TALES OF THE REVIVED

an exploration of natural leftover resources

Sandra Moberg & Josefin Eliasson

Examiner: Krystyna Pietrzyk • Supervisors: John Helmfridsson & Anita Ollár • Chalmers School of Architecture, Department of Architecture and Civil Engineering

TALES OF THE REVIVED

CHALMERS

Master Thesis Spring 2019

Examiner: Krystyna Pietrzyk
Supervisors: John Helmfridsson & Anita Ollár

Chalmers School of Architecture, Department of Architecture and Civil Engineering
Architecture and Planning Beyond Sustainability

Gothenburg, Sweden

THANK YOU!

Family & friends
Felicia Andersen & Taleen Josefsson
John Helmfridsson
Anita Ollàr
Tommie Månsson
Lasse Lind
Abhijit Venkatesh
Shea Hagy & Ásgeir Sigurjónsson
Dina Andersen
Ida Toll
Lin Tan
Quan Jin
Mats Torring
Paula Wahlgren
Anja Persson & Gunnarshögs Gård
Mahmood Hameed, Torleif Bramryd & NSR
Rodrigo Arvidsson & Oceanbryggeriet
Derome
Bjernareds sågverk
Oatly
Thomas Jacobsson & Österlen hampa
Nordic Sugar
Blackbird & PorterPelle restaurant
Lantmännen AB
Svensson & Örn Snickeri AB
Stencentrum

Consider there being no waste, only leftover resources.

Now imagine reviving them.

Figure 1. Graphical abstract.

ABSTRACT

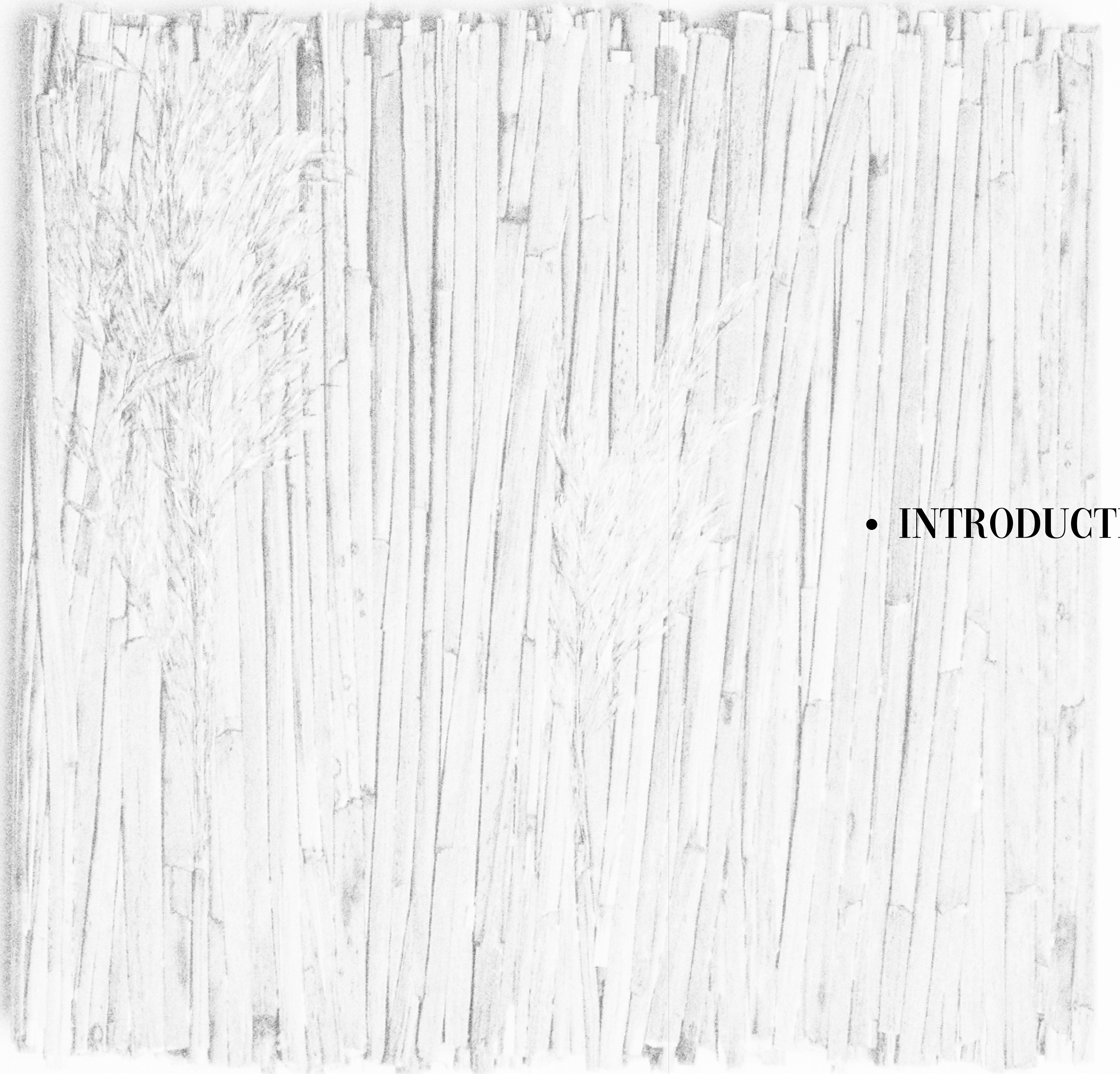
This thesis explores and showcases the qualities and potentials of natural leftover materials in an architectural context. Furthermore, it investigates how the materials can be applied and manifested as surface materials, seeking how they affect our health, wellbeing and perception. It aims to study the relationship we have to materials, challenging the idea of what waste and raw materials is.

The point of departure is the global challenges of diminishing natural resources, making the building industry's shift to circular design crucial. IPBES (2019) states how nature is declining more than ever in human history. Currently 60 % more natural resources are used than the planet can sustain (WWF, 2016) and more than a third of global material resources are consumed by the building sector (UNEP, 2011). In large parts of the world, the population spends around 90 % of their lives indoor (Norsk Treteknisk Institutt, 2016), suggesting that indoor air is a bigger determinant of what a human breathes in than outdoor air. Research shows that many surface materials used in buildings emit volatile organic compounds (VOC) causing danger to human health (Nriagu, 1992). A transition towards a sustainable building practice means the architect has a responsibility to evaluate and act on what role the built society has in a future, creatively turning challenges into opportunities.

This thesis focuses on discarded natural raw materials, that is; pre-consumer waste. This includes leftovers from *agriculture*, *forestry* and *ground work*. Valorising materials left behind in the process of making a product, is what we call *revived materials*.

The project consists of experiments and design. As a first step, material investigations are made out of natural leftover resources. They are made as *surface materials* mainly for indoor environments. Factors like indoor climate, cultural and ecological values and perceptions of the materiality are evaluated. The investigations are displayed in seven sequences, shifting from public to private. The main result of the thesis is an exploration of using discarded resources, where spatial experience of circular design can spark dreams and unfold a story of a resource being revived.

TABLE OF CONTENT



• INTRODUCTION

STUDENT BACKGROUND

Sandra Moberg

2017-2019
Architecture and Planning Beyond Sustainability
Master of Science, Chalmers University of Technology

2016-2017
Structural engineer internship
VBK Konsulterande Ingenjörer

2013-2016
Architecture and Engineering
Bachelor, Chalmers University of Technology

mobergs.sandra@gmail.com
0736789741

Josefin Eliasson

2017-2019
Architecture and Planning Beyond Sustainability
Master of Science, Chalmers University of Technology

2016-2017
Architect internship
Norconsult AB

2013-2016
Architecture and Engineering
Bachelor, Chalmers University of Technology

eliasson.josefin@gmail.com
0732015830

Image 1. Urbanization - aerial photo of New York by night (NASA).

Image 2. Feeding humanity - aerial photo of agricultral landscape (Förster).

PROBLEM STATEMENT

Natural resources are depleted on earth, only 1/4th of the land is free from impacts of the human (IPBES, 2018). Global consumption requires 1.7 planets in order to be sustained at present rate, and if global consumption equaled Sweden's, 4 planet earths would be needed (WWF, 2018). It is estimated that by 2050 there will be 9,7 billion people in the world (UN, 2015) and 2/3 living in cities (UN, 2018). This development puts enormous pressure on the world's already stressed resources and the demand for urban constructions is therefore huge. The building sector consumes more than a third of the global material resources (UNEP, 2011), making the professional agenda of the architect to act highly important. Additionally, many materials used in buildings emit high amounts of VOCs, jeopardizing the health of the human (Nriagu, 1992). In large parts of the world, the population spend around 90 % of their lives indoor (Norsk Treteknisk Institutt, 2016), making indoor air a significantly bigger part of what a human breathes during a lifetime, than outdoor air. Even though circular business models are emerging, the traditional way of handling resources is nonetheless almost entirely linear, equalling; taking, making, wasting (GXN et al, 2018). The current situation humanity has put the world in, demands a vast change of how to deal with future development, from structural transitions to individual choices.

PURPOSE

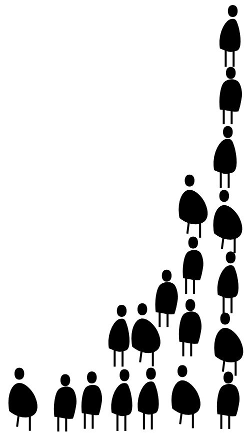
The purpose of this thesis is to challenge the idea *of what waste is*. Today's throwaway society needs to shift into one that takes care of what is. Considering the building industry is one of the most material demanding productions in the world (Goodbun & Jaschke, 2012) this especially concerns striving for a changeover to *circular building materials*. This thesis should question and pose arguments against the unsustainable material industry of today and thus touching a global problem of declining natural resources.

Goals

1. Inspire in a transition towards circular design through a shift of the concepts raw materials and waste.

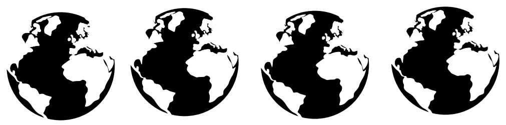
2. Emphasize the importance of materials connection to health and wellbeing.

3. Be at the forefront of current global goals such as Goal 12 from United Nations - 2030 Agenda for Sustainable Development; responsible consumption and production.

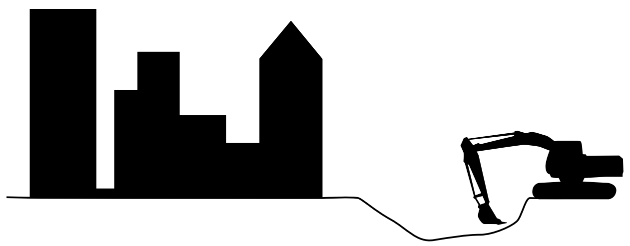


9,7 billion people in the world by 2050 (UN, 2015).

We are living as if we had **1.7 planets** with today's global consumption (WWF, 2018).

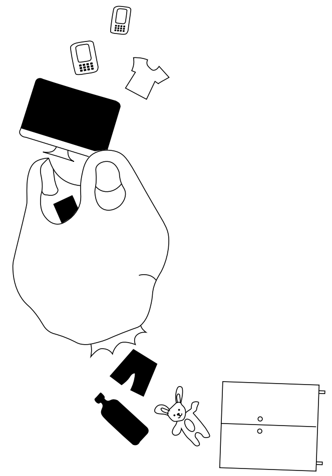


In Sweden we live as if we had **4 planets** (WWF, 2018).

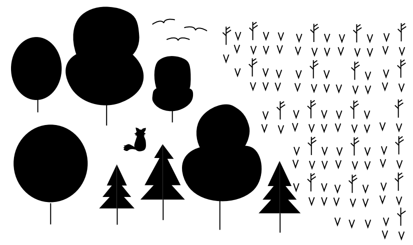


Each year up to **50 billion tonnes** of sand and gravel are excavated, it is the largest extractive industry on the planet (WWF, 2018).

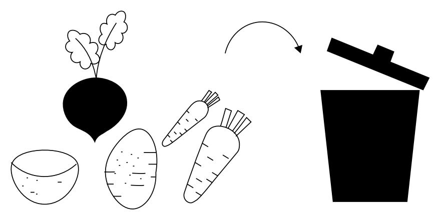
Figure 2. Illustrations of problem statement.



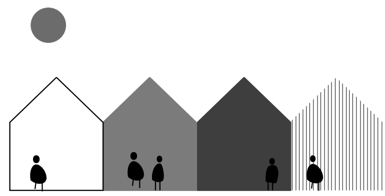
99% of the stuff we buy is trashed within 6 months (Leonard, 2007).



Only **1/4*** of land on earth is substantively free of the impacts of human activities. *by 2050 projected to reach a tenth (IPBES, 2018).



30% of the food produced worldwide is lost or wasted every year (UN environment).



In large parts of the world we spend around **90 %** of our lives indoor (Norsk Treteknisk Institutt, 2016).

Figure 3. Illustrations of problem statement.

Image 3. Goal 12 from United Nations' 2030 Agenda for Sustainable Development declares responsible consumption and production.

AIM

The aim of this thesis is to explore and showcase the qualities and potentials of natural leftover materials in an architectural context. It aims to study the society's current, past and future relationship to materials, as well as exposing revived materials' positive impact on human health and wellbeing. The thesis intends to investigate how they can be applied as surface materials and further how they are perceived in different spatialities.

RESEARCH QUESTION

1. How can natural leftover resources from industries of today be revived and applied in architecture?

2. Can architecture, through the use of materials, invite wellbeing, create perceptions and compose narratives?

METHOD

This thesis is built on theoretical research, material collection, experiments as well as design proposals. As a first step in the process, literature, study visits and interviews formed a framing of in what extent leftover materials exist as well as the potential they possess. Study visits included professionals working in the field, such as the architectural firm GXN in Copenhagen, along with chosen industries producing and acquiring leftovers from different productions. Through interviews, a greater understanding of the current field and situation was achieved, and the discussions derived helped form a framework for this thesis.

After getting a deeper understanding of the industries, materials were collected through mainly study visits. The method thereafter consisted of material experiments, starting out explorative and ending up with a higher level of knowledge of how to reach a desired outcome. The experiments were based on reference projects and research as well as artistic visions. As realisations were made, more materials were collected and alterations to experiments were made.

In parallel to the experiments, the architectural qualities of the materials were investigated as well as a forming of a design proposal. The design proposal was developed through discussions of different spatial experiences of the

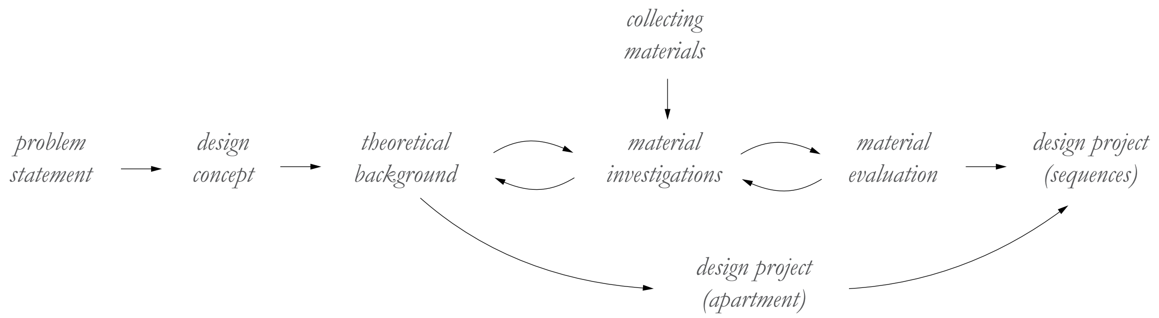


Figure 2. Diagram of the method of this thesis.

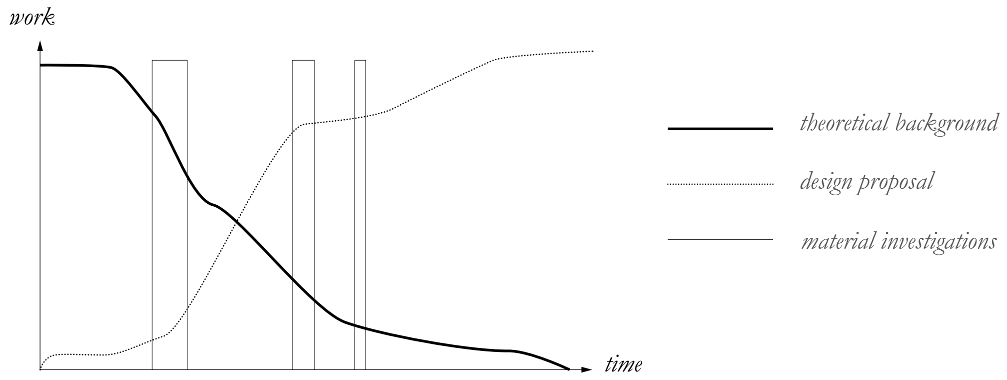


Figure 3. Diagram of process showing the amount of time spent on the three main parts; Theoretical Background, Material Investigations and Design Proposal.

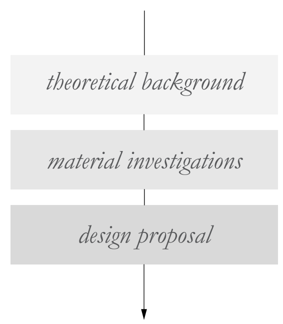


Figure 4. Reading instructions.

materials. Evaluation of the materials were carried out as the experiments were made; Firstly, believed perception of the materials was evaluated and then social, economic, ecologic, climatic and user performance was estimated. This evaluation formed the basis of which materials to use in the design proposal consisting of different sequences.

DELIMITATIONS

The material investigations in this thesis are made out of *natural leftover resources* from *agriculture, forestry* and *groundwork*. The resources collected and tested are limited to the season and what is locally and affordably available. They are *pre-consumer* leftovers, meaning they are disposed before reaching the customer. The material investigations are restrained to *surface materials*. The methods used are either compressing the materials into boards or assembling larger pieces into panels. The materials are not tested for their physical performance, but merely for their architectural promises. However, the materials are *evaluated* according to several criteria and a few of the samples are chosen to be a part of a design project. The evaluation is based on theory and estimations, not calculations or tests. The design project is developed to emphasize the qualities of the materials investigated, as well as explore the architecture of spatialities ranging from public to private. The design project consists of *seven sequences*, four of them are in a home environment of an apartment. The fifth sequence shows the entrance of the apartment building, the sixth a restaurant and the seventh a space for music. The apartment layout has been an important part of the design project, developed in parallel with the sequences, with focus on a flexible layout allowing for a variety of people, and narratives through materials. Nevertheless, layout and materials have been simultaneously developed and each room has been explored and shaped through material, light, vibrance, spaciousness, privacy and nature of space.

READING INSTRUCTION

This booklet is divided into three main parts. The first one is *Theoretical background* that aims to give a deeper understanding of the situation of today, depicting topics and references relevant to this thesis. The second is *Material investigations* where material concepts are introduced, collection of materials are explained as well as explanation of chosen methods and approaches. Foremost it includes results of chosen material experiments with evaluation. The third, *Design proposal,* is where the design project is introduced. Here knowledge and executed material investigations from the previous chapters are woven together and showcased in seven sequences.

• THEORETICAL BACKGROUND

Figure 5. The waste ladder

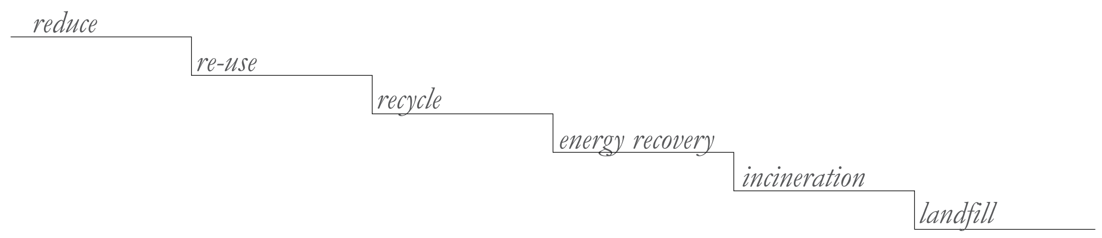
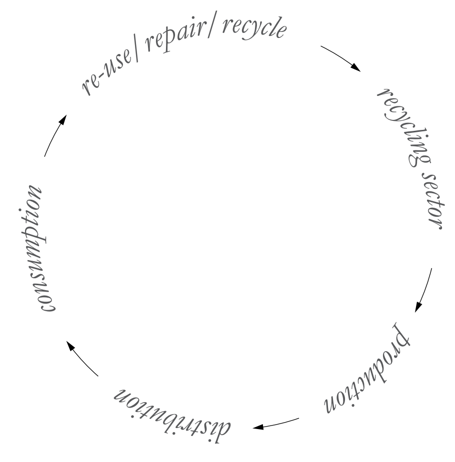


Figure 6. Linear economy

Figure 7. Circular economy



DEFINITIONS

Revived materials
The use of materials derived from discarded natural raw materials.

Raw materials
A material that has been extracted from nature but not been treated.

Healthy materials
Materials that do not emit toxins in unhealthy amounts.

Biodegradable materials
A material that after its intended purpose can go back to earth and be broken down by living organisms.

Pre-consumer waste
Generated before we consume it, meaning it is created through industry and manufactures.

Natural materials
Materials that are naturally occurring on planet earth originating both from bedrock and growing nature (Nationalencyklopedin, 2019).

Circular economy
An economical model containing a high level of reuse and an efficient use of resources. Characteristics are that leftover resources from one production becomes the resource for another production (Nationalencyklopedin, 2019).

Linear economy
Often presented as the opposite to circular economy, where products are produced, used and thrown away (Nationalencyklopedin, 2019).

The waste ladder
One way of illustrating the hierarchy of waste management. Aiming to reduce waste and the use of virgin resources, the options of waste management are ranked according to what is best for the environment, the higher up the ladder the better (Recycling.com, 2019).

Wellbeing
A good or satisfactory condition of existence; a state characterized by health, happiness, and prosperity; (Dictionary.com, 2019) This thesis uses the word wellbeing to describe a state of delight as well as physical and mental health.

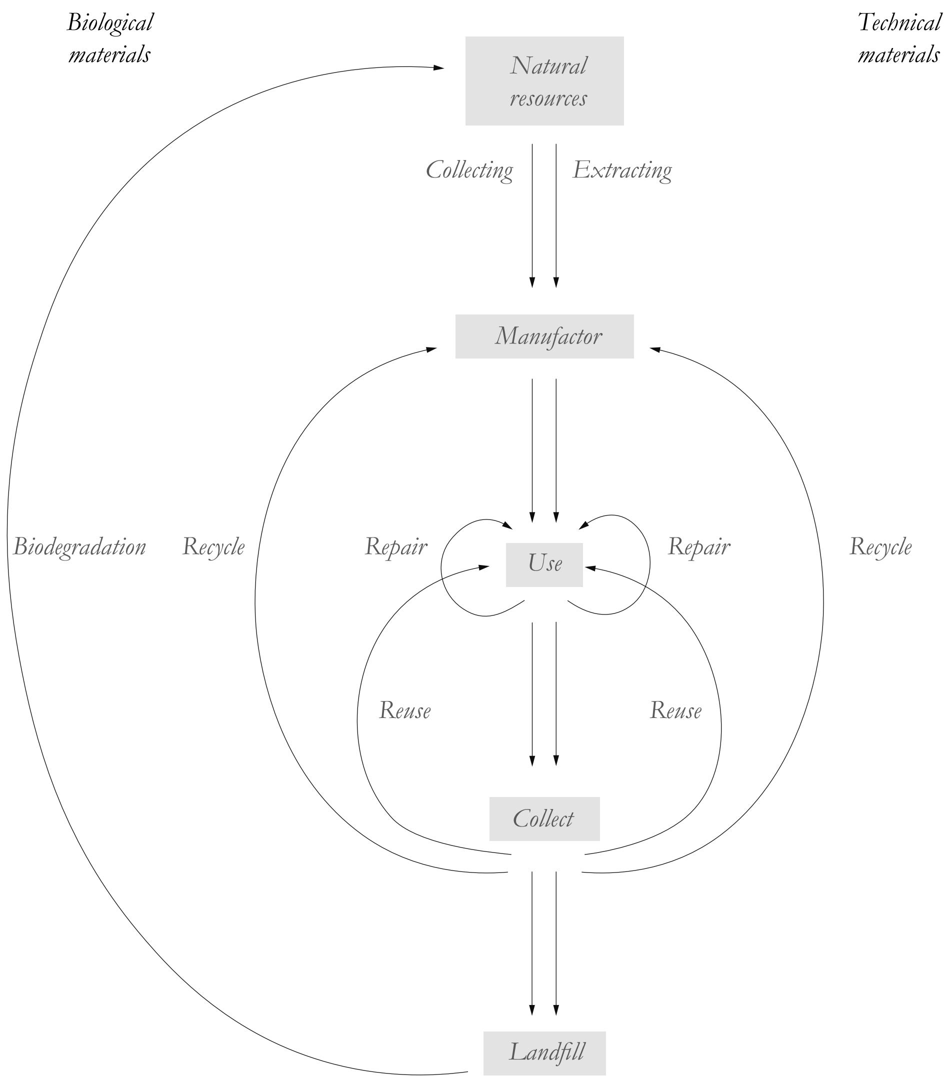


Figure 8. Supply chain showing linear and circular economy model.

Lasse Lind, GXN about sustainable materials on the market:

"Change is happening slow in the building industry, and therefore It can be difficult to introduce sustainable materials in buildings and further onto the market. But today's market is asking for sustainable solutions, so the market has to deliver it. It can be uphill, but we are many working with it."

