the experimentation will be applied to the project site. The implementations now have clear reasons and can be augmented with the two first accomplished steps.

Research Methods

Methodologies

A comparison on a scientific level based on building requirements, exisitng methodologies in the criteria of **fire, acustics, affordability and flexibility.**

Simulation and Modelling

1:1 models through digital fabrication and evaluation of the experiments.

Site&Design Research

By researching on the context of the site many design opportunities will be taken into closer account.

Methods 2

Literature research

To understand the production and construction methods it is necessary to be well-informed about the current state-of-the-art application of CNC milling to compare existing systems on a scientific level. Also, the current challenges for the systems to meet building regulations need deeper knowledge about the material and the properties to meet the building code challenges successfully.

Case study

In order to find out how the existing systems perform on the different criteria in comparison to each other it is fundamental to use empirical methodologies for each criteria.

The **structural**, **fire** and **accustic** requirements will be measured with remodeling of the wall systems and comparison to the dutch building code requirements for the housing use.

Affordability will be the possible additional material costs + the commercial selling price of the companies.

For **flexibility** of the wall systems and existing methodology for *"Analysis of the structural measures of flexibility and agility using a measurement theoretical framework"* by Giachetti, R. E (2002) can be used.

Research Hypothesis:

By creating a catalog of existing systems and a rating system that can compare these systems with each other, it will be possible to make hybrid systems during the experimentation and implementation phase of the research with a sophisticated choice of what system to use for the design. The research should have the potential to help more students to get a fast overview and be able to get an idea how the different systems perform.

Figure 14: Relevant literature for research

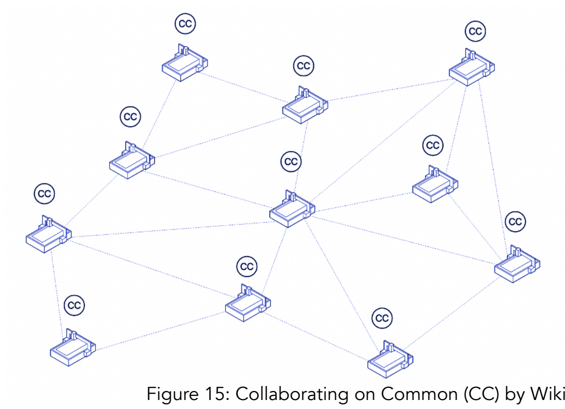


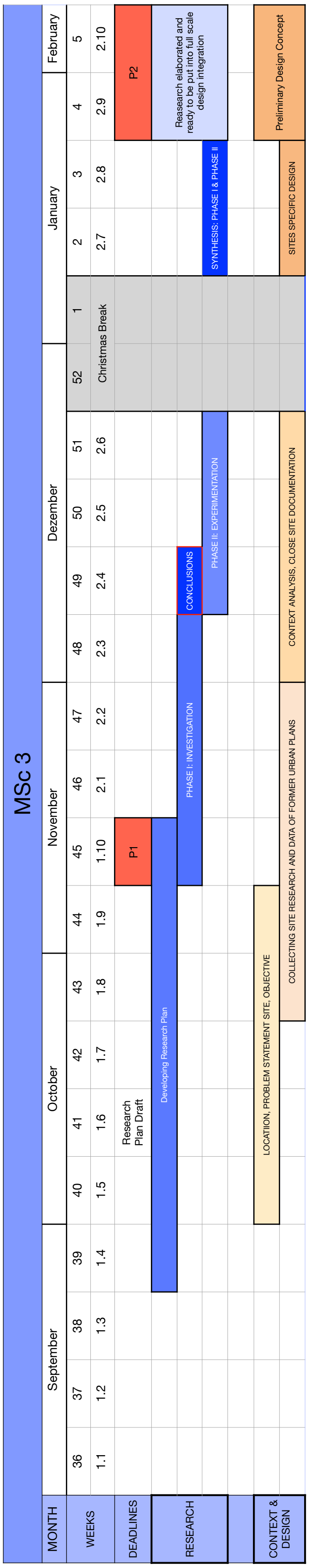
Figure 15: Collaborating on Common (CC) by Wikihouse

Figure 16: Research criteria

			KG		
System A	X	X	X	X	X
System B	X	X	X	X	X
System C	X	X	X	X	X
System D	X	X	X	X	X
Results	X	X	X	X	X

Figure 17: Research Path

Research Planning



Relevance

The relevance of this graduation project in a larger technical, social, architectural, and scientific framework is to develop a methodology to maximize the reuse of existing structures with a circular and digitally fabricated approach.