BEYOND SUSTAINABILITY

Circularity

Consuming six times more resources than produced in the European union, more focus is starting to be put on a circular business models (GXN et al, 2018). However, the traditional and typical way of waste management is undeniably a very linear way. Following a linear model often called "cradle to grave" the materials of a typical building is extracted, manufactured, put into use and once the building has reached its end of life, the materials are either downcycled or left in a landfill (GXN et al, 2018). The concept of Cradle to Cradle argues that all materials can be part of cycles, either technical or biological ones, and thus be nutrients forever (McDonough, Braungart, 2013).

In nature, circularity is nothing but natural. Everything is part of a continuous cycle, where the energy of the sun converts into food, into soil and into food again. The human use of materials has every possibility to imitate this natural metabolic life cycle (Geiser, 2001) fully recirculating materials and forgetting the concept of the landfill. One industry's leftovers become raw materials for another's production. As shown in the diagram to the left (figure 8), possibilities of circularity occur in every step in the production and life of a product.

Innovation in the building industry

The concept of sustainability developed during the 1970's due to a general insight of humanity's impact on environmental and social crisis, more specifically it was catalyzed by the worldwide oil crisis (Wheeler, 2004 & Day, 2002). An ecological architecture simultaneously emerging has since then been passing several stages; focusing on energy efficiency in the 70's, indoor climate in the 80's and global warming in the 90's, resulting in the overwhelming question in the 2000 millenia: Can the earth manage humanity's ecological footprint? (Day, 2002). The general perception of the answer to this question today is: no! Change is needed. And this applies both to the private person, the system and the industries (Lacy & Rutqvist, 2015). As described by IPBES (2019) nature has the chance to be preserved if change is urgent and transformative.

For many years the discussion has been what's good for either nature or society, but replace or with and, and the view of sustainability becomes contemporary (Day, 2002). Furthermore, during the past couple of years businesses all over the world have started to understand the possible economical benefit in circular thinking (McDonough & Braungart, 2013).

Birch.

NATURAL MATERIALS

Definition

Natural materials are materials naturally occurring on planet earth. They are generally divided into two categories; materials from the bedrock, both with organic and inorganic origin, such as clay and sand, and organic materials, originating from growing nature, such as wood (Nationalencyklopedin, 2019).

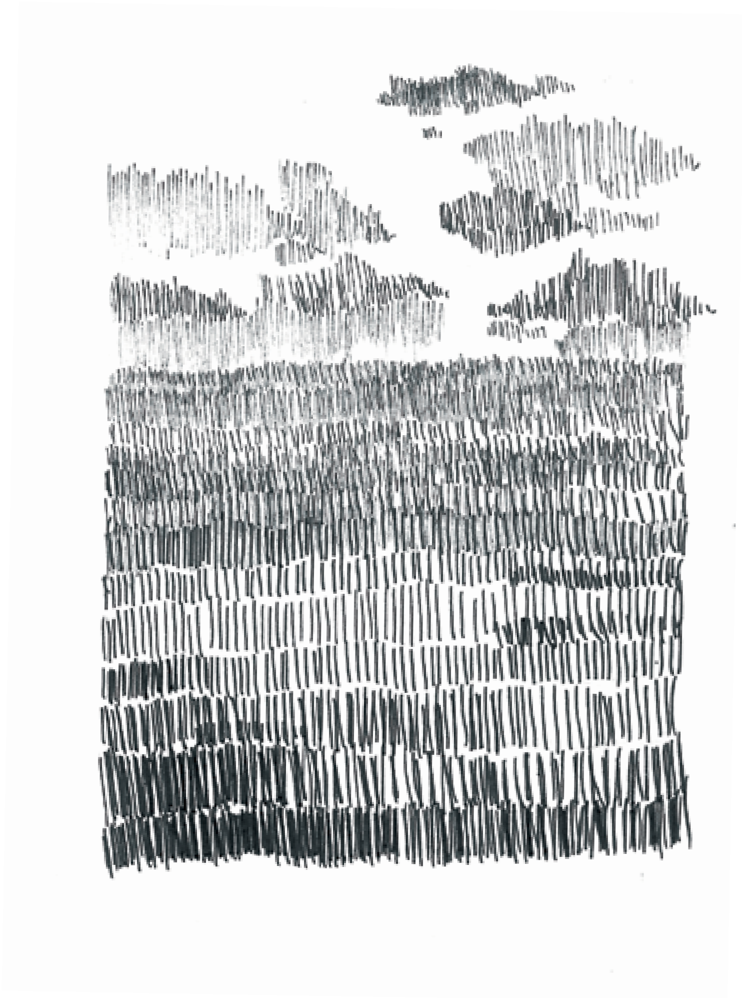
The natural choice of natural materials

This thesis argues that, supported by the theory of Biophilic design, the built environment should in much higher extension consist out of natural materials, and that natural materials have a significant positive impact on physical and mental health.

The theory of biophilic design comprice humanity's place in nature and the natural world's place in human society. It advocates for a society built upon mutuality, respect and enriching relations with nature, and for this to become the norm, not the exception (Kellert, Heerwagen & Mador, 2008). Natural materials are one corner stone of Biophilic design stating that people generally prefer natural over artificial materials.

> *"Natural materials, local, minimally processed and soften by the patina of age, connect us with life, place, time and continuum. Proven to perform well, they also incur minimal manufacturing to transportation costs. And they're healthier to live with." (Day, 2002, p. 78)*

Biological processes rely on few substances. Plant structures rely on cellulose and lignin and structural materials in animals rely on proteins. When thinking about it, most materials made by nature, ranging from plants to trees to the human body, are made by organisms at ambient temperatures and pressures, using no chemicals threatening the health of life, and finally producing no waste (Geiser, 2001).

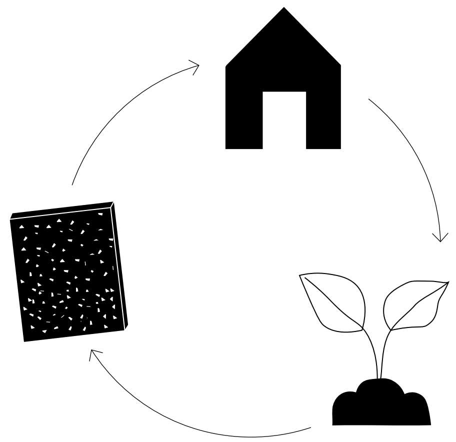


Safely back into soil

Environmental persistence is a chemicals ability to resist a natural biodegradation process. Many materials are made to resist biodegradation and thus be durable, an example of this is many plastics. Toxic materials that resist natural degradation are likely to remain toxic for a long time, also after disposal. They are problematic to nature and likely to resist metabolic transformations once absorbed into an organism, producing chronic effects in those organs exposed to them (Geiser, 2001). With this in mind persistent and toxic materials should be absolutely prioritised to avoid. It is those that are degradable and non toxic that are most compatible with nature.

> *"So we thought this was a revelation: You cannot downcycle life. Life upcycles. It is valuable at every step. The insect is not lowly compared to the human. It's just all part of the web of life. So there is no such thing as waste. No human who's a waste. No tree that's a waste. No piece of toilet paper. Upcycling means eliminating the concept of waste."*
> *(McDonough & Braungart, 2013, p. 46)*

This thesis imagines building materials that through its naturalness never downcycles but instead only upcycles. After many uses it goes safely back into the soil. Wood is a good example of a cycle that often is disrupt and if wood is not contaminated with toxins the tree can work its way through a natural cycle. The outcome is more use and creation of more jobs along the way (McDonough & Braungart, 2013).



Figre 9. Diagram of biodegradable building materials.

History, culture & natural materials

Historically, natural materials have been exclusively used in buildings, and this wouldn't change until the industrialization. Preserved swedish buildings from as early as the middle ages showcase the high quality of natural materials as well as traditional building techniques (Hall & Dunér, 1995). Looking back historically, buildings had a very strong connection to its local context and had an instinctive sense of human scale and rootedness. Buildings were defined by climate and available techniques and there was a union between thinking and feeling, doing and spirit. There was no separation between ecology and human beneficial. Today these aspects are often separated, making ecology an uncertain and doubtful part of a building (Day, 2002). According to the theory of biophilic design, mind and body evolved in a sensorially rich world (Kellert, Heerwagen & Mador, 2008), implying that the cultural heritage of living with natural materials is connected to a spiritual wellbeing.

Local resources

Leftovers from agriculture, forestry and groundwork are more or less comparable all over the world. The concept of this thesis can therefore be applied globally with local resources. Soil constitutes 68 % of the earth's surface that is not covered by water or ice (Walther, 2014). Worldwide, the clay content of soil is of wide range, but nearly all earth can be used as building material (Berge, 2009). About a third of the surface of the world is covered with forest (SkogsSverige, 2018) and about 1/10 of agricultural land (FAO, 2018).

In India, a widespread problem with air pollution is caused by farmers burning their agricultural residues to prepare for next years crop. One reason for this action is a lack of options what to do with their waste (ProEarth, 2016). Many categories of leftover resources exist both on a large industrial scale as well as on a local daily basis, and its application as building material could be applied industrially as well as in a do-it-yourself practise.

It is of great importance to use as much local building materials as possible due to both social, environmental and economic reasons (Berge, 2009). Except for the most obvious reasons, transportation and local climate, to build local forms a cultural identity, which is important for emotional as well as physiological reasons (Day, 2002).

Plastic design classics.

When plastic was introduced

Materials are seldom introduced very smoothly and the time it takes for them to be accepted is often long. The introduction of plastic illustrates this in an interesting way. When it first came it was often compared to the material it replaced and was often met with uncertainty and reluctance (Mossman & Morris, 1994). Through various exhibitions and demonstrations plastic was showed to be safe and easy to use, for example Monsanto's House of the Future exhibition that was a Disneyland attraction from 1957 to 1967 (Jean, 2014). Today this has changed, and plastic is fully accepted as a most useful material. The introduction of sustainable materials may be, conversely as it is, compared to the introduction of plastics (Bahrudin & Aurisicchio, 2018).

WASTE OR LEFTOVER RESOURCE?

> *"Waste is considered within a dead-end scenario of a linear process; to be literally buried from view – out of sight, out of mind – as a formless substance that has no value and is therefore covered by thick layers of earth or burned to ashes." (Hebel, Wisniewska & Heisel, 2014, p. 7)*

Prejudice of waste

When thinking of waste the word that often comes to mind is unwanted or undesired. Waste is common to trigger negative emotions of aesthetics and health. Seeing waste as something of value or potential of being a resource for the economy is somewhat excluded from people's awareness, and therefore people most often don't ask themselves what happens to the waste that leaves their home. It even costs to get rid of waste which only confirms just how invaluable and obsolete it is to today's society (Hebel, Wisniewska & Heisel, 2014). Papanek (1984) reflects whether, when people are persuaded and advertised to throw away and change items every few years, they may consider everything to be a disposable item, all consumer goods and even all human values.

The economic system of today depends on the extraction of natural resources for production and consequently on the production of waste. This system does not only function at the expense of the environment but also of the social structure. Economic success and modern lifestyle are symbolized by material consumption and disposal, making waste or the idea of reuse a means for the poor (Hebel, Wisniewska & Heisel, 2014). Making use of what is, and appreciating materials when in need, can be exemplified by times of poverty and scarcity. For instance, following a war, second life waste is valorised and everyday products are repaired or broken down for recycling purpose (Bahrudin & Aurisicchio, 2018).

The clean surfaces of the modernist movement

Architecture adopted a mindset in the early 20th century that responded to the unhygienic conditions in European cities resulting from a lack of waste management. Waste was seen as perhaps the biggest problem for authorities in urban settings. Definitions such as pure and clean were introduced to describe the ideal of architecture, primarily used by figures such as Le Corbusier and the Bauhaus protagonists in Weimar. Following this, architecture was assigned a role of cleansing and abolishing of waste and sickness by the means of design. Buildings were desired to be white, the colour of antiseptic state, stripped of ornaments or anything else that could disturb the pureness of it. The problem of waste and architecture are yet today entwined (Hebel, Wisniewska & Heisel, 2014).

Valorising imperfection

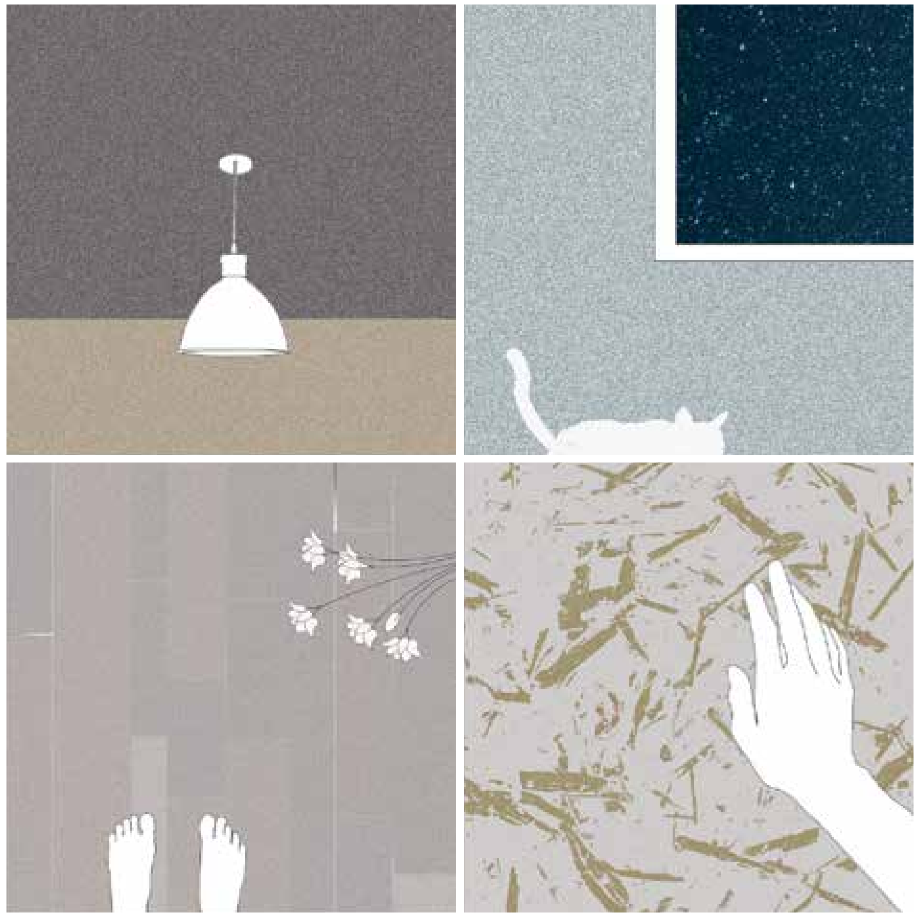
Imperfection is often a part of materials that are leftover or wasted. This can lower the consent to it, but it can contrarily also be valorised. The one of a kind sensorial qualities are today more and more valued, as an oppose to the perfect and plain surface (Bahrudin & Aurisicchio, 2018).

Wabi-Sabi is a Japanese form of aesthetic, where value is found in the beauty of things imperfect, impermanent and incomplete. The ideas of Wabi-Sabi originate from ideas about simplicity, naturalness and acceptance that was found in Zen Buddhism, but reached its most realization within the context of Japanese tea parties. The materials of Wabi-Sabi are natural, imperfect, earthy, intimate, simple and irregular. They encourage and inspire a smaller distance to themselves, close enough to touch and relate. The materials of Wabi-Sabi are not far from their original condition, often with a coarse and raw texture with a simplicity described as going down to the essence without removing the poetry (Koren, 2008). The spirit of Wabi-Sabi relates very much to the valorisation of leftover natural materials. Shifting the mindset from an idea of perfect and permanent to one more humble, where the imperfect and impermanent are valued, could inspire a change of view on unconventional materials.

Looking at examples in art, artist American Joseph Cornell, used found objects to tell a story in his much famous shallow wooden boxes with glass front housing poetic assemblage (Artnet Worldwide Corporation, 2018).

There is no waste, only leftover resources

Wasted resources and wasted life cycles can be seen as the biggest economic opportunity in contemporary history. It not only makes financial sense but also gives businesses and economy the chance to grow without putting further burden on constrained and limited resources. This enables possibilities for waste and the concept of waste to be diminished: where every resource has a value beyond the present use (Lacy, P., & Rutqvist, J. 2015).



The surfaces that surround us.

THE SURFACES THAT SURROUND US

The era of indoor life

In large parts of the world the population spends nearly all their days indoor (Norsk Treteknisk Institutt, 2016). It is therefore easy to argue that the indoor environment is highly important to the modern human. Once inside, the indoor environment is enveloped by the surfaces; the walls, the floor, the ceiling. These surfaces are constantly close and in view, having different effects on the spatial atmosphere, from mental to physical perceptions.

The home

With an increasing population, escalating rapidly in cities, the demand for housing is large. The home however, is not a place that should be mass produced without the deepest care. Away from the traffic and the chaos that a city or society entails, the home is meant to be a safe place where one can be the most vulnerable, proposing that the air of a home should be clean and safe.

It can even be argued that the indoor air is a bigger determinant of what one breathes than the outdoor air. This thesis therefore focuses on *interior surfaces*. What materials at the hand of architects affect the health and emotions of a human more direct?

"The connection between health and the dwelling of the population is one of the most important that exists."

- Florence Nightingale

(Compton & Shim, 2015, chapter 8)

Material	$[g/(m^2 \cdot \%RH)]$ Moisture buffer value (MVB)
Spruce panel	1,15-1,22
Clay plaster (Clayworks)	1,28
Gypsum	0,57-0,69

Figure 10. Table of moisture buffer value (MVB) of selected materials (Rode et al., 2005 & Clayworks 2019).

Material	$[10^3 \cdot kg/m^3]$ Specific weight	$[kJ/m^3 \cdot K]$ Thermal storage capacity	$[10^{-4} m^2/h]$ Thermal diffusivity
Granit	2,7	2133	29-68
Gypsum	2,3	2507	2,5
Massive wood	0,5	1150	4
Limestone	2,75	2500	18-19
Marble	2,7	2376	32-45
Timber (white pine)	0,35-0,5	525-750	10-19
Wood fibre board	0,18	415	4
Clay panel (Greenteck 700 Clayteck)	0,7	980	4,8

Figure 11. Table of specific weight, thermal storage capacity and thermal diffusivity of selected materials (Engineering ToolBox, 2009, Engineering ToolBox, 2004, Engineering ToolBox, 2003, Berge, 2009 & Claytec, 2018).

Climatics of natural materials

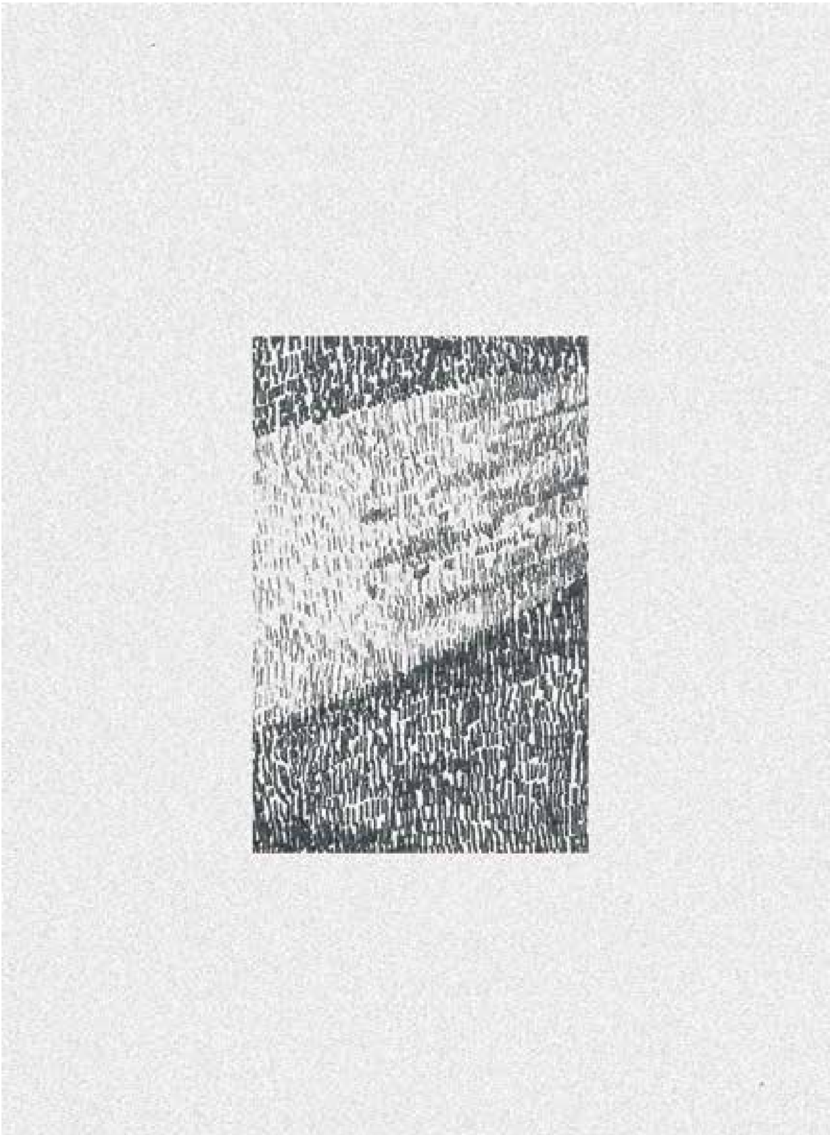
Important aspects for a satisfying indoor air quality are an even temperature level and moisture content. Some building materials contribute to a more stable indoor environment by counterbalancing temperature and moisture fluctuations by absorbing heat and/or moisture when these levels increase, and dispersing it when the levels decrease (Berge, 2009).

A material's ability to even out daily temperature fluctuations requires a combination of high thermal storage capacity and high thermal diffusivity. Thermal storage capacity is calculated as; Specific weight x specific heat capacity, meaning the higher density the higher thermal storage capacity. Thermal diffusivity is calculated as; Thermal conductivity/thermal storage capacity. See figure 11 to the left for values of some natural materials.

Stone, but also both massive wood and wood fibre boards, have good temperature regulating properties. Simplified, the outer layer of 10-20 cm can function as temperature regulating during a 42 hour cycle. The surfaces of interior walls, inner layers of outer walls and ceilings are the most effective, preferably without wallpapers or furnitures blocking it (Berge, 2009).

Materials that can release and take up humidity are called hygroscopic. Indoor humidity affects human wellbeing, and by using hygroscopic materials a healthy indoor environment can be created. Additionally, by creating stable levels of humidity the chance for microorganisms to grow is reduced, the amount of dust on surfaces is less and there is less need for vapour barriers. Most plant and earth-based materials have good moisture buffering properties contrary to plastics, metals and concrete. (See figure 10). The moisture regulating capacity is often measured by Moisture buffer value (MBV) (Berge, 2009).

Natural materials generally have good climatic properties, which results in a wide range of healthy qualities. To exemplify, on all interior plastic surfaces, the production of bacteria is generally several times greater than on mineral or wooden surfaces with moisture regulating properties (Berge, 2009).



Light and shadow.

The experience of materials - colour, light and texture

Interior surfaces should be pleasant to touch, generate a feeling of comfort and accomplish a higher level of finish, compared to for example exterior surfaces (Berge, 2009). The perception of colour is highly personal, some guidelines implies green and blue hues have a calming effect and red, orange and yellow an invigorating effect, but even this is highly general (Day, 2002). One can argue, supported by the theory of biophilic design, that natural colours, preferably the colours most common in nature, would be to prefer on interior surface materials.

> *"And context changes colour. Lit house windows at night look yellow. From indoors the night looks blue. But, indoors, houses don't look yellow and, outdoors, night doesn't look blue." (Day, 2002. p. 112)*

Studies indicate that a presence of natural patterns increases human wellbeing and that humans aesthetically are appealed to natural materials (Joye, 2007). Recognition of a material's origin is recorded as an important aspect of a material's property. For example, research has shown that materials connected to a memory or experience, with a possibility to relate to their origin, generate a feeling of naturalness. The level of naturalness is for example affected by the visibility of fibres in wooden composite materials (Norsk Treteknisk Institutt, 2016). Not only recognition but a perplexity seems to be satisfying when experiencing materials. An element of surprise in the visual-tactile experience of a material is perceived as intriguing. For example, materials looking rough but feeling smooth, and the other way around, are preferred compared to materials feeling and looking the same way (Sauerwein, Karana & Milano, 2017).

Extensive research investigates the impact of daylight on performance, mood and wellbeing and it has been showed that presence of daylight increases the performance and productivity as well as people's mood (Nicklas & Bailey, 1996). Dynamic and diffuse light is an important factor of daylight theory arguing for neither uniform lightning nor extreme daylight (Browning, Ryan & Clancy, 2014). Zumthor (2006) discusses the strong relationship between material and light. He argues that good architecture means factoring in lightning from the start, not thinking about it first when the building is already built. He takes up two examples to go about; one is to design a pure mass and let the light be another mass carving out the darkness, the other is to analyse every surface to see how the light falls on it. By making use of the light he considers how light on things almost can be a spiritual experience.

Furniture, appliances and building materials emit unhealthy emissions.

Natural materials to reduce toxins in building materials

In nature toxins exists, many green plants generate toxins as a defence against predators, and similarly do many animals. However, nature is cautious about its toxins, using them in restricted and controlled ways. A long period of evolution has determined how and how much toxins that can flow in and out of organic systems without detrimental effects (Geiser, 2001).

In the man-made world, on the other hand, materials created by humans emit toxins in unhealthy amounts (World Health Organization, 2010). Research shows that for example many surface materials used in buildings emit high amount of volatile organic compounds (VOC), particles dangerous to human health (Nriagu, 1992). Building materials such as plastic carpets, floor coverings, adhesives and paints emit VOC. Today, measurable contents of VOC are always present in indoor air, potentially leading to health problems like allergies, skin and membrane irritations, headache and insomnia. Certain VOC, like formaldehyde, is furthermore suspected to be cancerogenic (Que, Wang, Li & Furuno, 2013). The outdoors is polluted by industry and traffic and indoors the furniture, appliances and building materials emit gasses, leading to a reality where few breathe clean air (Day, 2002).

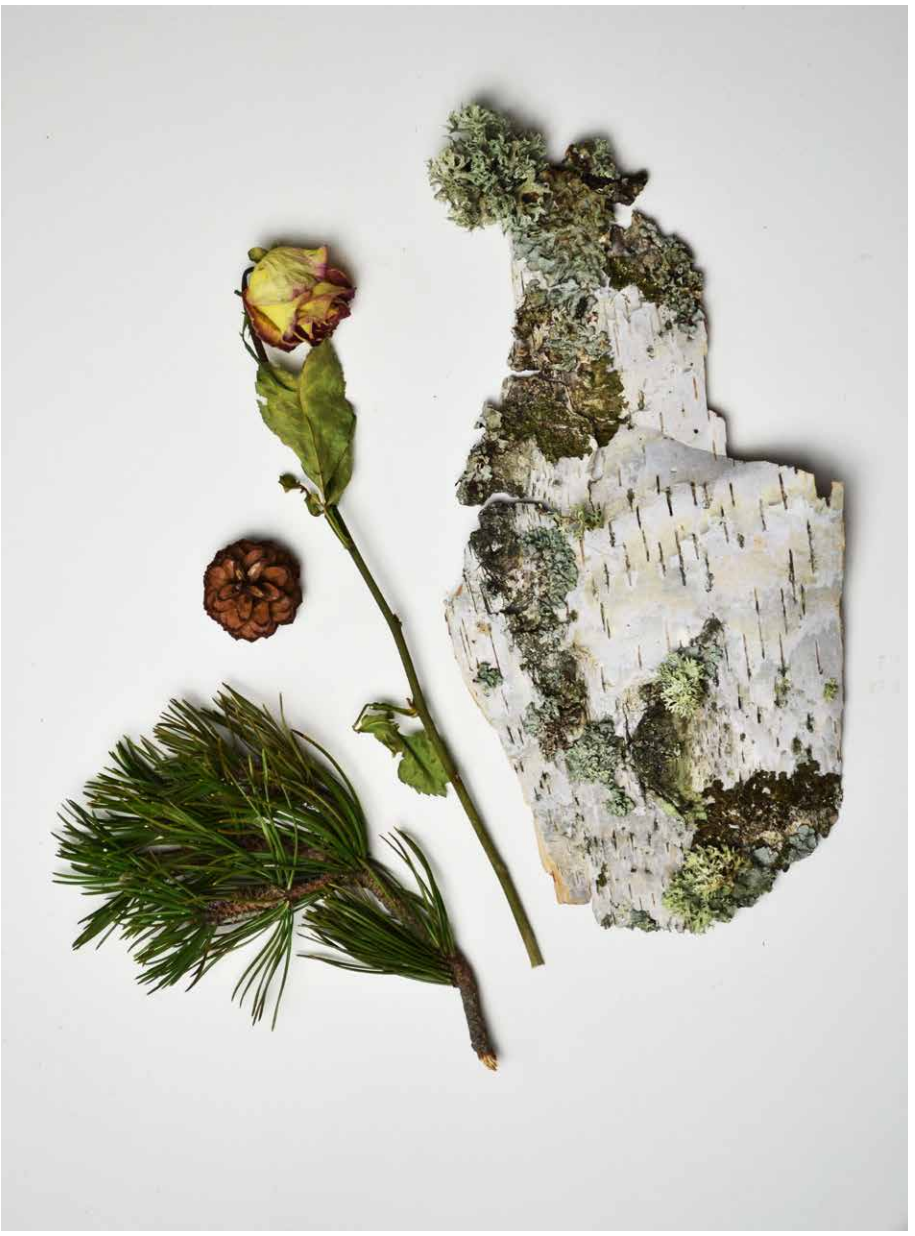
The adhesives in the commonly used surface materials particle boards, medium densified boards and plywood boards are emission sources of formaldehyde (Salem, Böhm, Srba, & Beránková, 2012). This makes the challenge to replace these with toxic-free adhesives highly urgent, and ongoing research successfully investigates using for example different kinds of starch and cellulose as adhesives instead (Basta, El-Saied, & Gobran, 2004 & Ferrández-García et al., 2012). Therefore, one important aspect in this thesis' material investigation is to use non-toxic adhesives, such as potato starch and cellulose.

The connection between air and emotion is strong. Just think of how most people respond to the pressure fluctuations of music. The lungs and the heart respond deeply to emotion, and the air one breathes sparks it all (Day, 2002).

• MATERIAL INVESTIGATIONS

1. Fir needles
2. Large pieces of bark from fir
3. Bark chips from birch
4. Leftover pieces of wood
5. Wood shavings
6. Camomile flowers
7. Small fibres of reed
8. Bark chips from fir
9. Large pieces of bark from birch
10. Saw dust
11. Hemp fibres
12. Dried roses
13. Reed
14. Small fibres of bark from fir
15. Leftover pieces of wood
16. Wooden chips
17. Fine hemp fibres
18. Pine needles

19. Dried barley
20. Carrot peels (pulverised)
21. Flaxseed oil mass (original state)
22. Rapeseed oil mass (original state)
23. Leftover piece of stone
24. White pigment
25. Wheat bran
26. Potato peels
27. Flaxseed oil mass (pulverised)
28. Rapeseed oil mass (pulverised)
29. Large pieces of dried clay
30. Crushed terracotta
31. Fine wheat bran
32. Beetroot peels
33. Dried pressed oats
34. Leftover piece of stone
35. Dried clay (pulverised)
36. Red pigment



Still life of leftover resources.

REVIVED MATERIALS

Materials derived from discarded raw materials is one large category of pre-consumer waste (Sauerwein, Karana & Milano, 2017). This thesis explores the revival of leftover resources from agriculture, forestry and groundwork. Valorising materials left behind in the process of making a product, is what this thesis calls revived materials.

The diagram below (figure 12) shows the linear and circular flows of resources and the, formed by this thesis, additional flows of leftover resources, bearing the possibility of becoming revived materials.

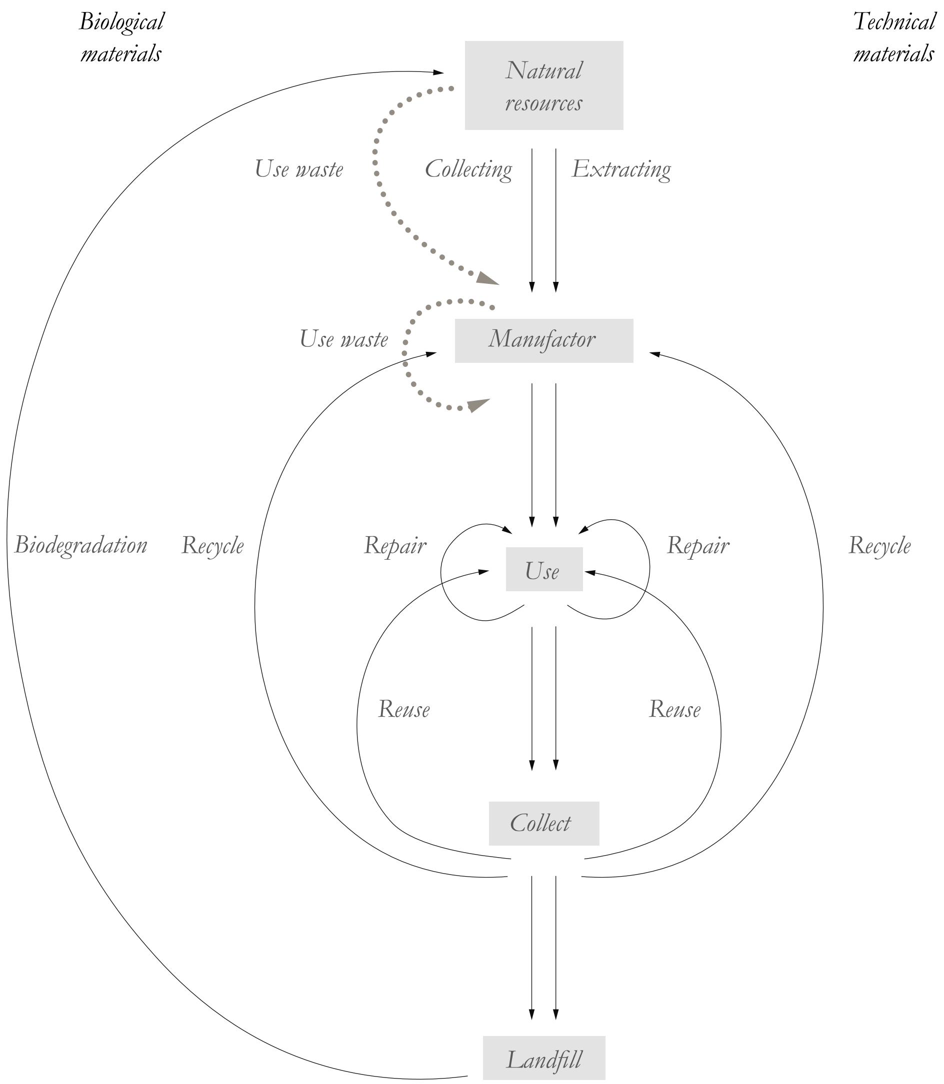


Figure 12. Supply chain showing linear and circular economy model
Revived materials

Agriculture

Forestry

Groundwork

The growing field.

The harvested field.

The leftovers.

The living forest.

The cut down forest.

The leftovers.

The unthouched ground.

The excavated ground.

The leftovers.

At the expense of producing things humans urge, products from forestry, agriculture and outcomes from groundwork, means by-products and leftover resources are produced. Examples are shown in figure 13.

Things produced:

Figure 13. Things produced.

1. *[Image 4] Field of barley (Bogdanov).*
2. *Leftover barley from Oceanbryggeriet.*

AGRICULTURE

Today, around 10 % of the world's land area is dedicated to cultivation of crops and about 1/3 of the food produced globally is estimated becoming waste, referring to edible parts of the crops, not including unwanted parts such as stalks, branches, straws, etc. (Nationalencyklopedin, 2019 & FAO, 2011). Agricultural leftovers globally count up to around 140 billion metric tonnes (UNEP, 2011).

Most plant-based fibres regulate humidity well. Looking at interior surfaces, the moisture buffer value is double as high for a spruce panel than a gypsum board. Cellulose fibres are also widely used for their insulating qualities and some, like hemp and flax, also have good rot resisting properties. A high content of cellulose and air can give high durability with thermal insulating properties (Berge, 2009). Leftover agricultural resources listed below are materials investigated in this thesis.

The four kinds of cereal

In Sweden, "de fyra sädesslagen" (translated to English: the four kinds of cereal) is an expression referring to the four most common cereal grains cultivated in Sweden; wheat, oat, rye and barley (Från Sverige, 2017). In the production of cereal crops, 50-70 % becomes residue after harvesting (Bauder, 2013). This includes straw that historically has been used as a building material (Berge, 2009), but the leftovers are most commonly used as feed for animals (Nationalencyklopedin, 2019). Due to current high temperatures in Sweden, there is a lack of straw for animal feed (SVT Nyheter, 2018), therefore this thesis focuses on the residues from cereal in food production. Oat, wheat and barley are represented as raw materials in this thesis. In the production of Oat drink the company Oatly gets 20 ton leftover oat fibres every day (L. Nordgren, personal communication, January 23, 2019), and Lantmännen AB gets a large amount of wheat bran leftover every year (A. Moldin, personal communication, February 6, 2019).

Leftovers from beer production

In beer production, all grains, most of them from barley, becomes a leftover product after extracting sugar and flavour from it. The leftover product is wanted by nearly no one and is often hard to get rid of, some breweries burn it for energy, or it becomes feed for animals. Oceanbryggeriet in Gothenburg produces around 600 kg of leftover barley grains per day, and breweries around Gothenburg produce together around ten times as much. (R. Arvidsson, personal communication, February 13, 2019).

1.

2.

3.

1. Pressing-mass from flaxseed oil production.
2. Red cabagge.
3. Production of flaxseed oil at Gunnarshögs gård.

Leftovers from rapeseed oil and flaxseed oil production

Rapeseed and flaxseed contain around 45 % oil, and the leftover mass after pressing contains 10-12 % oil. This makes the leftover mass suitable as feed for animals, but it could also have great potential for durable, water repellent building materials. Around 1/3 of the seed becomes oil, and 2/3 makes the leftover mass. Gunnarshögs Gård creates around 600 ton leftover mass from flaxseed and 2200 ton leftover mass from rapeseed oil per year. Today it becomes feed for animals but ongoing research investigates possible use in building materials (A. Persson, personal communication, March 8, 2019).

Flax has high resistance to rot and the oil produced from its seeds have traditionally been used as a protecting cover for other materials, such as plaster and wood. It dries by oxidizing into a protecting linoxin. Since it, in some extent, closes the pores of its underlayer, the moisture buffering capacity will not be at its full potential (Berge, 2009).

Vegetable by-products

In food production, peels are most often unwanted. Around 25 % of the potato plant ends up as waste, where peels make up an average of 8-12 % of the potato mass. Waste from potatoes are today either left to decompose in the field, become feed for animals, or more seldom used for biogas production (Singhania, Agarwal, Kumar & Sukumaran, 2018 & Salunkhe & Kadam, 1998). The carrot is the second most used vegetable after potato, and a large byproduct is carrot pulp from juice production, which is around 30-40 % of the carrot (Singhania, Agarwal, Kumar & Sukumaran, 2018).

Hemp

Hemp is a highly durable material, and has traditionally been used as rope, textiles and insulation in buildings. Historically, hemp has been richly cultivated in Sweden, but were during many years forbidden due to its other use as a drug. Today it is legal to cultivate industrial hemp (with low content of hallucinogenic substance) in Sweden (Nationalencyklopedin, 2019). Hemp has high resistance to rot and fungi (Berge, 2009).

1. Still life of leftover resources from forestry.
2. Needles from pine.

FORESTRY

Forests represent 30 % of the world's land area. In Sweden, 55 % of the land area is forest, and its industry represents 20 % of Sweden's export (Nationalencyklopedin, 2019). By-products from forestry; bark, sawdust and wood chips, are used in different ways, in paper industry and energy production, as well as building materials, mostly boards of different kinds (SkogsSverige, 2019). Leftover resources from forestry listed below are materials investigated in this thesis.

Conifer needles

The needle of a standard sized coniferous tree makes up 5-10 % of the total tree mass (Magnusson, 2015). Leftover conifer needles are today mostly used for energy recovery (Träguiden, 2017). They have a high content of nutrients and play an important role in the nourishing of the forest, which makes how to best handle contemporary industrialized forestry debated (Magnusson, 2015). However, leaving all needles on the ground can also be problematic, because of a risk of overfertilisation (Magnusson, 2015). Extracts from conifer needles can be utilized for impregnation and waterproofing (Berge, 2009). Needles oil is in some extent insect repellent (Government of Canada, 2016).

Bark

In the production of wood, bark is a leftover resource, today mostly used for production of energy (Träguiden, 2017). The bark of a standard sized coniferous tree makes up 5-6 % of the total tree mass (Magnusson, 2015). The bark from some trees can be used for their advantageous climatic qualities. For example, bark from cork provides good thermal insulation and birch bark has been commonly used through history as a long-lasting waterproofing membrane, especially under roofs (Berge, 2009).

1. Field of reed.
2. Forest.
3. Wood from oak.

Wooden leftovers

The Swedish building sector is responsible for 1/3 of the annual waste produced (Naturvårdsverket, 2018). In 2016 around 484 000 ton of the construction wood waste resulted in incineration (Naturvårdsverket, 2018). This thesis focuses on scrap pieces in wooden constructions, scaffolding wood and other temporary wooden constructions.

Wood has good climatic properties both in its original state or as sawdust or shavings. They are hygroscopic, regulating the moisture content of the indoor air. Sawdust and wood shavings regulate at a bit higher rate than timber. Timber also has a rather good insulation value (Berge, 2009).

Reed

Even though reed is a part of nature rather than forestry, it is here categorized as forestry. Reed grows on all continents except the Antarctic. Overgrown beaches and farming land are well-known issues that bothers those who live by the beach and farmers alike. In Sweden, the growth of reed has increased massively and is often compared to weed. However, only hundred years back reed was seen as a valuable natural resource. Even though reed dampens erosion and nutrient runoff as well as functions as an important home for many birds and other species, it is often cleared from beaches and farmland (Järki, 2018). According to research done by SLU, removal of wetland vegetation such as reed helps reduce the risk of over fertilization (Prade, Svensson & Tufvesson, 2017). Research is also being done on how the benefits of reed removal enables giving back the nutrients from reed to the fields to ensure farming (Järki, 2018). Like many plant materials reed give a high level of thermal insulation and has good moisture buffering properties (Berge, 2009).

1. Excavating clay for the project Västlänken.
2. Clay freshly taken from the ground.
3. Stone in the container at Stencentrum.

GROUNDWORK

Earth masses from groundwork forms the largest amount of waste produced in Sweden, around half of it becoming construction material and half of it landfill (Naturvårdsverket, 2018).

Clay from Gothenburg infrastructural project Västlänken

Västlänken is an ongoing project in Gothenburg where a railway in a tunnel under central Gothenburg will be built. The construction started in 2018 and is planned to be finished in 2026 (Trafikverket, 2017). 1/3 of the tunnel will be built in clay masses, which will result in approximately 1,7 million cubic meter leftover clay and earth masses (Trafikverket, 2017). Clay has excellent moisture buffering capacity. Additionally, it has good acoustic and thermal properties, where the mass of the clay helps to stabilize the temperature indoors (Berge, 2009).

Stone leftovers

During the twentieth century cut and polished stone products became more and more popular. The initial energy needed to extract stone is quite low, but the more cut, worked and transported it is, the larger the footprint (Berge, 2009). Because of stone being a heavy material with high thermal capacity it can stabilize room temperatures. Stone floors are mostly durable and easily maintained, however they can be cold and hard (Berge, 2009).

As an example, Sten & Marmor i Linköping AB, a small company producing stone sheets, mostly countertops, produces around 3 ton leftover stone pieces each month (K. Pettersson, personal communication, April 9, 2019).

Reviving barley

In the fertile fields of rural Sweden barley is growing to, for example, become raw material in the production of beer. To meet thirstiness, beer production means leaving behind all barley that is used for extraction of flavour and starch, as a leftover resource. The used barley either becomes incineration or feed for animals or, in best case, for energy recovery.

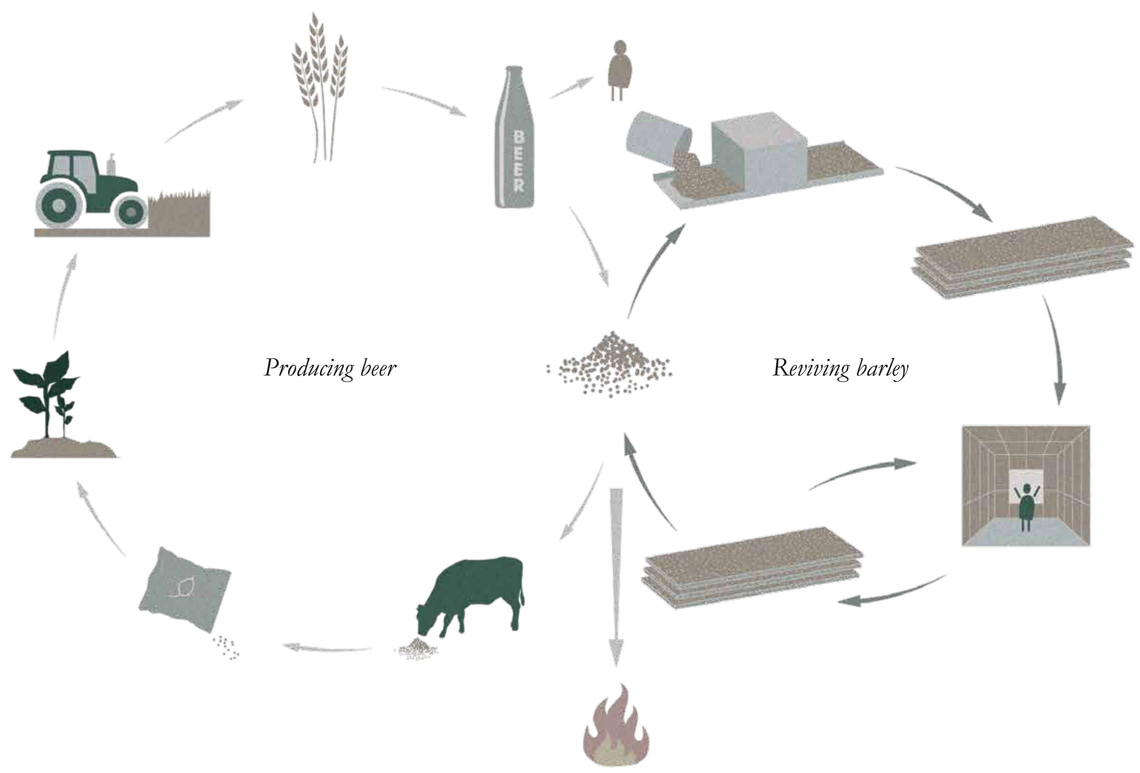


Figure 14. The diagram above shows a common cycle for the life of barley used to produce beer and the story of reviving its leftovers.

Reviving leftover barley could be mixing it into a mass and producing surface boards for interior application in architecture. The boards can easily be moved and reused in another building when change is wanted. When too worn out to reuse, the barley can be mixed down with new adhesive and become a surface board once again, or go safely back into soil.

Prolonging the life cycle, gives several advantages. Instead of burning the material, its carbon storage is kept, and the longer a material is kept in a cycle, the better. Also, no new resource needs to be extracted, conserving resources of the planet. Lastly, there is a beauty of a material that has a story of a former life to tell.

Reviving reed

In the nutritional lake bay, reed flourishes and overgrows the beach and the jetty stretching out in the lake. To meet the need of the closeby neighbours and visitors to bathe and reach the lake with their fishing boats, and to not let the entire lake be overgrown , the reed has to be cleared from the bay. The eliminated reed is either left to decompose nearby or left for incineration. A resource valuable to be revived.

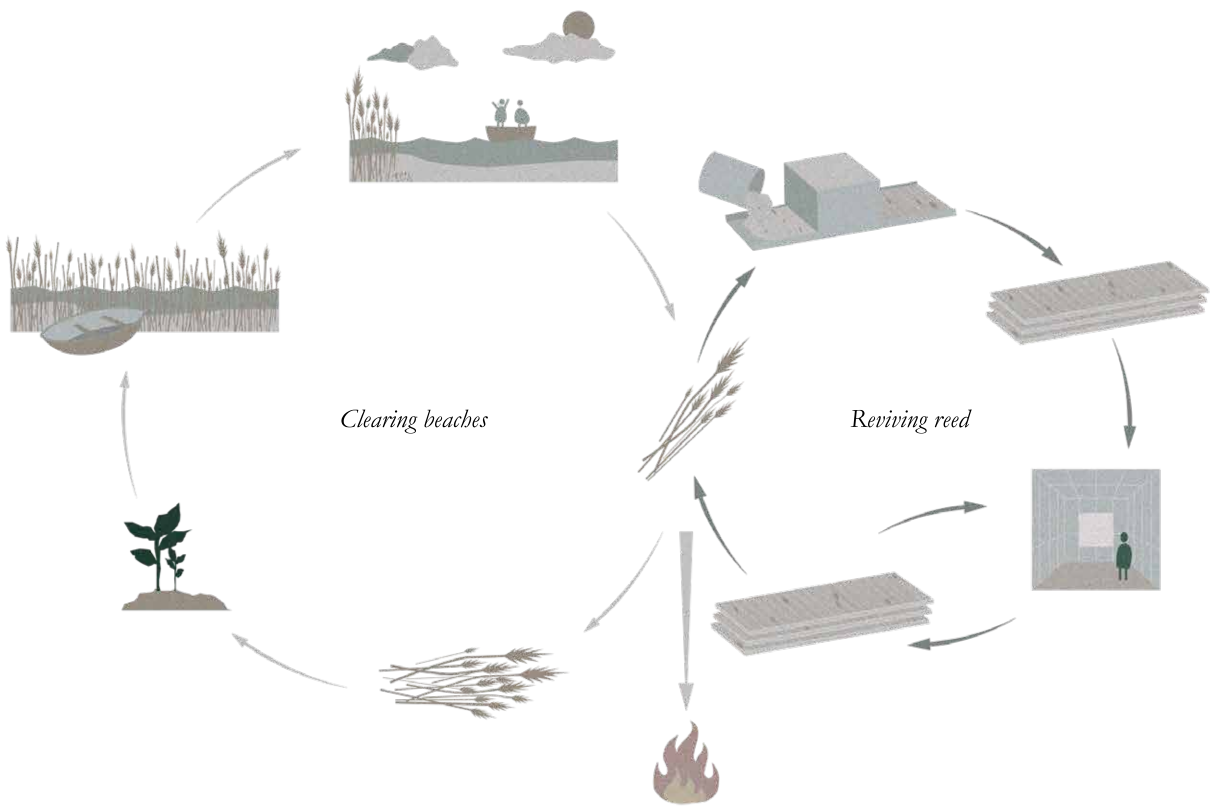


Figure 15. The diagram above shows a common cycle for the life of reed at the purpose of reed free beaches and the story of reviving its leftovers.