To reduce construction waste and to prevent as many building components as possible from going to landfills there are some construction principles that today's building industry will need to adapt more. One of them is the design for disassembly and it can be applied in architecture and the way we make building components. "Minimise the number of different materials and components, use mechanic connections rather than chemical ones, use modular design" (Crowther, 2005) are just some of the many things to keep in mind while designing for disassembly.
This strategy also implies that a building should be constructed to be fully disassembled, this could lead to the view of a building as stored assets that can be reused at a future point rather than a whole construction that loses value after a certain time because the building parts can´t be reused or resold after the use of the building.
Electrical devices like mobile phones or laptops are not thrown away because of existing recycling and reuse plans. The materials that are used in mobile phones have very high security plus they are very expensive for example copper and rare minerals. If architects and planners would see the assets of a building with this viewpoint during the planning it could change the end-of-life scenario for many future buildings.

The research will focus on a critical evaluation of existing infill systems and to increase the growing role of demountability and of prefabrication in architectural planning.

To gain more recognition the current systems need to be improved in terms of building requirements and building physics and still be affordable. In this frame, the research is aiming to find answers that can then be addressed in an architectural manner to make building conversions more sustainable in the future.

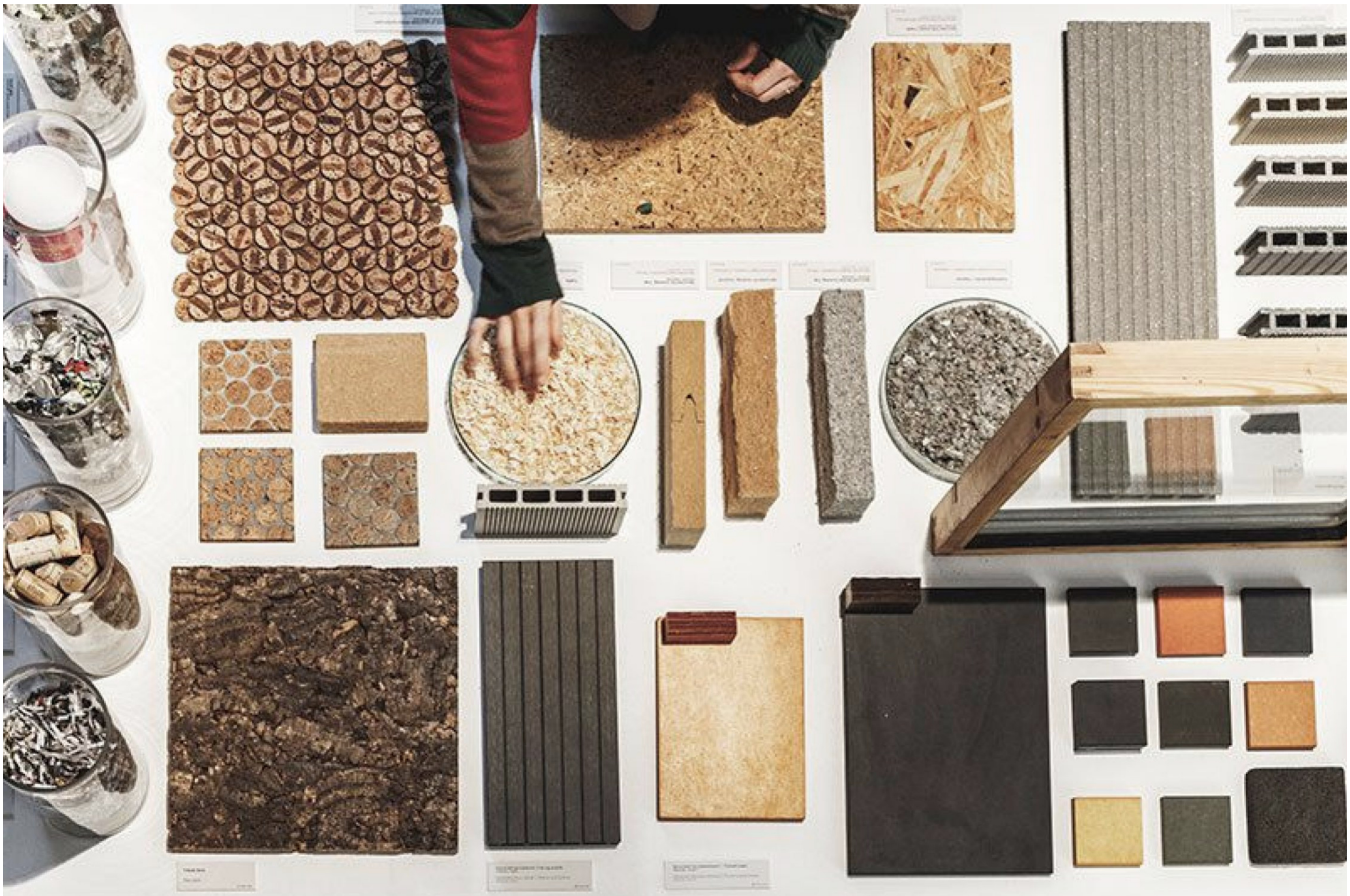


Figure 18: Biobased Materials from reference project of Djuric Tardio Architectes

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Figure 14:
Relevant research literature

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Figure 16:
Research Criteria

Figure 17:
Possible Result Chart

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