Reviving clay

In millennials, weathering of rocks has produced the fine grained soil called clay. In the settling of planet earth's growing population the need for underground infrastructure and constructions is resulting in large amounts of excavated clay ending up as roadfill or landfill. A resource valuable to be revived.

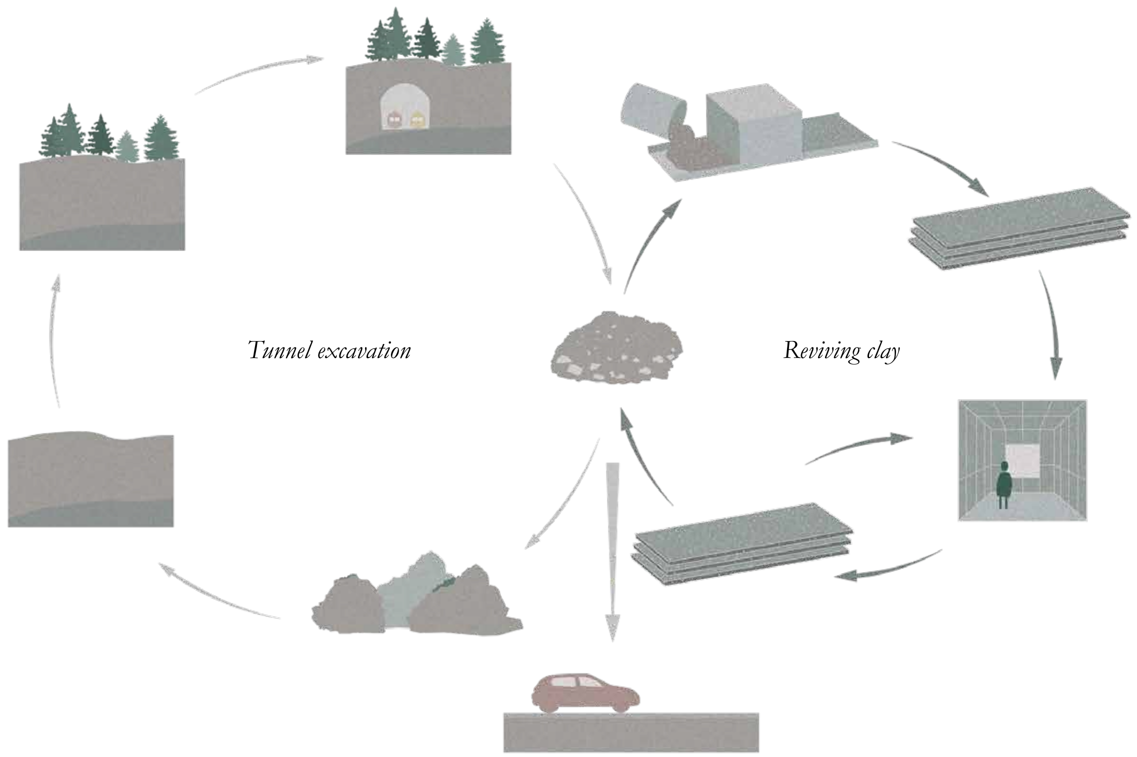


Figure 16. The diagram above shows a common cycle for the life of clay and the story of reviving its leftovers.

1. *[Image 6] Material samples investigated in the project Biological house (GXN).*
2. *Organoid Natural Surface (Personal contact)*
3. *Organoid Natural Surface - Wildspitze margeritta (Personal contact)*
4. *Material samples of wood fibre boards and soap made by NSR.*

REFERENCE PROJECTS

Biological house, GXN

The biological House by GXN is designed with circular economy in mind. The concept is to build with agricultural residues, like tomato stems, straw and eelgrass. For example, fibres from tomato stems are mixed with bioresin to create a new board material GXN (2019). This project has similarities with this thesis as it utilizes agricultural residues, making use of materials that otherwise would be burned, working with a concept following circular economy and healthy building materials. A study visit to GXN and interviewing Lasse Lind, Head of consulting, gave deeper knowledge of the ideas this project showed were possible, how it was received and what the challenges were. This project has been of great inspiration from the very start of forming the concept of this thesis.

Organoid

Organoid produces natural surfaces, made out of mostly organic raw material and ecological adhesives, attached to different carrying materials. Most of the surfaces have a strong visual connection to their original resource and some surfaces still have the smell of their raw materials, for example from vanilla pods and hulls from the cocoa bean (Organoid). The creative way of making surface materials out of organic raw materials is in line with what this thesis aims to create. Appreciation of the raw materials, and its qualities, is shown through out the products of Organoid.

Research by Nordvästra Skånes Renhållnings AB (NSR)

NSR is developing how to utilize wood waste and adhesives developed from organic residues to produce environmentally friendly chipboards, without any formaldehyde emissions (M. Hameed, personal communication, February 14, 2019). A personal meeting with Dr Mahmoud Hameed and Torleif Bramryd gave valuable insight into current research of this field. This thesis aims to use no harmful adhesives, and instead uses rather simple, natural ones such as starch. Therefore, current research on strong adhesives without harmful emissions enables one to imagine the outcome of the material investigations to have potential in a future development.

1.

2.

3.

4.

1. [Image 7] Ecoboard standard (Ecoboardinternational).
2. [Image 8] Clay house by Simon Astridge (Clayworks, photograph: Nicholas Worley).
3. [Image 9] CLAYTEC - Greentech 700 (Claytec).
4. [Image 10] Yosima (MaterialDistrict).

ECOBoard

Boards made from agricultural residues like straw or reeds that are bonded using the natural lignin from cellulose fibres. They are made without additives with VOC (ECOboard, 2017). The boards have for example a negative carbon footprint, are fire resistant and insulating (W. Chotkoe, personal communication, April 05, 2019). As these boards, made from residues and natural residues, show how durable and usable they can be, confidence has been given to the concept of this thesis.

Clayworks

Clay plasters for home, retail, restaurant, and work spaces (Clayworks, 2019). Inspiration to this thesis has been found in the contemporary, yet natural projects of Clayworks, where the clay forms a variety of surface textures, colours and spatialities.

Greentech 700, Claytec

Clay panels for interior surfaces, inner walls, floors and ceilings. They are made from clay, wood fibers, starch and jute fabric and are for example easy to install, regulate air moisture and have good acoustic insulation (Claytech, 2019). As a way to replace gypsum boards this thesis has found inspiration in the products of CLAYTEC, which shows an alternative that has most of the properties gypsum is liked for.

Yosima, Claytec

A clay mortar for plaster made from a mix of sand, coloured clay, clay perlite and cellulose fibres. After the ingredients are dried they are mixed together and grounded. Applications are on interior walls and ceiling finishes (MaterialDistrict, 2013). Through its method of production, variety in colour and application, this product inspired the experiments with clay made in this thesis.

Figure 17. Map of south of Sweden with the location of companies providing this thesis with raw materials.

COLLECTED MATERIALS

Raw materials used in the material investigations of this thesis have either been donated by companies, private persons or been collected from nature. Most of the materials were gathered during a collecting trip to south of Sweden. Below follows a list of the materials gathered for the investigations.

Barley from beer production
Oceanbryggeriet

Carrot haulm
Leftover from personal use

Reed
Collected from nature

Leftover wood pieces
Svensson & Örn Snickeri AB

Leftover stone pieces
Stencentrum

Bark, saw dust, wood chips & wood shaving
Derome

Pressing-mass from production of oat drink
Oatly

Dried pressing-mass from production of sugar (Betfor)*
Nordic Sugar

Hemp fibers and pressing-mass*, by product from hemp oil production
Österlen Hampa

Pressing-mass, by-product from rapeseed and flax oil production
Gunnarshögs Gård

Peels from carrot, beetroot & parsnip
Blackbird restaurant & PorterPelle restaurant

Wheat bran
Lantmännen AB

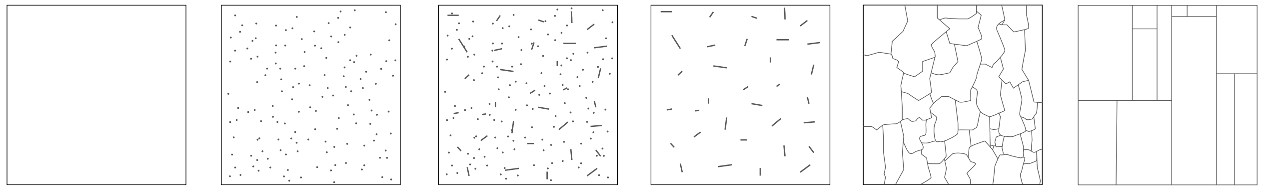
Bark from fir
Bjernareds sågverk

Christmas tree
Found in a local neighbourhood

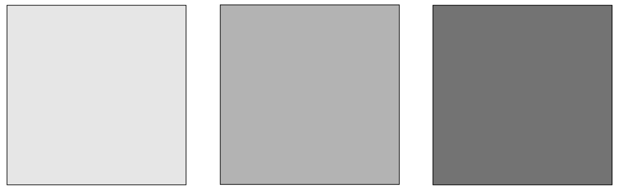
Roses
Given by Maybrith

**Not used in the material investigations.*

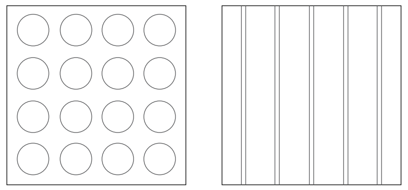
Size of particles



Uniform *Tiny grains* *Tiny grains + small fibres* *Small fibres* *Small pieces* *Large pieces*



Shades of colours



Textures

1. Pigmented clay
6. Flaxseed oil

2. Patterned add to mould
7. Flaxseed wax

3. Patterned add to mould
8. White pigment

4. Small pieces of bark
9. Brown pigment

5. Small fibres of bark
10. Red pigment

LEVELS OF EXPLORATION

In order to explore how revived materials are perceived, the samples have been developed with an aim to create a spectrum of experience. This has been done by exploring the materials at different grades of size of particles, shades of colour and texture. The surfaces are either created from a mixed mass or assembled pieces, this is described further on page 82-87.

Size of particles
The raw materials range from fine grains, such as wheat bran, to larger pieces, such as bark. Through mixing different size of particles, a divergent level of inhomogeneity was created. The level of recognition, namely how well a materials origin could be recognised, has also been explored through size of particles.

Shades of colour
The raw materials possess colours in a range from dark brown to light beige, in a palette of earthy shades. To expand the colour range, natural colouring has been tested, such as with red cabbage and earth pigments. To explore what happens when adding a homogen coat, white paint has been applied to two samples. Earth pigments have been used when making samples out of clay as well as mixing paint from pigment and organic wax. The pigments used are; white - titanium dioxide, black - carbon black (wood-fired), red - burnt terra and brown - burnt umbra.

Texture
Natural textures are created by the different size of particles. To explore textures further, moulds with created textures have been used. The textures aim to create a wider range of tactile and visual experience.

Binder
Most samples have adhesive in them. An important aspect has been to use organic, biodegradable and nontoxic adhesive. The adhesives used are starch (potato and corn starch), CMC (carboxymethyl cellulose), wallpaper paste (methyl cellulose) and agar agar (which is a gel obtained from certain algae).

Coating
To refine and increase durability and cleanability of the surfaces, flaxseed oil and wax has been added to some of the samples. The wax used is an ecological flaxseed oil hard wax, containing flaxseed oil, beeswax and a few other vegetable waxes.


Drying oven, Structural engineering laboratory


Earth lab


Hydraulic press, Materials and manufacture laboratory

LOCATION OF EXPERIMENTS

Structural Engineering Laboratory, Chalmers University of Technology

The fibre boards were made at the Structural Engineering Laboratory at Chalmers. The equipments used were a drying oven, a mould consisting of an aluminum tin and a wooden board fitting in it, and four clamps. The pressure was achieved by screwing the clamps by hand. The samples were all 200 mm x 200 mm in dimension, with a thickness varying from a few millimeters to a few centimeters.

Materials and Manufacture Laboratory, Chalmers University of Technology

In order to test making material samples out of the same materials as in the Structural Engineering Laboratory at a higher pressure, some were conducted in the laboratory of the department of Materials and manufacture at Chalmers. A hydraulic press, Bucher-Guyer KHL 100, was used which provided the possibility to apply a pressure of 500 bar. The samples were 100 mm x 100 mm in dimension with a thickness of a few millimeters.

Earth lab, Kolgruvan at Ringön

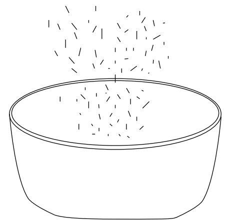
All the clay samples were made at Earth lab in Kolgruvan situated at Ringön, Gothenburg. The equipments used were a lever, earth rammer and a mould, consisting of a wooden frame and a wooden board fitting in it. After mixing clay with sand and water it was put into the mould and compressed through first the lever and afterwards the earth rammer. The samples were 200 mm x 200 mm in dimension with a thickness ranging between 20 and 40 millimeters.

Architecture workshop, Chalmers University of Technology

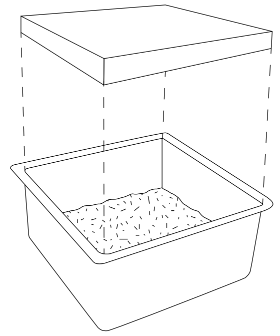
The wooden samples were made in the Architecture workshop at Chalmers.

Fibre board under compression.

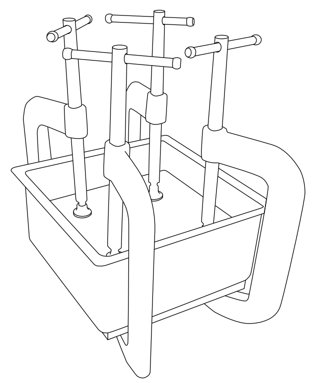
METHOD OF FIBRE BOARDS



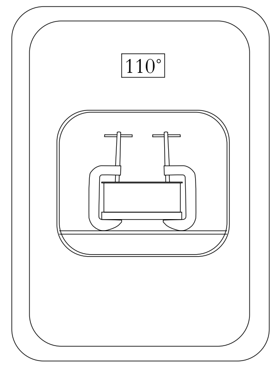
1. Mix fibres, adhesive & water



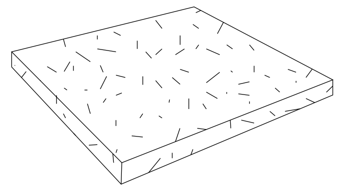
2. Put the mixed mass in mould



3. Put pressure on mould



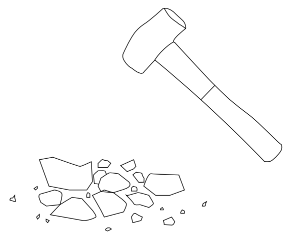
4. Heat during compression



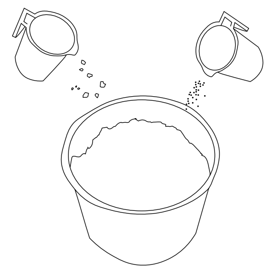
5. Remove mould and leave to dry completely

Pressing tool for clay panel production.

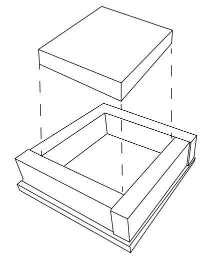
METHOD OF CLAY PANELS



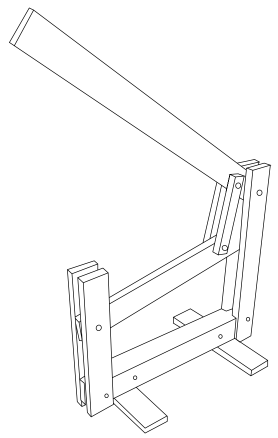
1. Crush clay



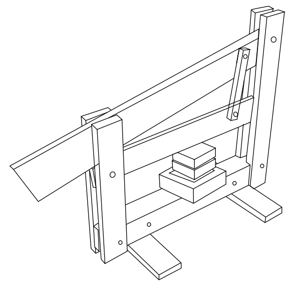
2. Mix clay, sand, soil and water



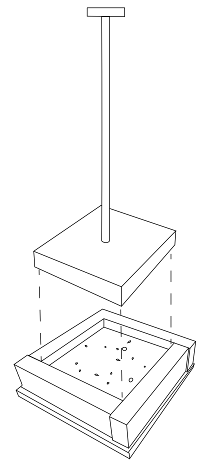
3. Put the mixed mass in mould



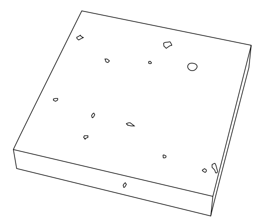
4. Put pressure on mould



5. Put pressure on mould



6. Put additional pressure on mould



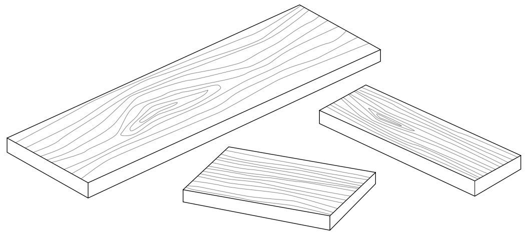
7. Remove mould and leave to dry completely

1.

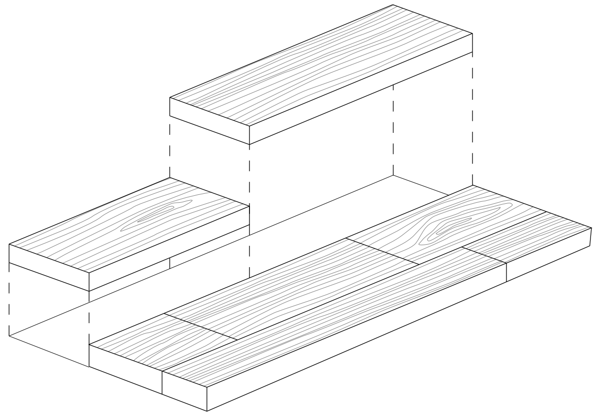
2.

1. Leftover pieces of wood.
2. Leftover pieces of stone.

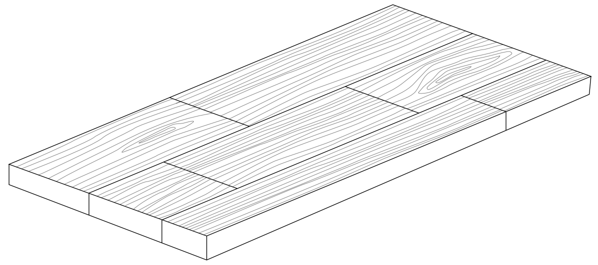
METHOD OF ASSEMBLING



1. Select suitable pieces

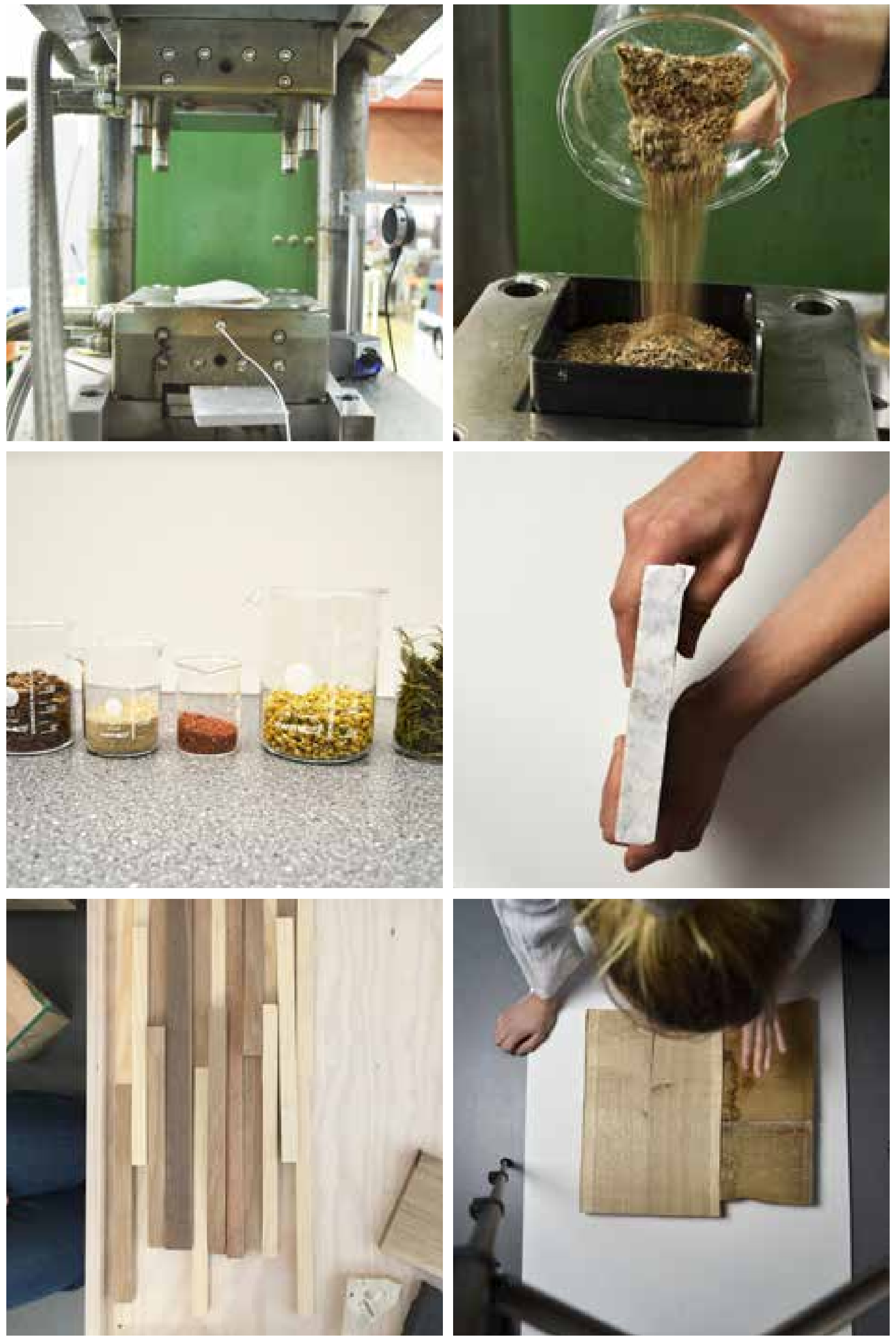


2. Assemble pieces into pattern



3. Leave to dry

Process of producing fibre boards.



Process in Laboratory of Materials and Manufacture & of leftover pieces of wood and stone.

Process of producing clay panels.

Clay plaster.

EVALUATION CRITERIA

The aim of the material investigations has been to explore their architectural promises. The materials investigated are evaluated according to the list of criteria described below. The evaluations that are made are not based on physical tests but on estimations based on theory and references. They are evaluated according to their present state, with the current surface treatment in mind if assumed needed even if industrially produced. However, if potential is a part of the evaluation criteria, the material is evaluated to its estimated prosperity. The first six criterias are connected to the perception of the material, which has been a tool to create different narratives in the design proposal.

Tactile experience
How the material feels when touched, rough or smooth, soft or hard.

Visual experience
How the material looks when viewed upon, rough or smooth, homogeneous or inhomogeneous. Homogeneous refers to a material's visual unity on a distance, and inhomogeneity meaning the opposite, where each part of the material is one of a kind. For example, different sized particles can create an inhomogeneity, hence a uniqueness to its whole.

Recognizability
How easy it is to recognize the source and origin of the material.

Reflectance of light
How much light the material reflects.

Moisture regulating
Refers to the materials ability to absorb and release moisture. So called hygroscopic materials can stabilize and regulate the moisture content of the indoor air, improving indoor health (Berge, 2009).

Temperature regulating
Refers to materials that regulate and stabilize indoor air temperature through high thermal storage capacity and high thermal diffusivity (Berge, 2009). The estimations are made with the knowledge of different materials thermal properties, see figure 11 on page 42, and thereafter compared by potential weight.

Free from VOC
Materials that emit no VOC to the indoor air. These are particles that can lead to health problems like allergies, skin and membrane irritations, headache and insomnia. Certain VOC, like formaldehyde, is suspected to be cancerogenic (Que, Wang, Li & Furuno, 2013). The Evaluation of VOC is made in comparison to common building materials and therefore the content is considered to be negligible even though it potentially could contain a very small amount.

Circularity
Means the material can be part of a biological cycle. After many uses it can go safely back into the soil, and thus be a nutrient forever.

Energy efficient production
An estimation of how much energy is required to produce the material, referring to mainly drying, heating and pressing processes.

Availability of resource
An estimation of, in what extent, the resource is available in a Swedish context.

Industrialisation potential
An estimation of how satisfyingly the material could be produced industrially in an economically gaining way.

Affordable
An estimation of how affordable the material could be to produce. Is the resource already put into good use, can it be freely collected in the nature or is it leftovers that industries pay to get rid of?

Local
How locally the resource is available.

Building tradition
The connection the material has to building traditions in history.

Potential durability
Expected potential durability with the correct industrialized methods. Durability can for example refer to putting a nail in it and wear over time. This is analyzed a bit differently depending on the materials characteristics. For example, stone is durable because it is hard, easy to maintain and long lasting.

Potential cleanability
Expected potential cleanability including possible natural surface treatment (sanding, oil and/or wax coating).

Note: With conventional varnishes and seals durability and cleanability can be improved. However, this means the natural climatic and healthy qualities of the materials are weakened.

Painted gypsum board.

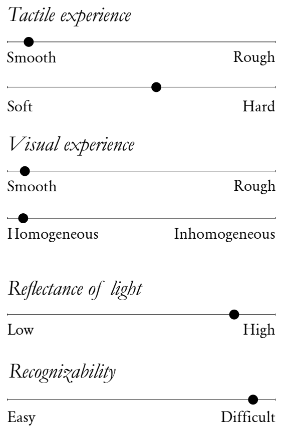
Plastic floor.

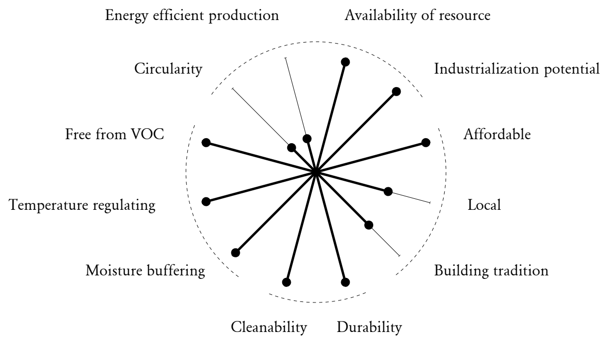
OSB.

COMMON BUILDING MATERIALS

To compare the material samples created in this thesis to a few materials commonly used as surfaces in the building industry today, evaluation has been made on three conventional surface materials; gypsum board, plastic floor and oriented strand board (OSB).

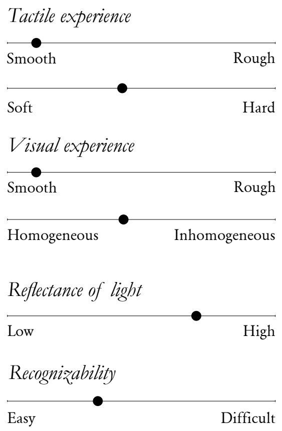
Gypsum board

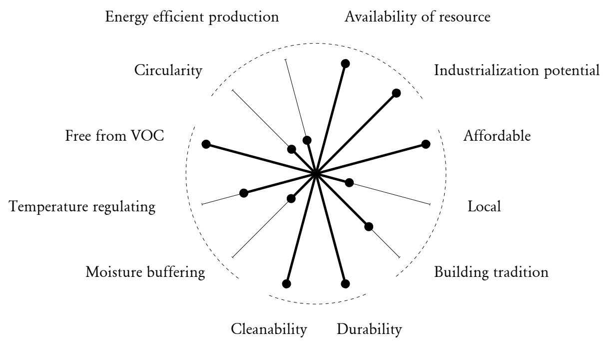




(Berge, 2009 & Nationalencyklopedin, 2019)

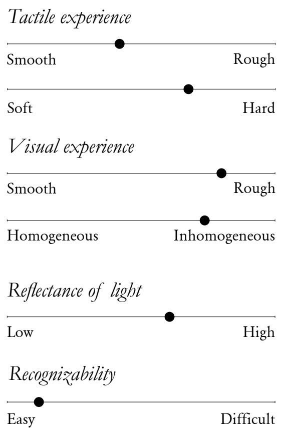
Plastic floor

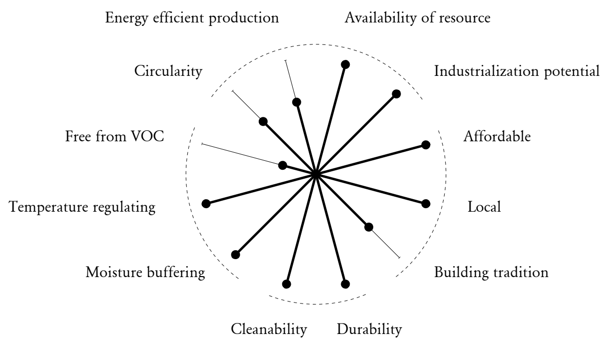




(Berge, 2009)

Oriented strand board (OSB)





(Berge, 2009)

1.1 Barley & potato starch

1.01 Barley, reed fuzz & potato starch

1.2 Fine wheat bran & corn starch

1.02 Wheat bran & corn starch

1.03 Wheat bran, dried roses & cellulose adhesive

1.3 Saw dust, wheat bran & potato starch

1.4 Saw dust, wheat bran, potato starch & white paint

1.5 Saw dust, wheat bran & potato starch

1.6 Pressed oats, fine hemp fibres, wood chips & potato starch

1.7 Flaxseed oil mass, reed fibres & potato starch

1.8 Flaxseed oil mass & agar agar

1.9 Rapeseed oil mass, saw shavings & potato starch

CMC = carboxymethyl cellulose

1.10 Rapeseed oil mass, fine hemp fibres & potato starch

1.11 Beetroot peels, fine hemp fibres & CMC

1.12 Carrot peels (pulverized), fine hemp fibres & CMC

1.04 Potato peels & potato starch

1.05 Carrot haulm & CMC

2.1 Saw dust, red cabbage, lemon juice & potato starch

2.01 Saw dust, red cabbage & potato starch

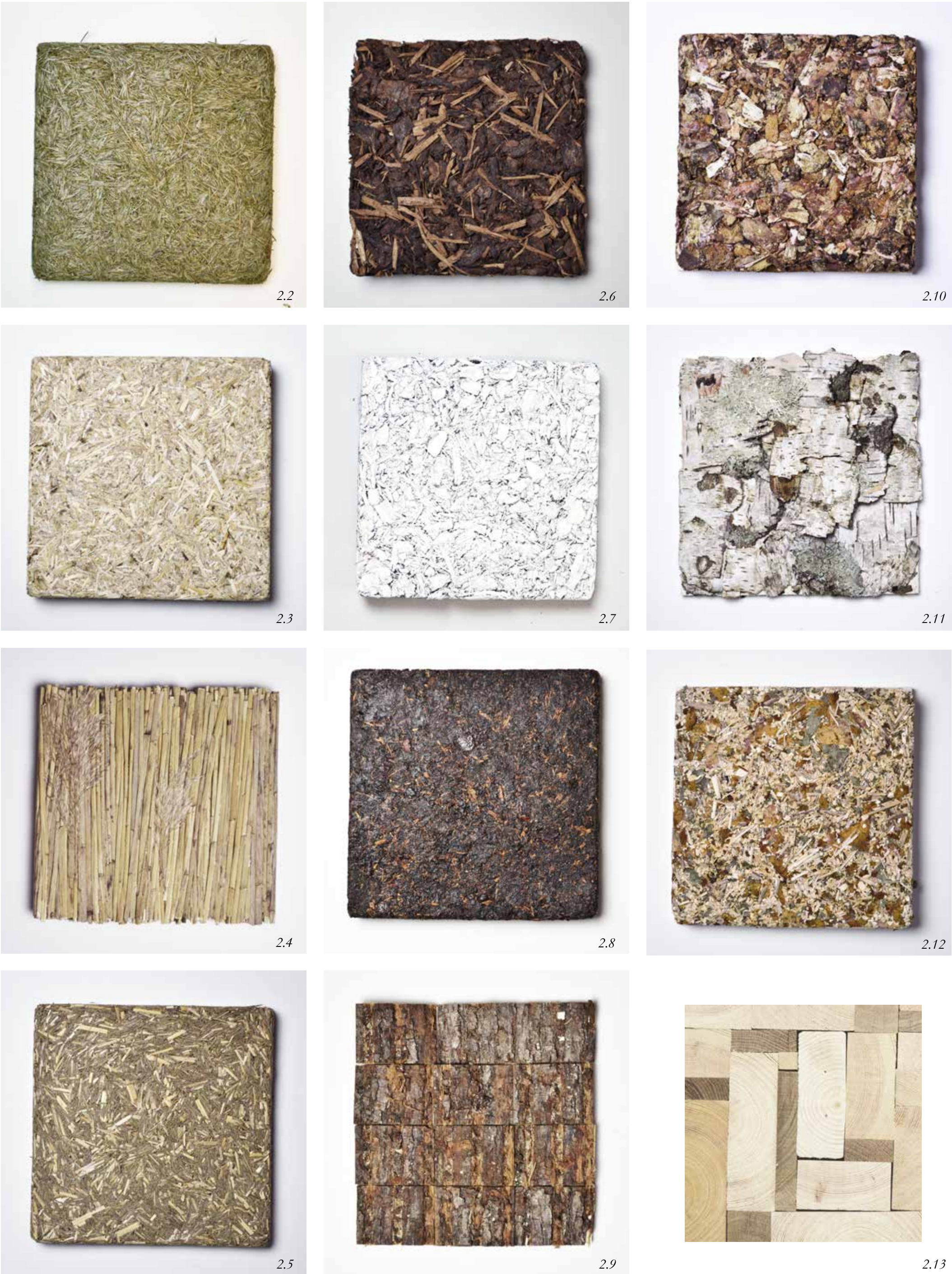
2.02 Saw dust, red cabbage, bicarbonate & Potato starch

2.03 Saw dust, barley & potato starch

2.04 Saw dust, saw shavings, barley & potato starch

2.05 Saw dust, saw shavings, parsnip peels & potato starch

2.06 Wheat bran, fine hemp fibres & potato starch



2.2 Fir needles & agar agar

2.3 Small fibres of reed & Potato starch

2.4 Reed & CMC

2.5 Fir needles, reed & potato starch

2.6 Bark chips from fir & cellulose adhesive

2.7 Bark chips from fir, CMC & white paint

2.8 Small fibres of bark from fir & potato starch

2.9 Large pieces of bark from fir

2.10 Bark chips from birch & CMC

2.11 Large pieces of bark from birch & cellulose adhesive

2.12 Dried roses, reed fibres, sawdust & CMC

2.13 Leftover pieces of wood

2.14 Leftover pieces of wood

2.07 Wooden chips & potato starch

2.08 Hemp fibres & potato starch

3.1 Clay & sand

3.2 Clay, sand & red pigment

3.3 Clay, sand & white pigment

3.4 Clay, sand, brown pigment & crushed terracotta

3.5 Clay, sand, black pigment & fine hemp fibres

3.6 Leftover pieces of stone & lime mortar

3.7 Leftover pieces of stone & lime mortar

4.5 Camomile flowers & CMC

4.12 Potato peels, red pigment & CMC

MATERIAL SAMPLE 1.1

Content: 140 g barley from beer production + 130 g potato starch + 2 dl water
Method: compressed 45 minutes at 110°

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

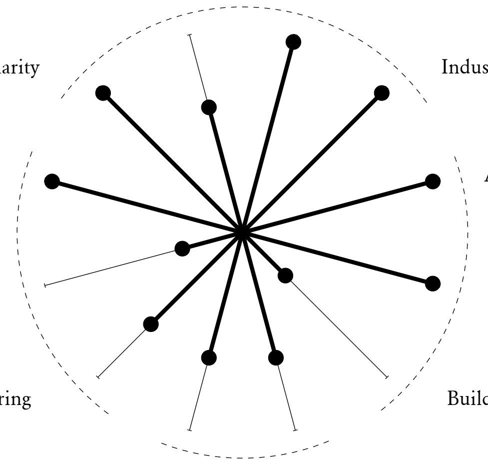
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ☐ Ceiling

Comments

Barley from beer production contains about 75 % water, making the drying process quite energy consuming.

MATERIAL SAMPLE 1.2

Content: 200 g wheat bran + 130 g corn starch + 2 dl water
Method: compressed 50 minutes at 110°
Coating: flaxseed oil + flaxseed wax

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

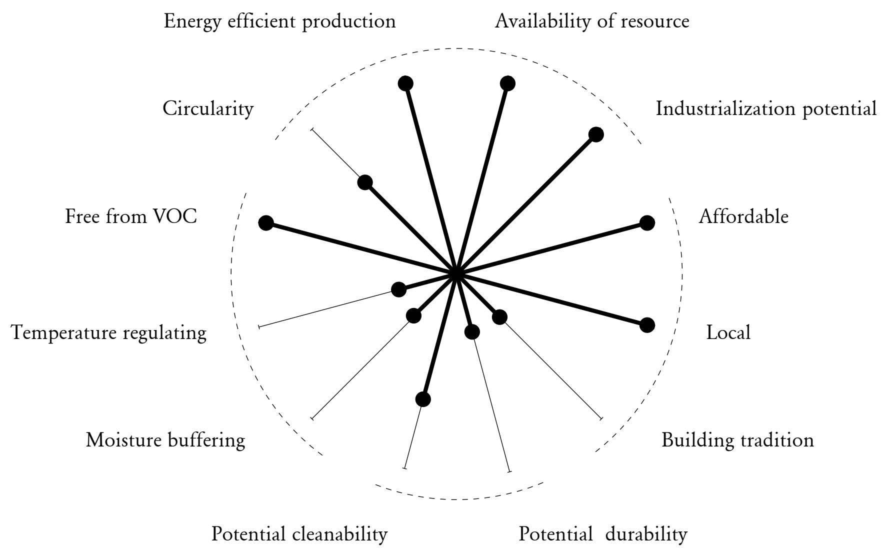
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ■ Ceiling

Comments

Due to the need of coating, probably even if industrially produced, values of moisture buffering, thermal regulation and circularity are lowered.

MATERIAL SAMPLE 1.3

Content: 160 g wheat bran + 80 g sawdust + 130 g potato starch + 2 dl water
Method: compressed 45 minutes at 110° with circle patterned wood mould
Coating: flaxseed wax

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

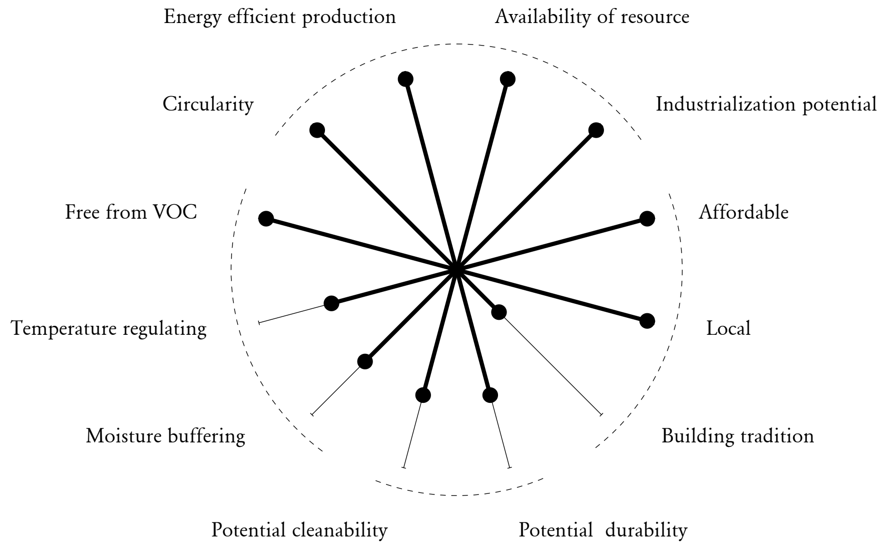
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ☐ Ceiling

MATERIAL SAMPLE 1.4

Content: 160 g wheat bran + 80 g sawdust + 130 g potato starch + 2 dl water
Method: compressed 45 minutes at 110° with circle patterned wood mould
Coating: Flaxseed wax with white pigment

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

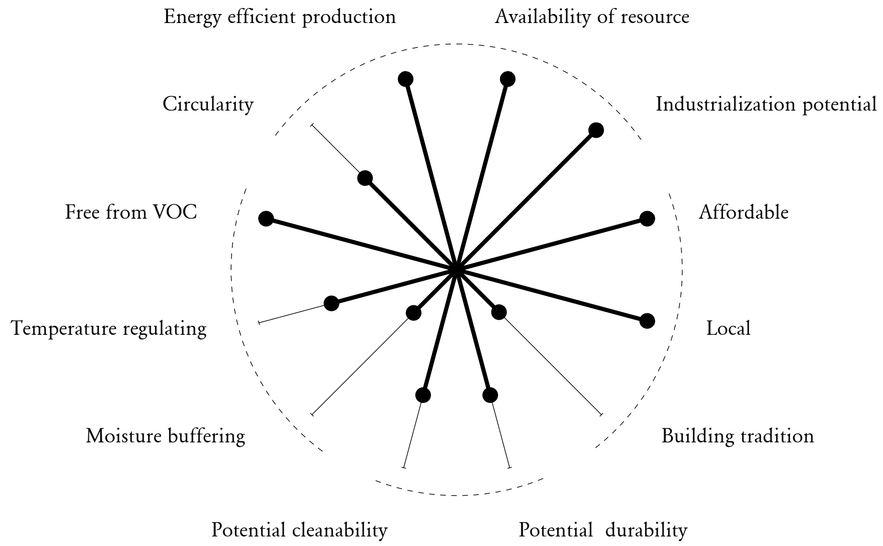
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ☐ Ceiling

Comments

Depending on what paint is used, VOC can differ.

MATERIAL SAMPLE 1.5

Content: 160 g wheat bran + 80 g sawdust + 130 g potato starch + 2 dl water
Method: compressed 45 minutes at 110° with stripe patterned wood mould
Coating: flaxseed oil

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

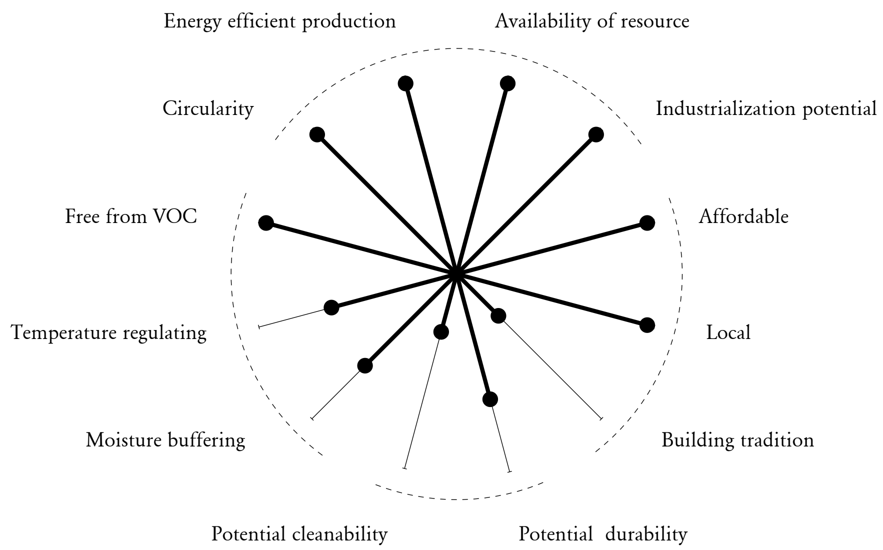
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ☐ Ceiling

MATERIAL SAMPLE 1.6

Content: 200 g pressed oats + 20 g hemp fibres + 20 g wood chips + 100 g potato starch + 1.5 dl water
Method: compressed 45 minutes at 110°

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

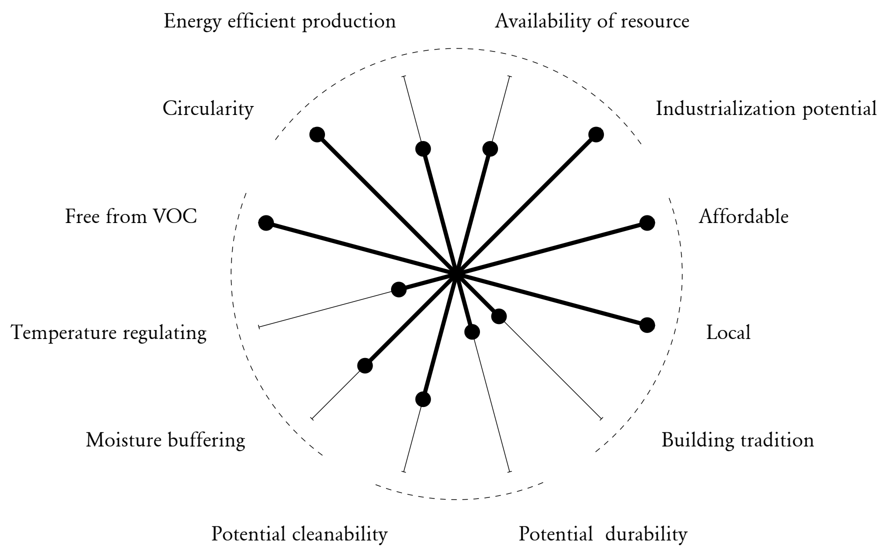
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ■ Ceiling

Comments

Pressed oats from oat drink production contains about 65 % water, making the drying process quite energy consuming.

MATERIAL SAMPLE 1.7

Content: 500 g flaxseed oil mass + 0.5 dl water & agar agar (1:15)
Method: compressed 45 minutes at 110°
Coating: flaxseed oil

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

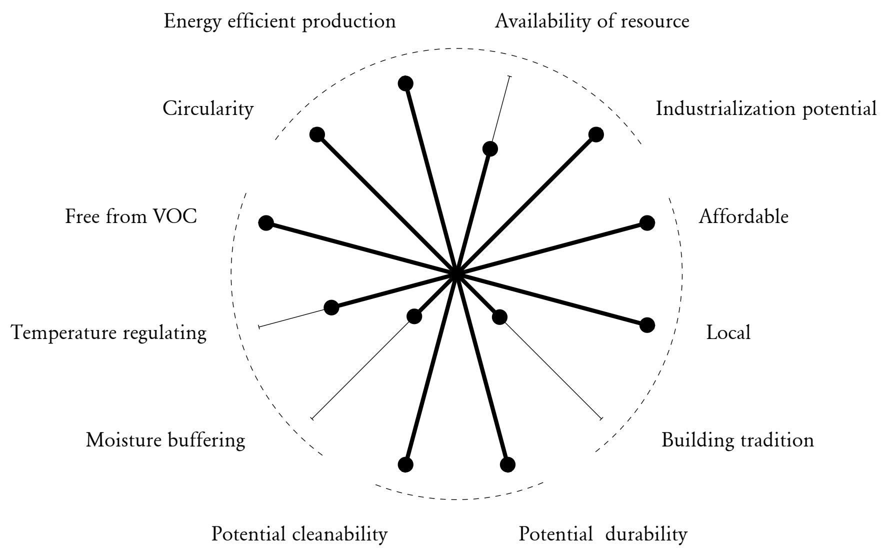
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



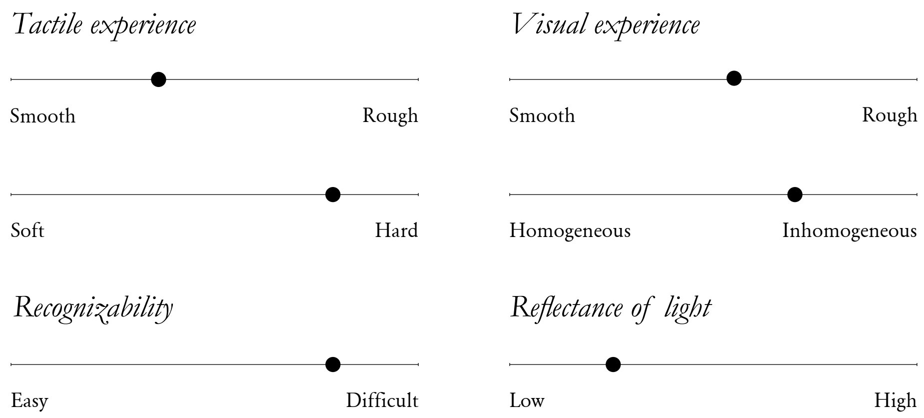
Suitable surfaces

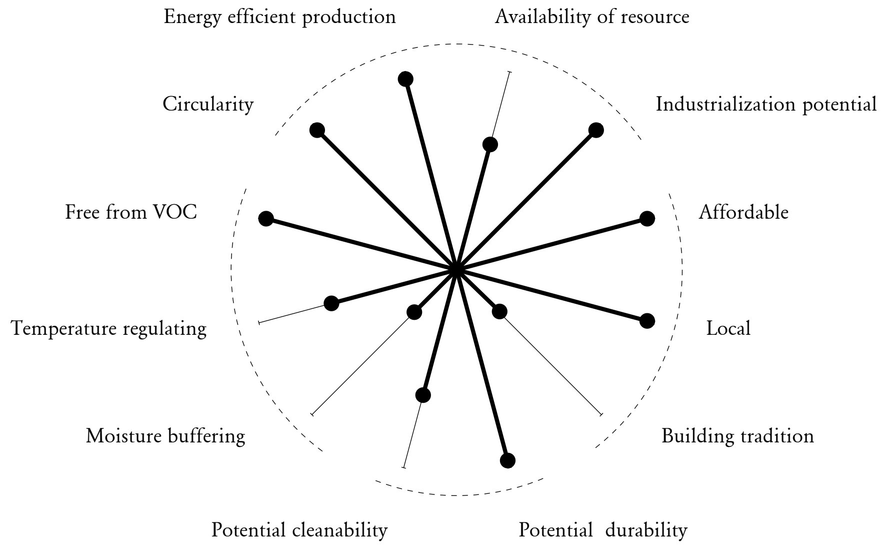
■ Floor ■ Wall □ Ceiling

Comments

Due to its high oil content, moisture buffering is presumably low. With an industrialized production it could have the potential to become a durable water repellent material, almost like a tile.

MATERIAL SAMPLE 1.8





Suitable surfaces

☐ Floor ■ Wall ☐ Ceiling

Comments

Due to its high oil content, moisture buffering is presumably low. With an industrialized production it could have the potential to become a durable water repellent material, almost like tile.

MATERIAL SAMPLE 1.9

Content: 300 g rapeseed oil mass + 15 g wood shavings + 65 g potato starch + 1 dl water
Method: compressed 45 minutes at 110°
Coating: flaxseed oil

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

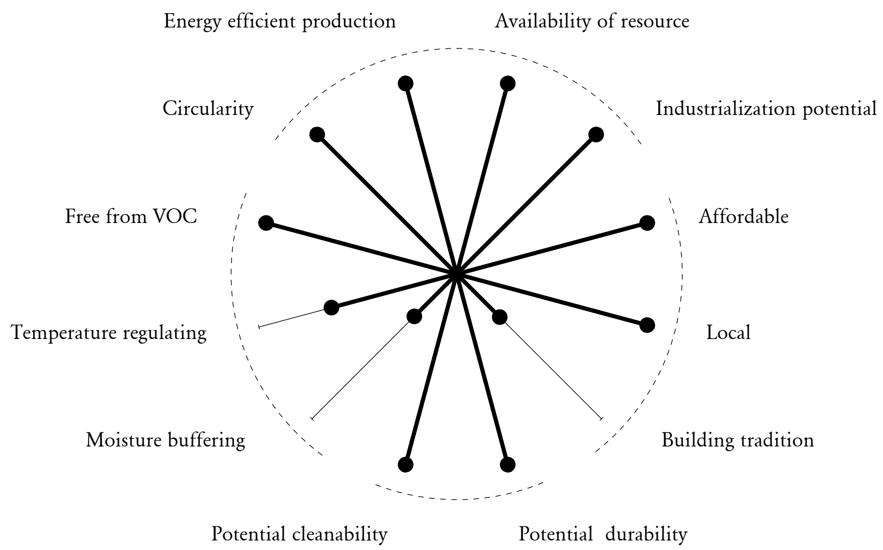
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



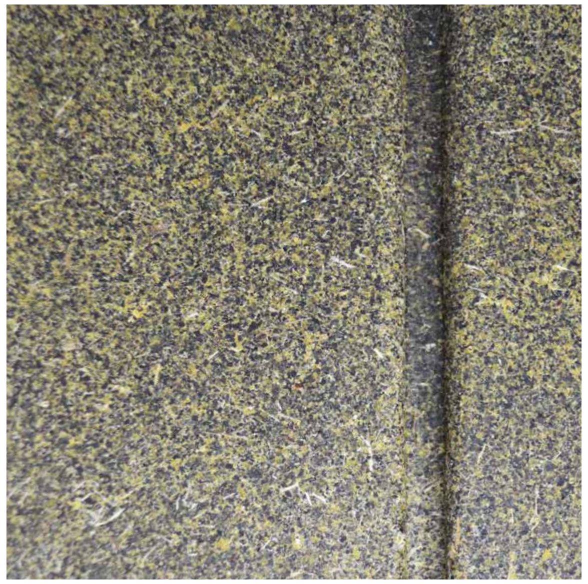
Suitable surfaces

■ Floor ■ Wall □ Ceiling

Comments

Due to its high oil content moisture buffering is presumably low. With an industrialized production it could have the potential to become a durable water repellent material, almost like a tile.



MATERIAL SAMPLE 1.10

Content: 320 g rapeseed oil mass + 20 g hemp fibres + 65 g potato starch + 1 dl water
Method: compressed 45 minutes at 110°

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

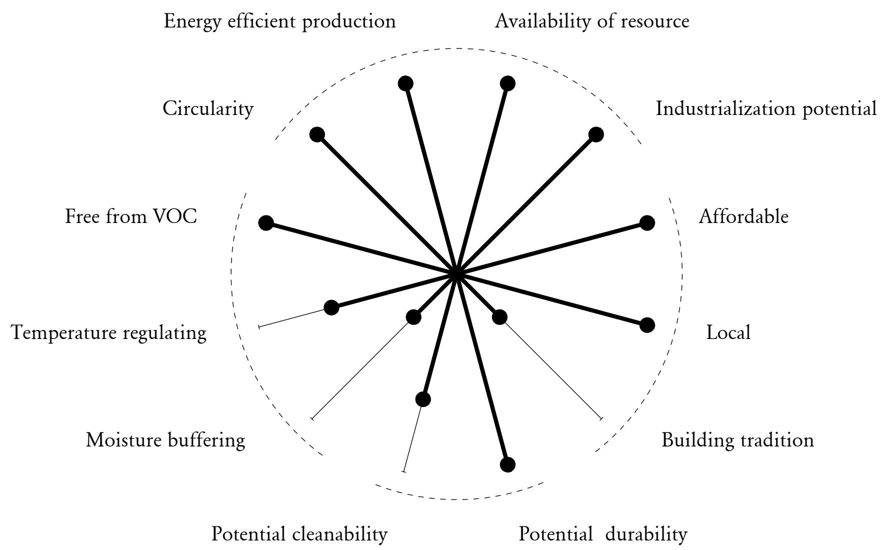
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

- [ ] Floor
- [x] Wall
- [ ] Ceiling

Comments

Due to its high oil content moisture buffering is presumably low. With an industrialized production it could have the potential to become a durable water repellent material, almost like a tile.

MATERIAL SAMPLE 1.11

Content: 110 g beetroot peels + 20 g hemp fibres + 0.5 dl water & carboxymethyl cellulose (1:30)
Method: compressed 60 minutes at 90° + dried 60 minutes at 75°

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

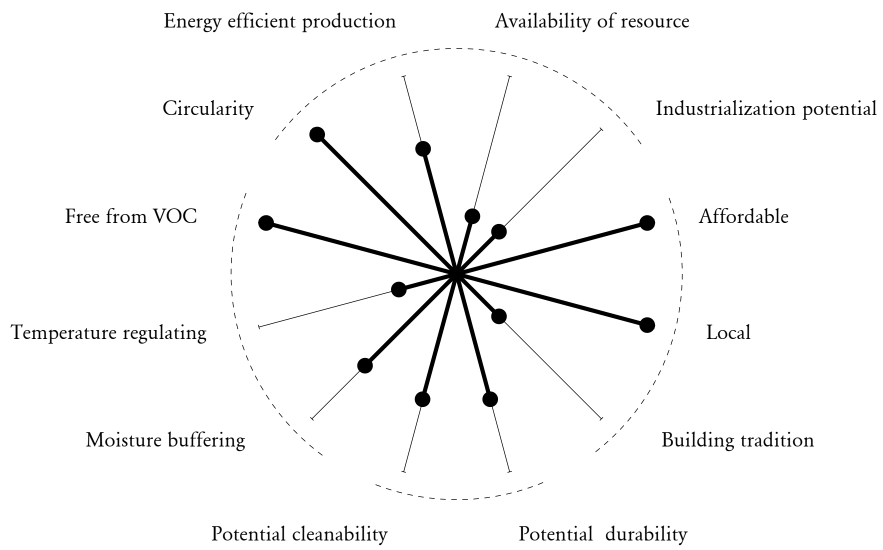
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ■ Ceiling

Comments

To improve the industrialization, potential peels from beetroot boiling industries are to prefer over peels from raw beetroots.

MATERIAL SAMPLE 1.12

Content: 200 g carrot peels + 10 g hemp fibres + 1 dl water & carboxymethyl cellulose (1:30)
Method: compressed 60 minutes at 90˚

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

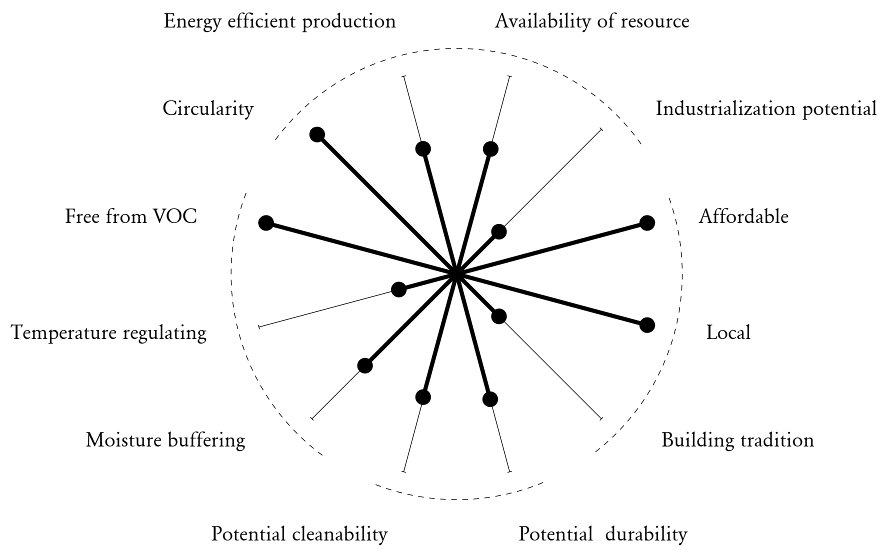
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

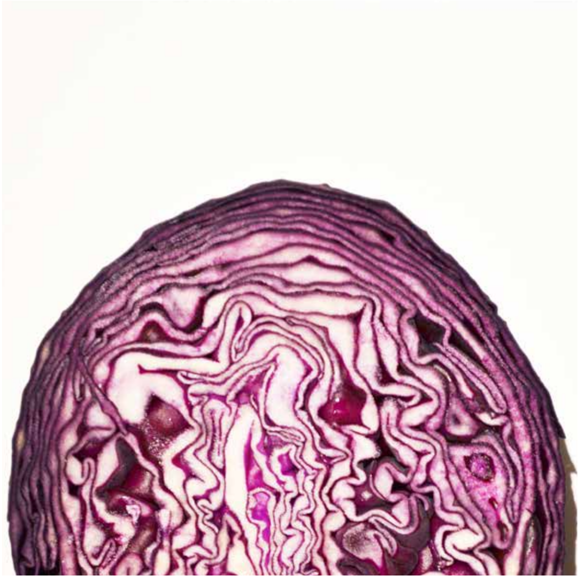
Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ■ Ceiling



MATERIAL SAMPLE 2.1

Content: 150 g sawdust + 100 g potato starch + 1.5 water (boiled with red cabbage and lemon juice)
Method: compressed 45 minutes at 110°

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

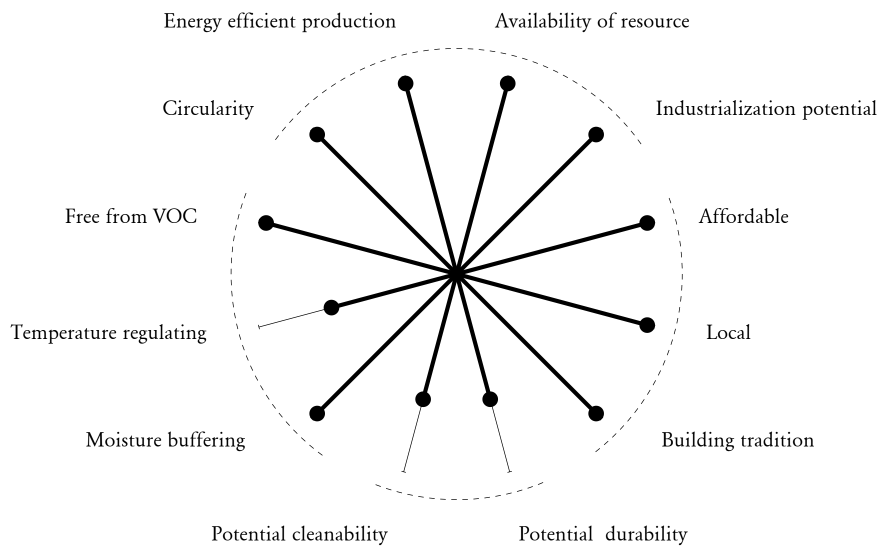
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ■ Ceiling

Comments

The durability of the colour is low since natural dying is affected by sunlight. Recognizability of the colouring, red cabbage, is regarded difficult.

MATERIAL SAMPLE 2.2

Content: 190 g conifer needles + 1 dl water & agar agar (1:30)
Method: compressed 45 minutes at 110°
Coating: flaxseed wax

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

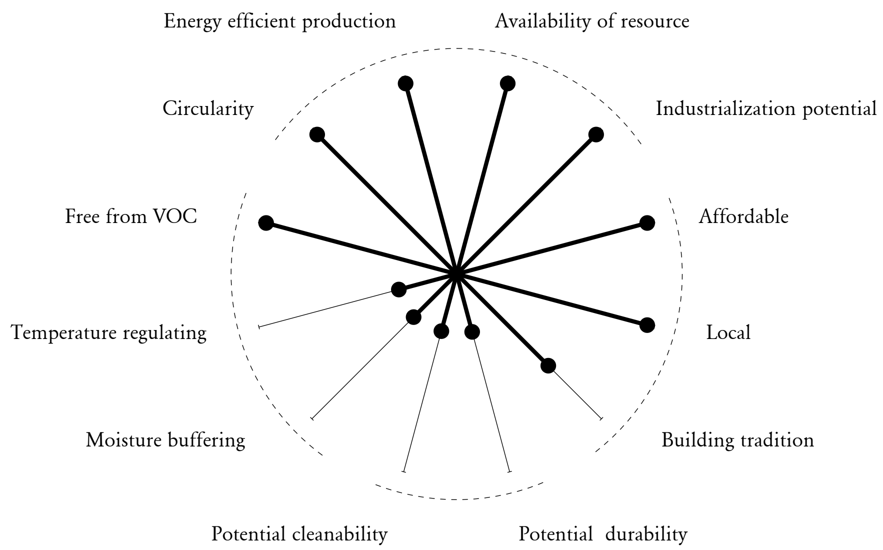
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ■ Ceiling

Comments

Due to its texture and high content of air it possibly performs well as an acoustic material, absorbing sound.

MATERIAL SAMPLE 2.3

Content: 160 g reed + 100 g potato starch + 1.5 dl water
Method: compressed 45 minutes at 110°

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

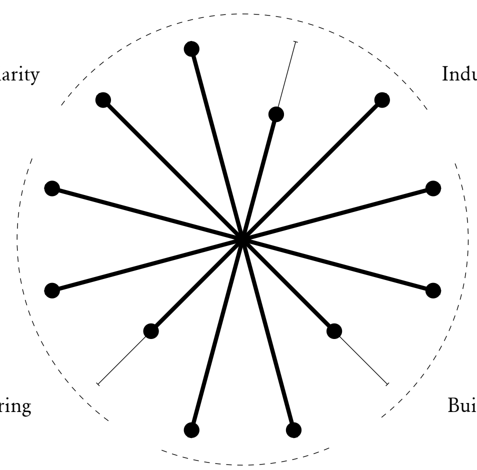
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

■ Floor ■ Wall ■ Ceiling

MATERIAL SAMPLE 2.4

Content: 90 g reed + 1 dl water & carboxymethyl cellulose (1:30)
Method: compressed 30 minutes at 110°

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

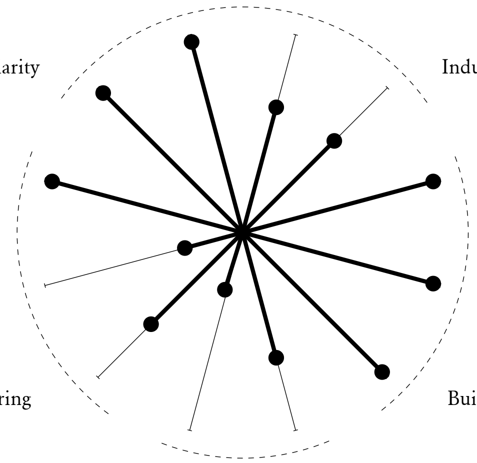
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ☐ Ceiling

Comments

If produced thicker its thermal regulating properties would increase.

MATERIAL SAMPLE 2.5

Content: 70 g reed + 100 g conifer needles + 100 g potato starch + 1.5 dl water
Method: compressed 45 minutes at 110°

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

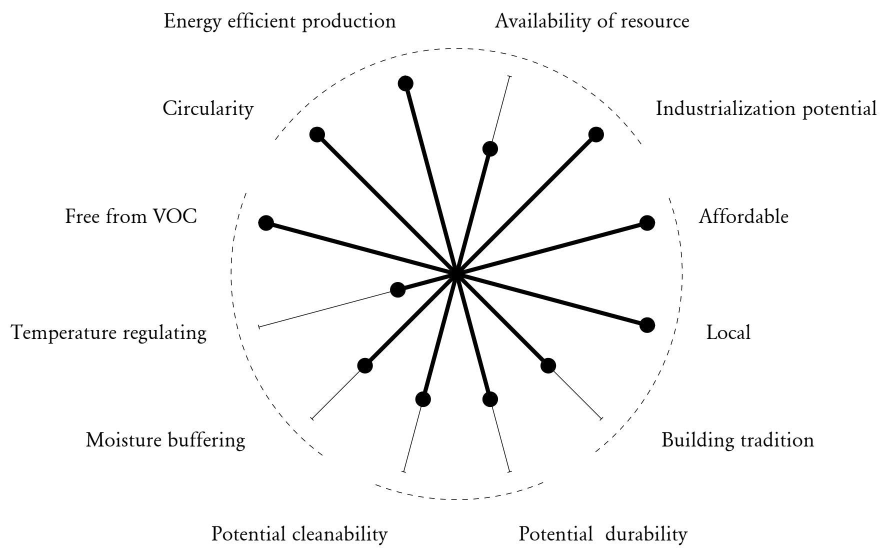
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ■ Ceiling

MATERIAL SAMPLE 2.6

Content: 230 g bark + 1.5 dl water & cellulose adhesive (1:40)
Method: compressed in room temperature

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

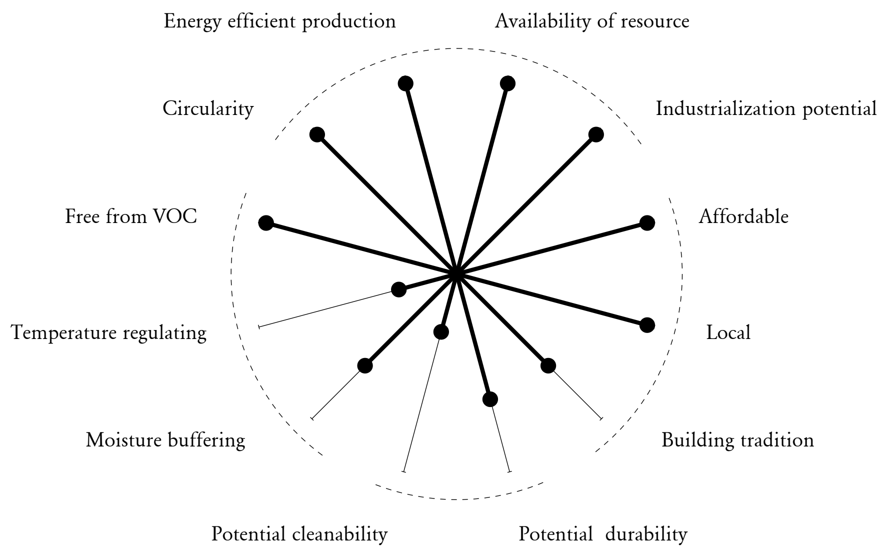
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ■ Ceiling

MATERIAL SAMPLE 2.7

Content: 290 g bark + 1.5 dl water & carboxymethyl cellulose (1:30)
Method: compressed 50 minutes at 110°
Coating: White paint

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

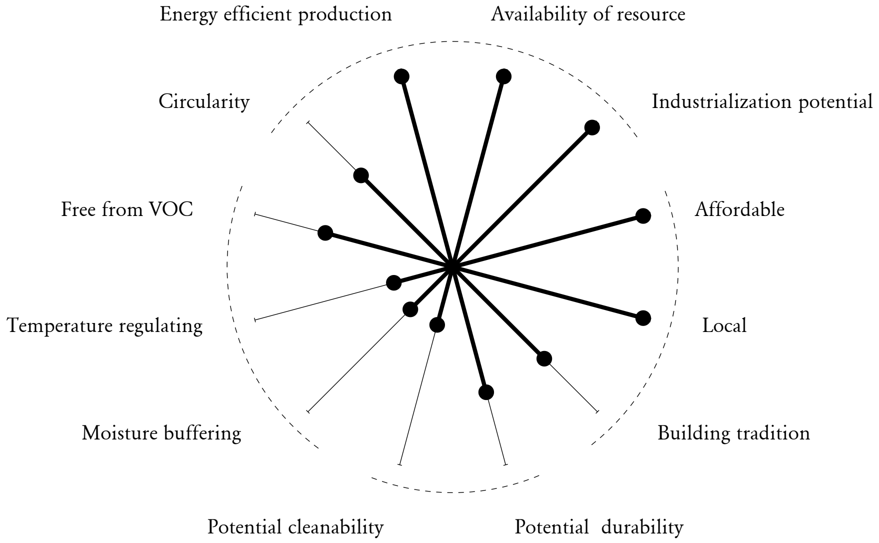
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ■ Ceiling

Comments

Depending on what paint is used, VOC and circularity will differ.

MATERIAL SAMPLE 2.8

Content: 380 g bark + 130 g potato starch + 2 dl water
Method: compressed 45 minutes at 110°
Coating: flaxseed oil + flaxseed wax

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

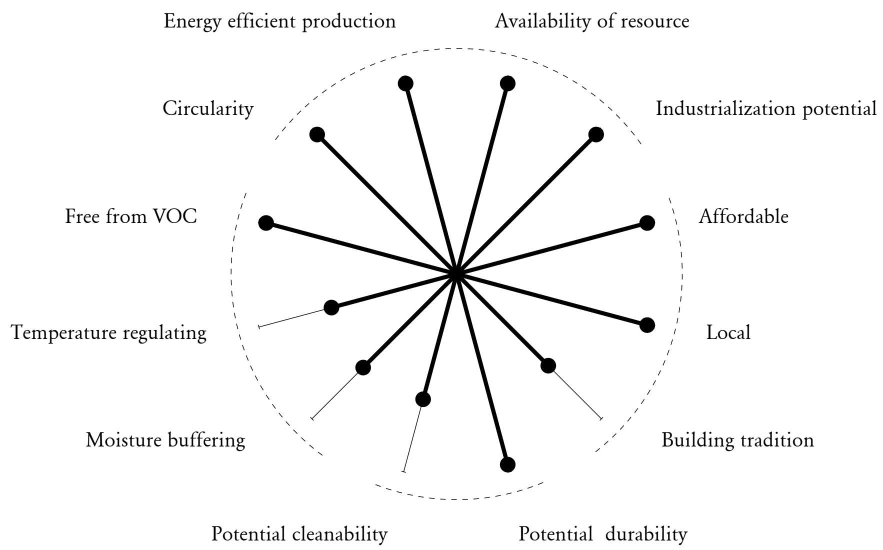
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ■ Ceiling

MATERIAL SAMPLE 2.9

Content: bark
Method: assembled

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

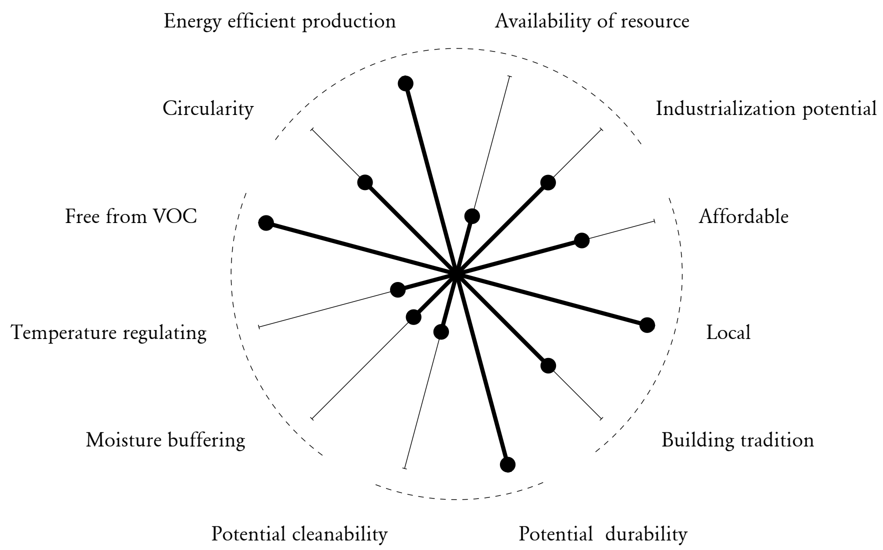
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ☐ Ceiling

Comments

Depending on what glue is used, VOC and circularity will differ.

MATERIAL SAMPLE 2.10

Content: birch bark + 1 dl water & carboxymethyl cellulose (1:30)
Method: compressed 45 minutes at 110°
Coating: flaxseed wax

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

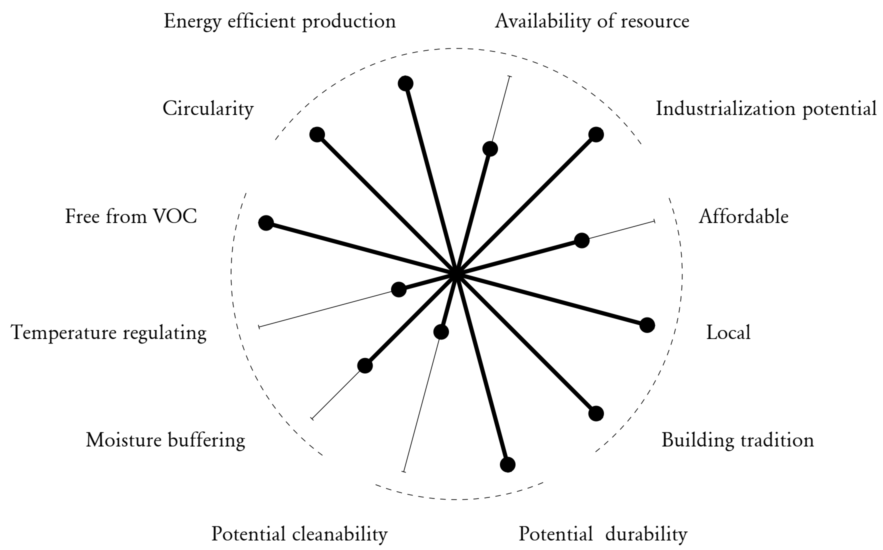
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ■ Ceiling

MATERIAL SAMPLE 2.11

Content: birch bark + 1 dl water & carboxymethyl cellulose (1:30)
Method: compressed 45 minutes at 75°

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

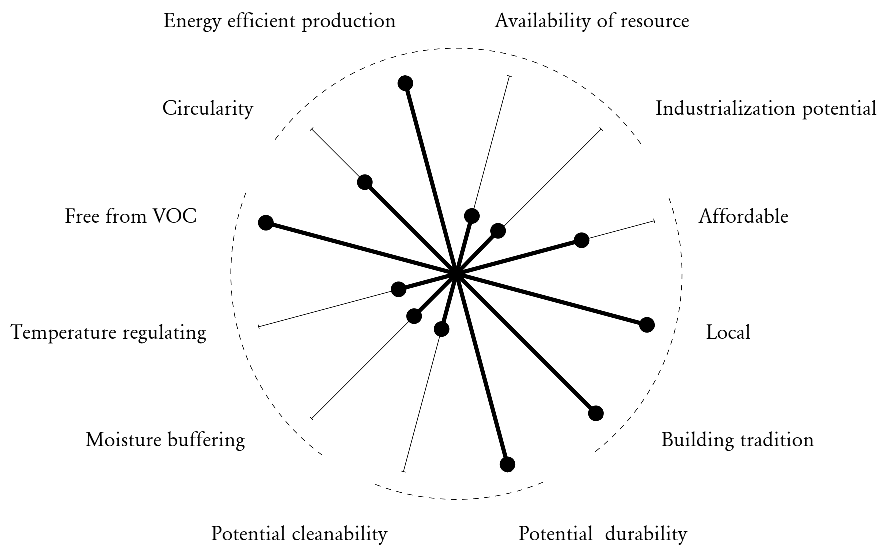
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ☐ Ceiling

Comments

Birch bark is very resistant to moisture, making it one of the most long-lasting building materials.

MATERIAL SAMPLE 2.12

Content: reed + sawdust + dried roses + carboxymethyl cellulose
Method: compressed 30 minutes at 75°
Coating: flaxseed wax

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

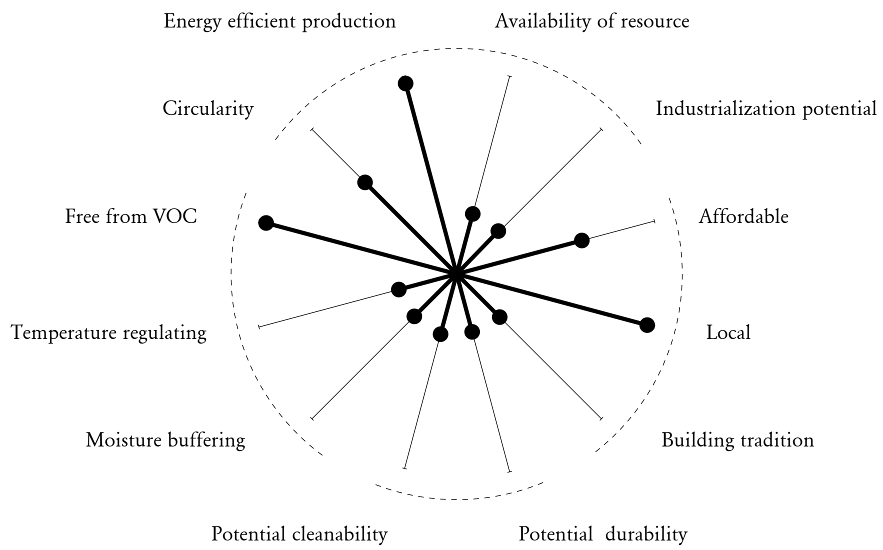
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ■ Ceiling

MATERIAL SAMPLE 2.13

Content: leftover pieces of wood
Method: assembled

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

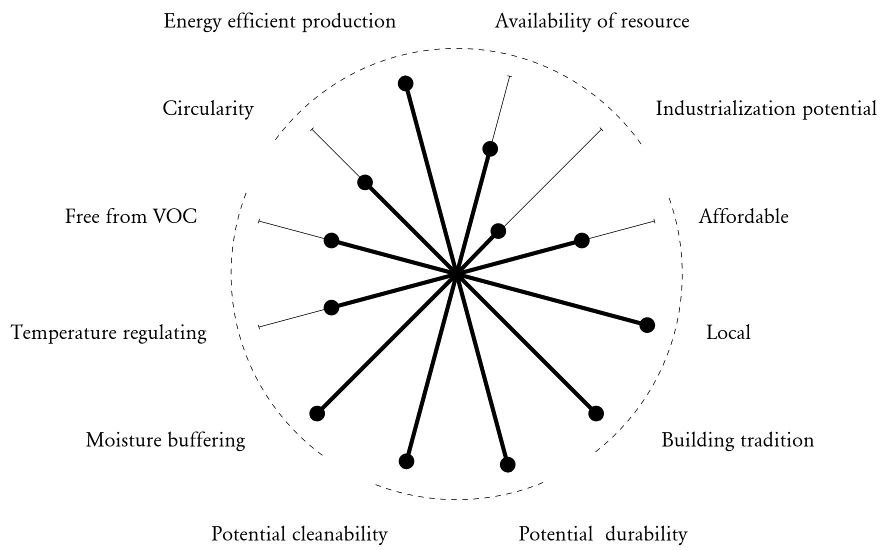
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

■ Floor ☐ Wall ☐ Ceiling

Comments

Depending on what glue is used, VOC and circularity will differ.

MATERIAL SAMPLE 2.14

Content: leftover pieces of wood
Method: assembled

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

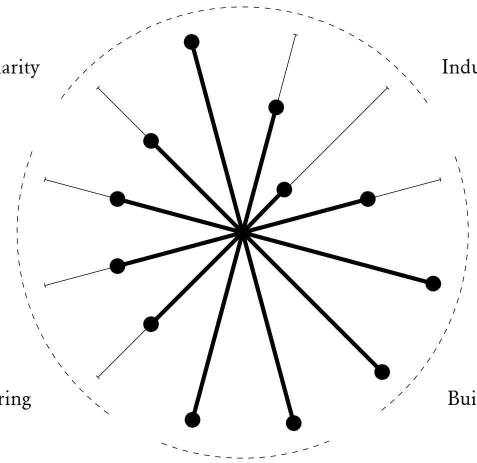
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

- [x] Floor
- [ ] Wall
- [ ] Ceiling

Comments

Depending on what glue is used, VOC and circularity will differ.

MATERIAL SAMPLE 3.1

Content: 1.5 part of clay + 2 parts of sand + 1 part of soil + water
Method: compressed
Coating: flaxseed oil

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

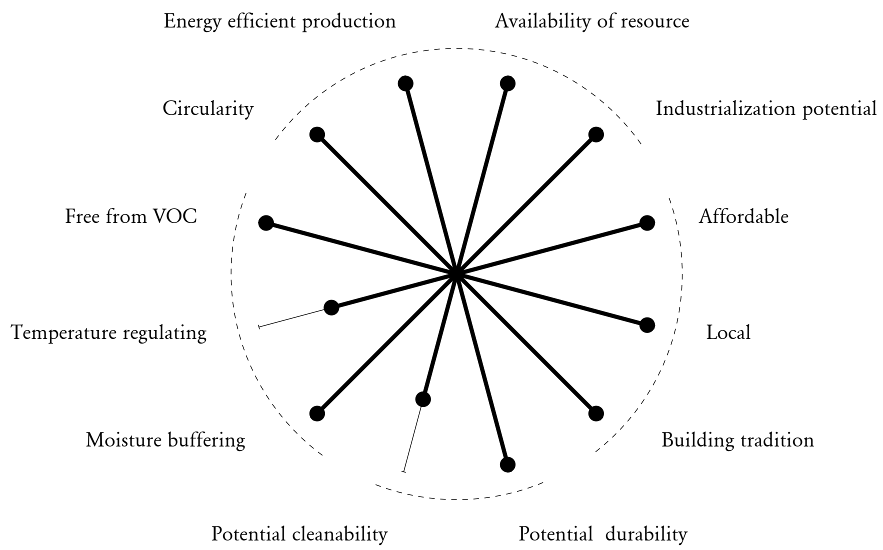
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

■ Floor ■ Wall ■ Ceiling

Comments

Depending on the origin of the clay, VOC will differ.

MATERIAL SAMPLE 3.2

Content: 1.5 part of clay + 2 parts of sand + 1 part of soil + water + red earth pigment
Method: compressed
Coating: flaxseed oil

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

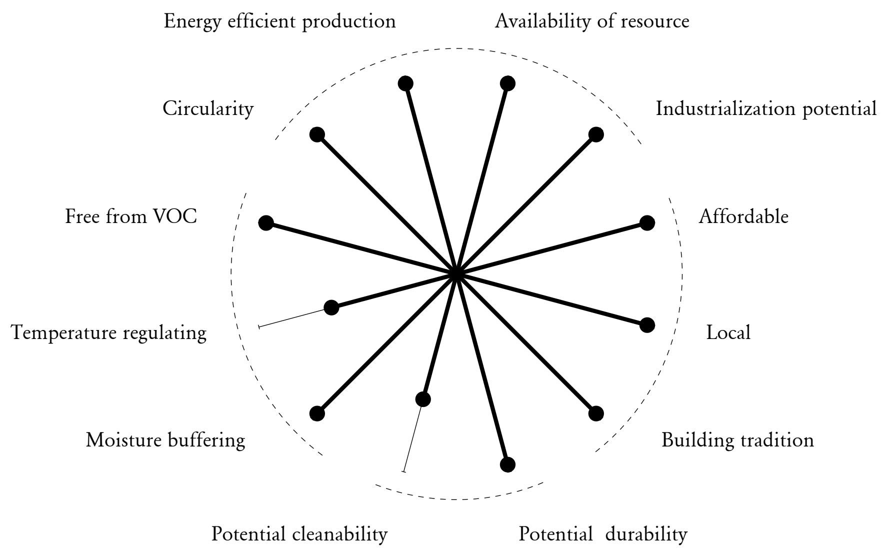
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

☐ Floor ■ Wall ■ Ceiling

MATERIAL SAMPLE 3.3

Content: 1.5 part clay + 1 part sand + 1 part soil + hemp fibres + water
Method: compressed
Coating: clay plaster (1 part clay + 1 part sand + water + titanium dioxide (white pigment))

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

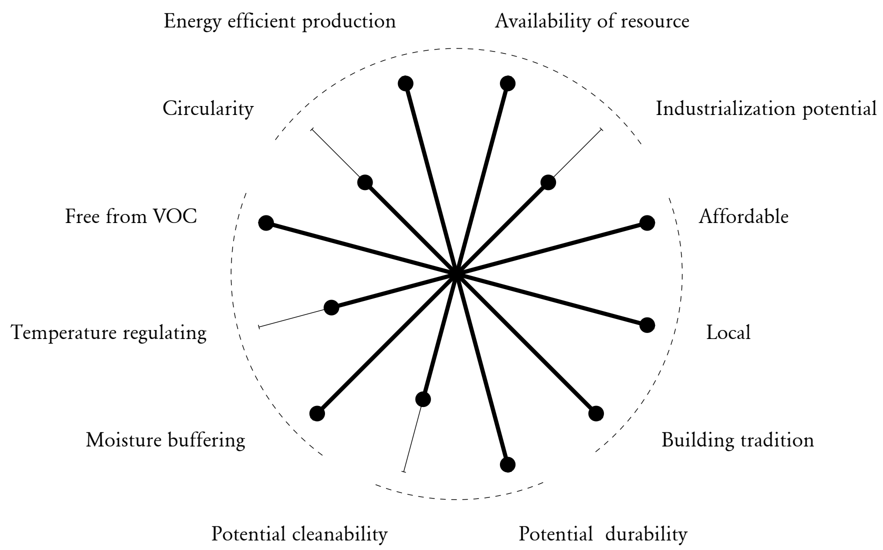
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High



Suitable surfaces

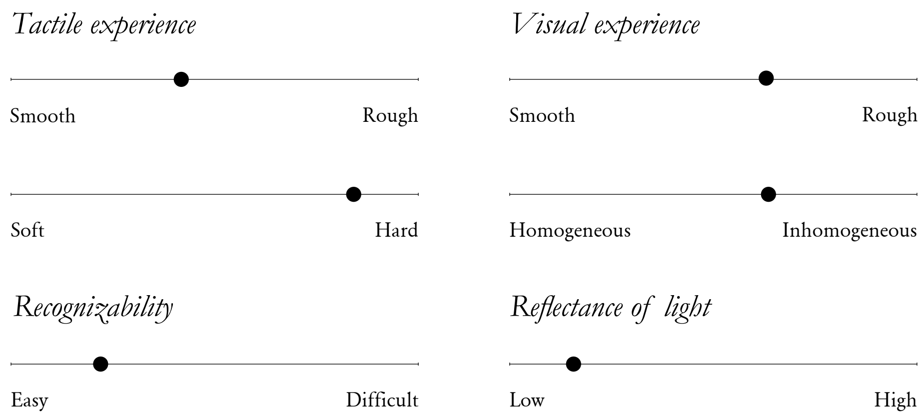
☐ Floor ■ Wall ■ Ceiling

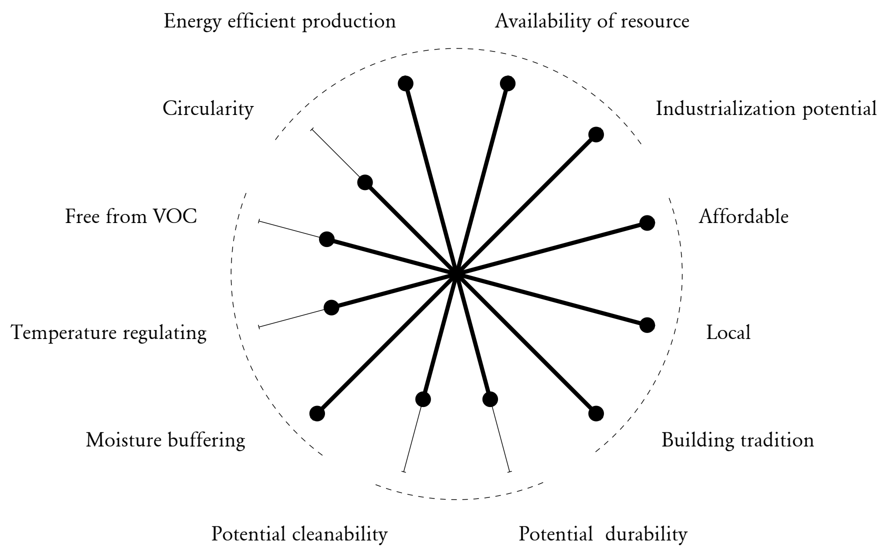
Comments

Due to its layer of plaster, a wall can become seamless, but the industrialization potential and circularity will not be as high.

MATERIAL SAMPLE 3.4

Content: 1.5 part clay + 1 part sand + 1 part soil + water + brown earth pigment + crushed terracotta
Method: compressed





Suitable surfaces

■ Floor ■ Wall □ Ceiling

Comments

Depending on the origin of the clay and terracotta, VOC will differ.

MATERIAL SAMPLE 3.5

Content: 1.5 part clay + 1 part sand + 1 part soil + hemp fibres + water + black pigment (carbon black)
Method: compressed

Tactile experience

Smooth — Rough

Soft — Hard

Recognizability

Easy — Difficult

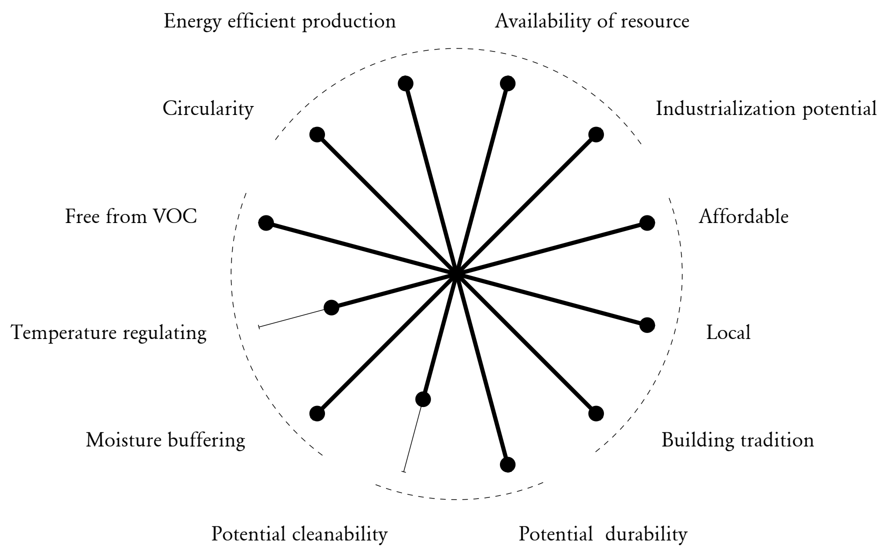
Visual experience

Smooth — Rough

Homogeneous — Inhomogeneous

Reflectance of light

Low — High



Suitable surfaces

■ Floor ■ Wall ■ Ceiling

MATERIAL SAMPLE 3.6

Content: Leftover pieces of stone
Method: assembled

Tactile experience

Smooth — Rough

Soft — Hard

Visual experience

Smooth — Rough

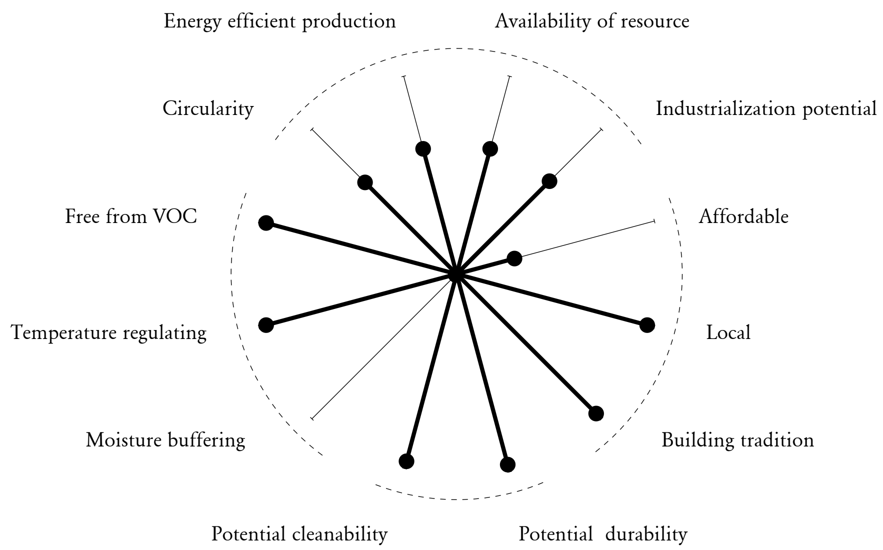
Homogeneous — Inhomogeneous

Recognizability

Easy — Difficult

Reflectance of light

Low — High

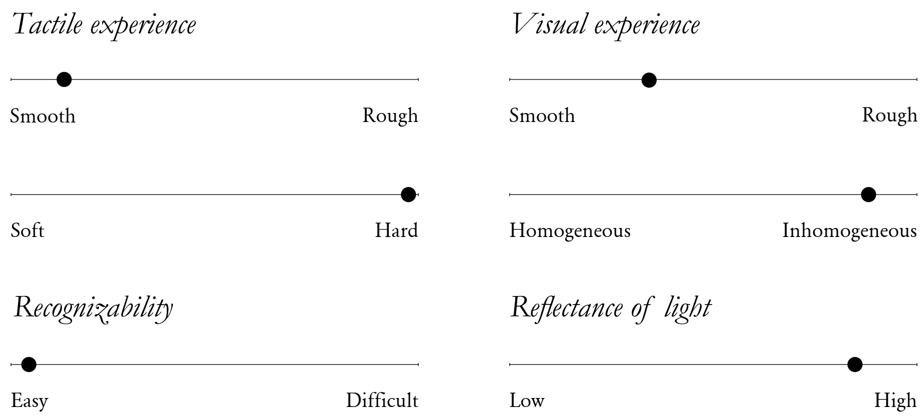


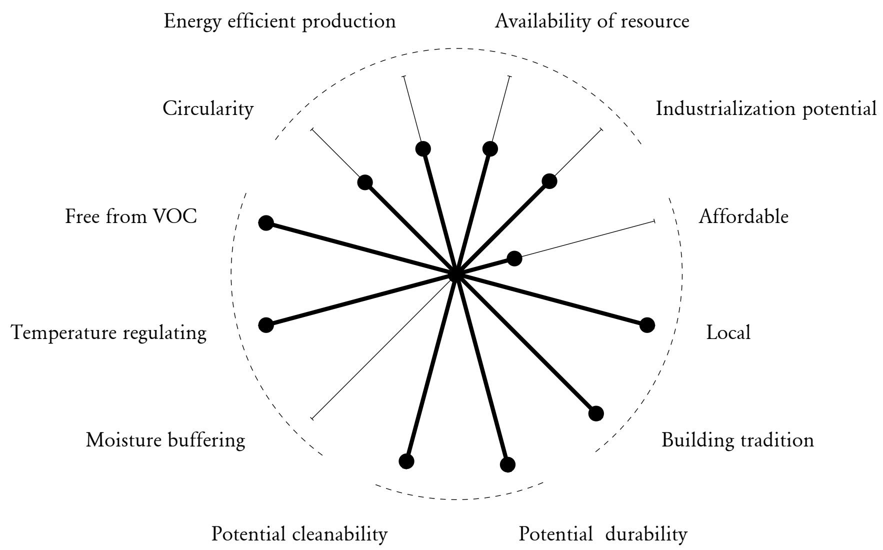
Suitable surfaces

■ Floor ■ Wall □ Ceiling

MATERIAL SAMPLE 3.7

Content: Leftover pieces of stone
Method: assembled





Suitable surfaces

■ Floor ■ Wall □ Ceiling

MATERIAL SAMPLE 4.1 - 4.12

Material sample 4.1 - 4.12 are made in a hydraulic press located in the laboratory of Materials and Manufacture, Chalmers University of Technology.

The samples are 100 mm x 100 mm wide and 1 to 10 mm thick.

Sample 4.4, 4.6 and 4.10 are made with a pressure of 500 bar and a temperature of 110 Celsius degrees.

The rest of the samples are made with a pressure of 500 bar and room temperature.

From left to right:

4.1 Hemp fibres & carboxymethyl cellulose
4.2 Carrot haulm, camomile flowers & carboxymethyl cellulose
4.3 Fir needles, camomile flowers & carboxymethyl cellulose
4.4 Rapeseed mass & hemp fibres
4.5 Camomile flowers & carboxymethyl cellulose
4.6 Flaxseed mass & hemp fibres
4.7 Barley & carboxymethyl cellulose
4.8 Fir needles & carboxymethyl cellulose
4.9 Bark from fir & carboxymethyl cellulose
4.10 Bark from fir & carboxymethyl cellulose
4.11 Pressed oats, hemp fibres & carboxymethyl cellulose
4.12 Potato peels (pulverised), red earth pigment & carboxymethyl cellulose

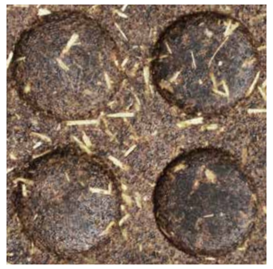
From left to right: bark, wheat bran, potato peels, camomile flowers & conifer needles.

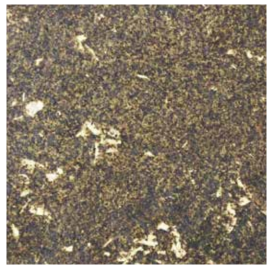

1.2 Wheat bran

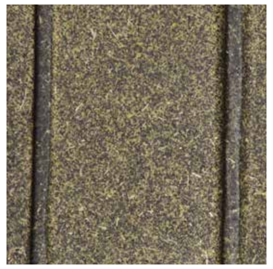

1.4 Wheat bran, saw dust & white paint


1.6 Pressed oats, hemp fibres & wood chips


1.7 Flaxseed oil mass


1.8 Flaxseed oil mass & reed fibres


1.9 Rapeseed oil mass & wood shavings


1.10 Rapeseed oil mass & hemp fibres


2.2 Conifer needles


2.3 Reed fibres


2.6 Bark chips from fir


2.7 Bark chips painted white


2.8 Bark fibres from fir


2.9 Pieces of bark from fir


2.10 Bark chips from birch


2.11 Pieces of birch bark


2.12 Reed, sawdust & dried roses


3.1 Compressed clay


3.3 Clay with clay plaster


3.6 Leftover pieces of stone


3.7 Leftover pieces of stone

EVALUATION

The evaluation of the material samples is a way to reflect upon them and to be able to suitably apply them in a design. The evaluation has been used as a tool to bridge the material samples to the design project. Below follows a reflection on the evaluation of chosen materials.

Perception
When creating revived materials, a significant aim has been to bring about different perceptions. As discussed in chapter *"The experience of materials - colour, light and texture" an element of surprise* in the experience of a material can be intriguing. For example, a material looking rough but feeling smooth, and the other way around, but also when the surfaces are made of unexpected materials. An example of this could be material sample 2.3, made of reed fibres, looking rough but feeling smooth upon touch. The samples of rapeseed and flaxseed mass (sample 1.7, 1.8, 1.9 & 1.10) to some extent resemble clinker, but when coming close a difference can be observed. Reflecting on this, supported by the samples made in the hydraulic press, the actual tactile smoothness would probably increase if the samples were industrially produced. Therefore, the evaluation of visual experience of smoothness/roughness is perhaps more interesting to look at,where different grain sizes can make the material look smooth or rough.

The evaluation of whether a material feels *soft or hard* has been important when imaging which materials would be preferred to walk on, lean one's back against, or sit on. For example, the stone samples (material sample 3.6 & 3.7) are hard and are argued to be suitable for flooring in areas with a rough character, but not where one walks barefoot.

The reason to evaluate whether a material is *homogeneous or inhomogeneous* has been to search for materials either providing a space with deeper character, or with a more anonymous appeal to let the room itself stand for the character of the space. For example, regarding the material sample 1.6, made of oat, flax and wood chips, the mix of different sized particles makes every piece one of a kind, whereas material sample 1.2, out of fine wheat bran, creates a homogenous and harmonic feeling.

In order to attempt to intertwine architecture and light, *reflectance of light* on the samples has been evaluated. As a way to create a few samples with higher reflectance of light, two samples have been painted white, sample 1.4 & 2.7, with a successful result.

The ability to recognize a material's origin, has been evaluated through *recognition*. Visual and tactile experiences as well as the smell of the material has been considered. The samples made from bark were considered some of the easiest to recognize the origin of, as well as conifer needles, smelling and reminding of forest (sample 2.2, 2.6, 2.8, 2.9, 2.10 & 2.11). Generally, the larger pieces of the raw material, the easier to recognise. The smell of a material can evoke positive feelings but can also be a concern and though few samples smell remarkably much, coatings could be added to reduce smell when needed.

Physical performance

In terms of physical performance, the potentials of *cleanability* and *durability* have been evaluated. Not all the material experiments have been successful looking at actual, and not potential, durability. Some have shown great durability, and some have been more fragile. This is foremost a consequence due to simple tools and methods, executed by hand. For this reason, some material samples were carried out in a hydraulic press in order to compare the performance of some of the handmade samples with more industrially made samples of the same material ingredients. The material samples made in the hydraulic press generally showed higher physical performance than the handmade ones. The ones with both heat and pressure showed great durability with a high level of finish.

Through the evaluation potential durability and cleanability has been predicted and estimated, strengthened by the hydraulic compressed samples. When evaluating potential durability, focus has foremost been on the possibility to put a nail in the samples, as well as how they would wear over time. The evaluation of potential durability has therefore been different between the samples, as stone has been evaluated only according to wear over time, as has the samples of rapeseed and flaxseed mass. Accordingly, they can be suitably applied in a design; stone on the floor and rapeseed and flaxseed mass on for example floor, walls and cupboards of a kitchen. Samples showing a lower degree of durability could be applied on the upper parts of a wall and as the ceiling. Examples are samples made from conifer needles that could work as acoustic panels and other materials having good climatic properties but due to their unsealed and porous surface are harder to clean, such as an untreated clay surface.

Climatics

Like nearly all natural material, the samples of this thesis have generally good performance when it comes to *moisture buffering*, *temperature regulation* and being *free from VOC*. Especially samples made from clay can be considered advantageous, since they have a very good moisture buffering capacity, along with good thermal and acoustic properties (Berge, 2009) Additionally, studies indicate that clay has the potential to adsorb VOCs (Qu, Zhu, & Yang, 2009 & Jarraya, Fourmentin, Benzina, & Bouaziz, 2010) Due to its great climatic properties, clay is suitable to be applied in bedrooms (Simonson, Salonvaara & Ojanen, 2002).

In samples where glue has been used (for example sample 2.9), VOC has been considered, but depending on the choice of glue it can vary in amount. Some samples have been coated with organic wax, to reach a higher finish, but all samples have been evaluated according to what coating they could need when made industrially. For example, the sample of dried roses, saw dust and reed fibres (sample 2.12) would probably need a finish even if industrially made.

Cultural values

Many of the samples comprise of traditional building materials but in a non-traditional way, making their cultural values differ. For example, birch bark is a traditional building material but commonly not used to produce indoor surface panels, like material sample 2.10. All the materials are local and affordable making them suitable for a do-it-yourself production.

Environment

All material samples are circular in the way that they can either be reused as they are or recycled as materials, and in the end of their life they can be safely returned to the soil. Most of the samples have been through little processing and the use of *energy of the production* is often low. In the evaluation of energy efficient production, the drying process of the raw materials has been considered, as well as the temperature needed when producing the panels. When evaluating *circularity*, all materials mixed with biological adhesives, even if several different raw materials have been mixed, are regarded as highly circular due to their biodegradability. The glued samples are regarded to have a less circular life cycle due to their lower level of reuse.

Economy

Most of the materials are considered to have a good *industrialisation potential* both in terms of *availability of resource* and processing. The assembled samples, like the ones made from leftover pieces of wood and stone, are regarded less economically beneficial due to their lower industrialisation potential.

Comparing the created samples to common building materials

Comparing the created samples of this thesis to the evaluation of the common building materials gypsum board, plastic floor and OSB board gave the following conclusions; gypsum walls contain no element of surprise in tactile and visual experience, and neither does plastic floor. OSB on the other hand, possesses this quality, and out of these three it is the material most similar to the created samples. The adhesives' impact on VOC emissions is what differs the most in the evaluation of OSB, compared to the created materials of this thesis.

• DESIGN PROPOSAL

A STORY OF DISCARDED RESOURCES

Designing atmospheres with revived materials

This thesis searches for how revived materials can bring about different atmospheres and perceptions. Several spaces have been designed to showcase a few of the materials investigated in this thesis. The spaces are presented as sequences, giving the viewer a feeling of being there. Based on the evaluation of each material sample, they have been chosen to create a desired atmosphere and to tell a story, relating to its space.

Even though the design of the spaces is meant to allow for a reuse and change of materials, followed by standardized measurements, the spaces are foremost created in correlation with the materials, making them a part of each other.

From sample to wall

The samples of 200 x 200 mm, or 100 mm x 100 mm, would industrially become bigger boards. In the design proposal of this thesis the dimensions of the boards are inspired by Japanese tatami mats, which often has the proportion 1:2 (Nationalencyklopedin, 2019), however they are still adapted to swedish standards. Therefore, they have a base width of 600 mm. The boards are designed for disassembly, meaning they could be picked down and moved when wanted elsewhere. When they are too worn out to be reused, they can easily be recycled into new boards. Alternately, they can be returned to its origin; earth.

The design of the sequences, as well as the entire apartment, is adapted to fit favourable measurements of the boards. The boards are highlighted through a division at 1200 mm in height and carefully chosen end odd pieces. For the clay panels, a clay plaster can be added to cover the joints and create a seamless wall.

• DESIGN PROPOSAL •

Design through sequences

As a way to bridge the material samples to the design of the sequences, each sequence has been explored through seven different concepts. Privacy, vibrance, nature of space* and spaciousness illustrates the desired spatial atmosphere and activity that the materials can support. Colour and texture and light is a more direct description of the material, which characters in turn affect the spatiality. Consequently, material and space meet.

*Nature of space includes four spatial concepts, inspired by nature. These are: spaces to withdraw [1], spaces to overlook [2], spaces to gather [3]and spaces that inspire exploration [4] (Browning, Ryan & Clancy, 2014).

1. 2. 3. 4.

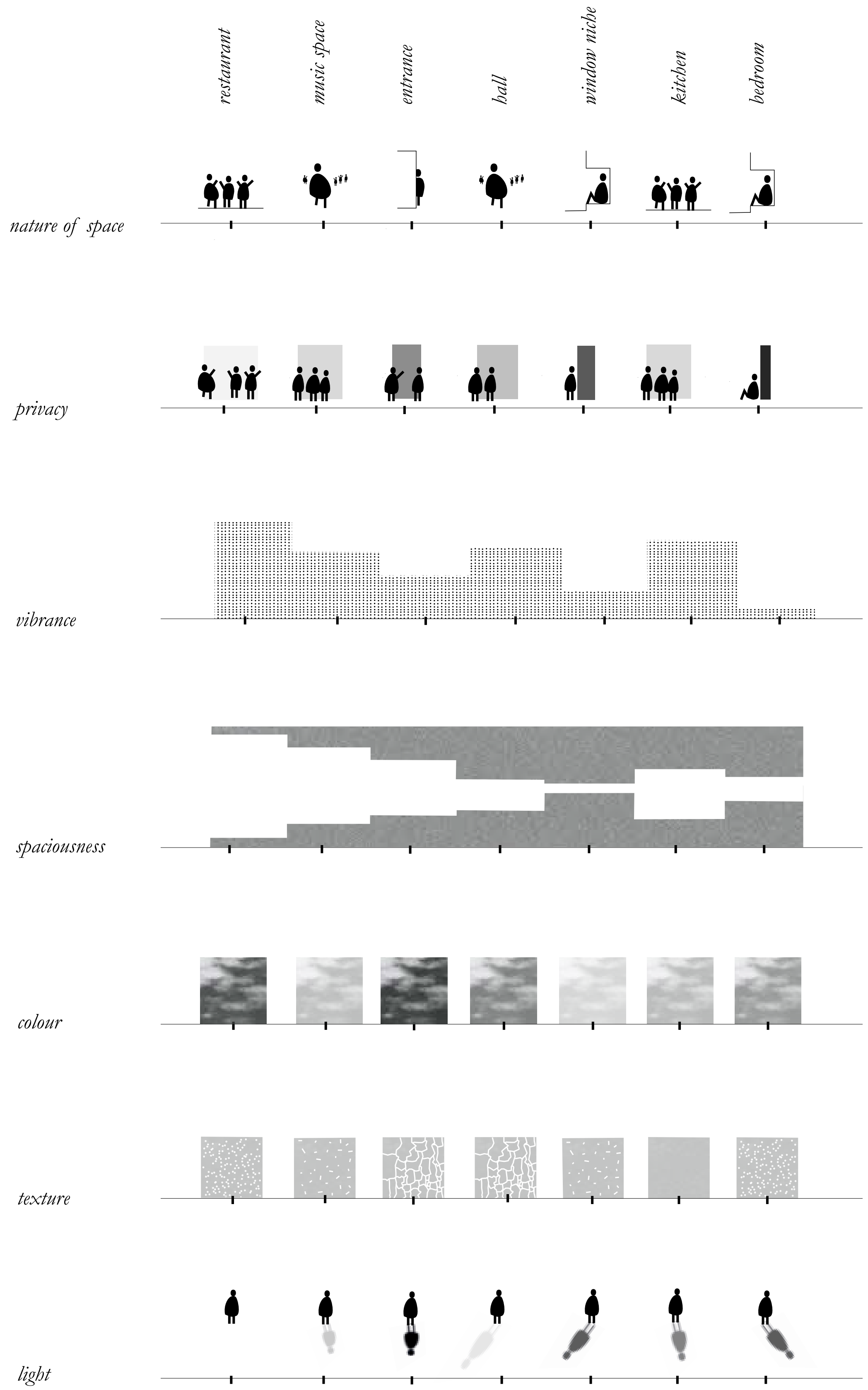
From public

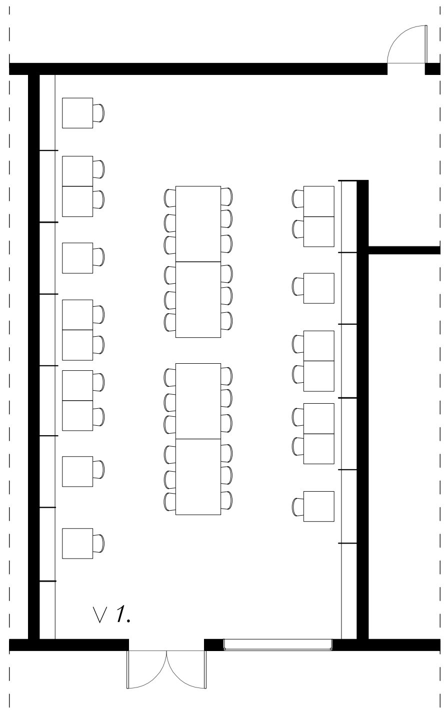
One can imagine many of the material samples in a public atmosphere, where the freedom to explore materiality is far greater than in private architecture. Therefore, this thesis explores a spectrum of spatialities, ranging from public to private. The public spaces chosen to be displayed are; a restaurant, where the architecture has a freedom to be conceptual, and a space for music, where the materials can correspond with acoustics and harmonies. As a transition between public and private, an entrance to an apartment building shows a place holding narratives, inviting to intimate meetings between neighbours.

To private

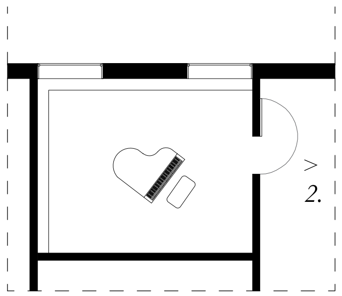
Following layers of privacy, the last sequence of the apartment becomes the most private. In a private space, the materiality may affect you in a more frail and sensitive way than when in a public one. It may therefore be more challenging to explore materiality in a private space than in a public one. However, as an exploration of alternatives to the standardized materials in apartments of today, great focus has been put on designing an apartment, aiming to showcase alternative materials and further the atmosphere they can add to a home.

The design of the apartment is meant to allow for flexibility, reuse of materials and for a personalized materialiality.

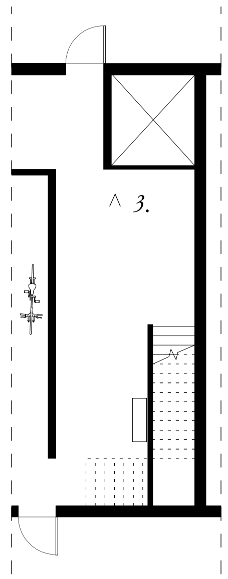


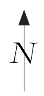


Restaurant
1:200

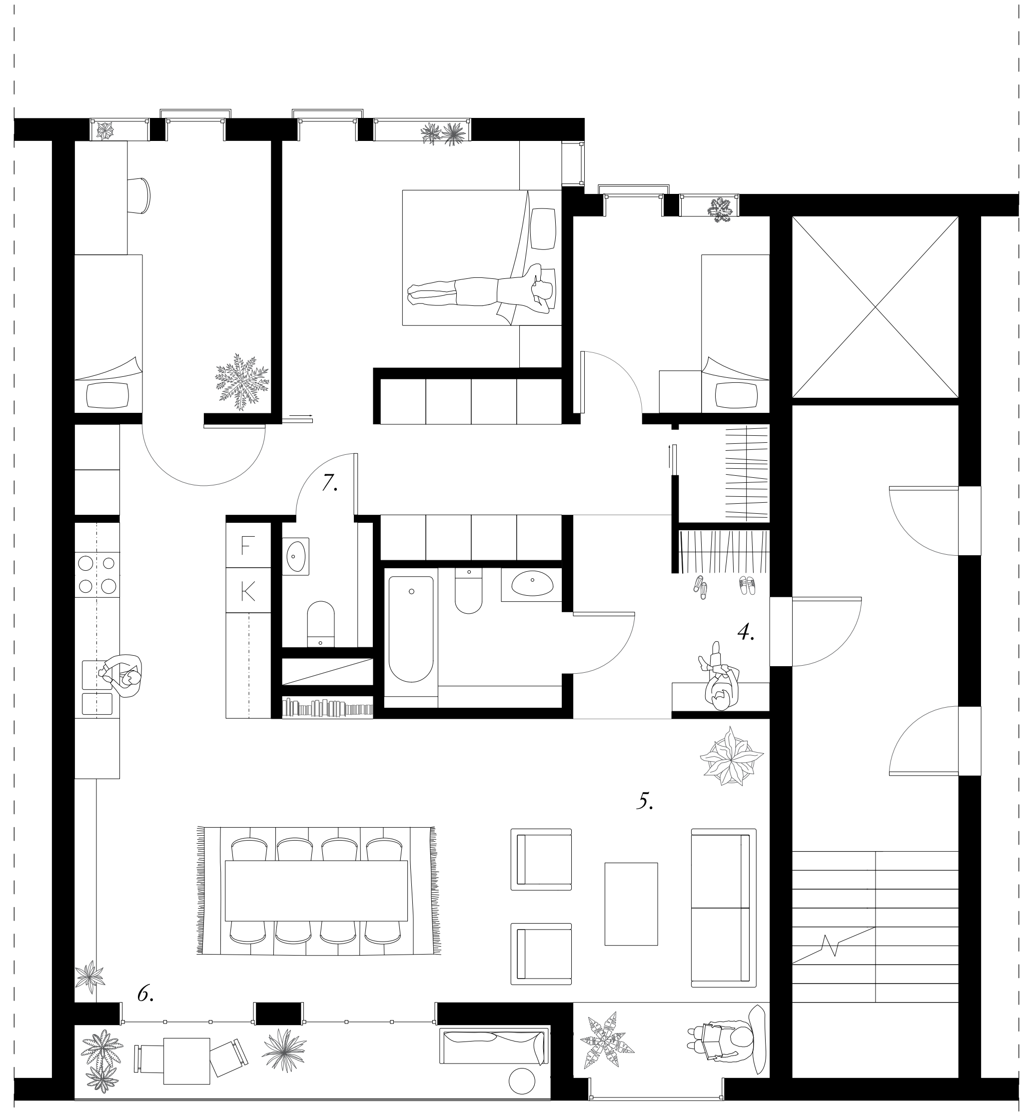


Music space
1:200





Entrance
1:200



Apartment
1:100

Sequences

1. *Restaurant*
   Velvet reminding walls
2. *Music space*
   Green soft sounds
3. *Entrance*
   Dreamily forest
4. *Hall*
   Calm wilderness
5. *Window niche*
   Sense of withdraw
6. *Kitchen*
   Layers of altering surfaces
7. *Bedroom*
   Down to earth

Main design concepts

- *Possibility to circulate*
- *Layers of rooms to move through*
- *Sightlines*
- *Possibility to create several small or fewer larger rooms with many different possible furnishings*
- *No storage in rooms, creating space-efficient, flexible rooms*
- *Spaces to withdraw*
- *Spaces to overlook*
- *Spaces to gather*
- *Spaces that inspire exploration*
- *Daylight from all directions*

VELVET REMINDING WALLS

You arrive right before lunch rush, so you can choose your favourite table for your lunch date. This dim, yet cosy restaurant makes you starving, watching the velvet reminding walls. Knowing they are made from peels makes you think of how much you throw away at home and sparks your fantasy to do something fun and useful with them, at least compost them. Ordering a soup brings about a smile when imagining its peels ending up on the walls around you.

Wall panels made of beetroot peels (material sample 1.11) and a floor out of flaxseed mass (material sample 1.7) writes the restaurant a circular story.

GREEN SOFT SOUNDS

Entering this space makes you feel you are visiting a forest glade on a spring morning. The light from the large window to the north spreads a consistent light in the room and the green embracing blanket above softens the sounds from the violin. The textured clay walls diffuse the sound around you whilst standing on the floor, perfect in its resonating hardness.

Conifer needles (material sample 2.2) above create a soft sounding atmosphere, and a clay floor balances a comfortable indoor air.

DREAMILY FOREST

Heading for the inner yard, you pass through the entrance hall of your apartment block . It holds a sense of mass and the light seeping in leads you either further up in the building or to the garden on the other side, whilst walking the hard stone floor. The room smells dreamely of forest making you feel curiously reminded and you always have to stay a while on the bench to absorb the atmosphere of the room. Sometimes a neighbour passes by and you relate noting the mysteriousness of the room.

Walls of bark (material sample 2.6) evoke dreams of forest and a stone floor (material sample 3.6) presents a long lasting surface to walk.

CALM WILDERNESS

Coming home, you take your shoes off on the irregular stone floor, its grains, hues and faint sparkle meeting your feet. With the reed walls, and a gentle stream of daylight, you can daydream of how you feel entering a lake bay on a Sunday walk. Taking off your coat, you glance into the living room to see if someone is there before moving into your home.

A stone floor (material sample 3.7) and reed walls (material sample 2.4) whisper a calm wilderness.

SENSE OF WITHDRAW

Every home should have a proper window niche. Here, you are allowed to withdraw from the rest of the room whilst beholding the cityscape, or hide from the urban life outside, whilst looking out over the apartment and glimpsing the sky from the window to the west. The concave texture suggests pausing, inviting you to come close and touch. Light falls on the surface creating alluring shadows both from a distance and up close.

A foreground of reed (material sample 2.3) and a niche of painted wheat bran walls (material sample 1.4) echo the light.

LAYERS OF ALTERING SURFACES

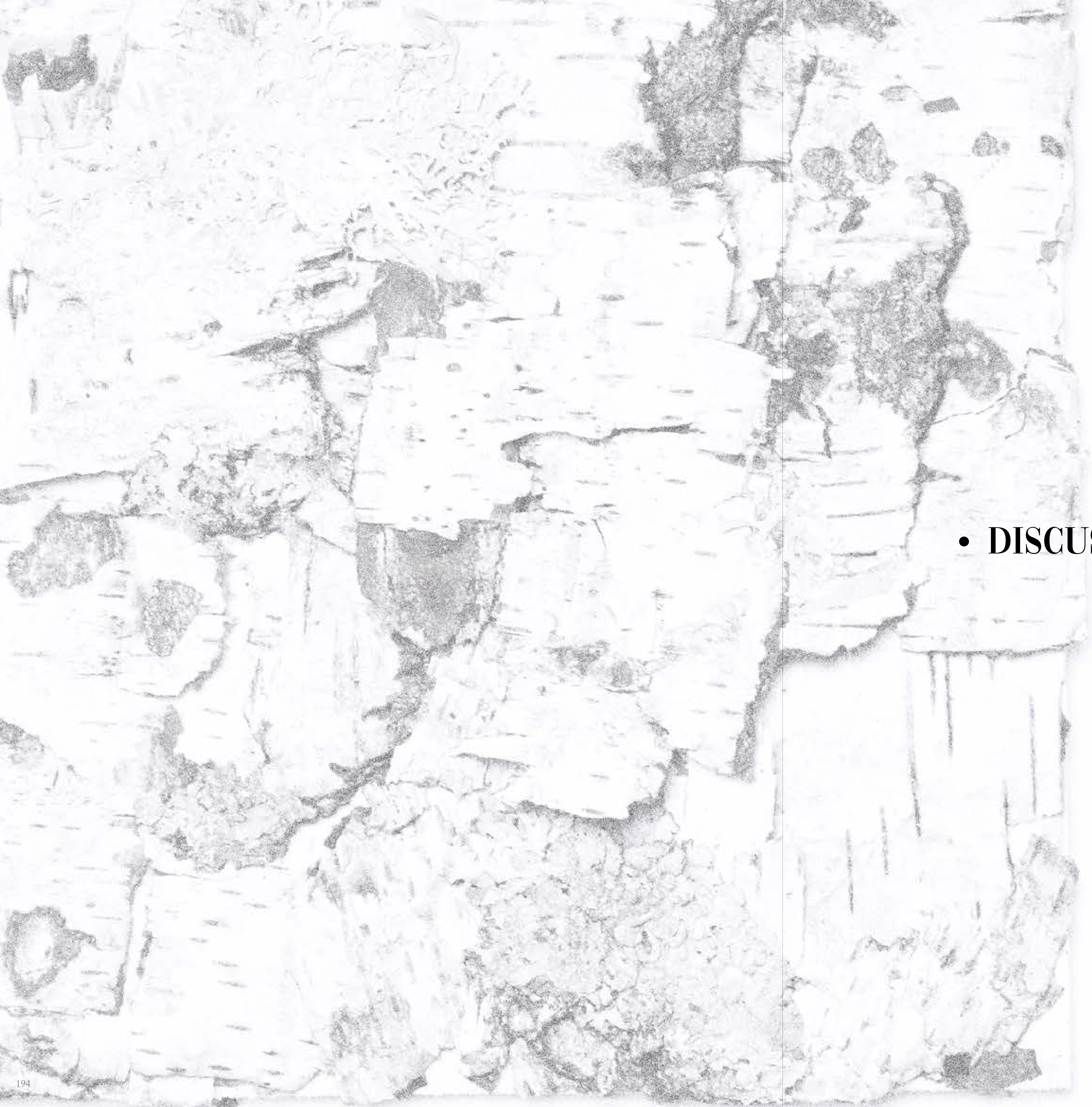
Leaving the balcony for the bedroom, you can see to the other side, where trees on the inner yard dance in the wind. The beige, fine grained surface in this common room forms a breezeless homogeneousness. From this view, the kitchen is fully visible in its eatable pride, but it is a release to only glimpse it from the window niche. Layers of rooms become a flow of movement through altering surfaces.

Uniform wheat bran panels (material sample 1.2) make room for personal expressions and kitchen surfaces of rapeseed (material sample 1.9) provide a playful and durable kitchen.

DOWN TO EARTH

You are moving through the space that transitions between private and public. This zone holds space for your rituals of getting dressed and washing your face. Nearing the bedroom you turn along the rough bark panels, touching them lightly with your fingers. The morning light hits the wooden floor and the clay walls of the bedroom, catching its irregularities and hues. The materiality brings you to a state of feeling down to earth going to bed as well as well as waking up.

A transition space with surfaces of bark (material sample 2.8) becomes an intimate, dark room to move through towards the bedroom, a room with clay surfaces (material sample 3.3) that diffuses morning light and healthy air to breath.



• DISCUSSION

Formulating the discourse of this thesis took off in current global problems. Through background research, a knowledge of the amount of leftover resources left behind by industries of today was shaped. Aspiring to consider materials used in architecture, the aim for this thesis has been to investigate the potential of natural leftover materials in an architectural context. The limitation to natural leftover materials derived from the aim to create materials for human wellbeing.

This thesis seeked the answering of two main questions.

1. How can natural leftover resources from industries of today be revived and applied in architecture?

This thesis turns natural leftover resources into material samples for interior surfaces, and thus shows how the life of the leftovers can be prolonged or be given new life. It showcases other alternatives than common life cycles of burning the resources for energy or leaving them to decompose, where, what would be considered waste, becomes a raw material. With the global issue of diminishing resources in mind, this thesis shows how, when valorizing leftovers from industries, extraction is minimized. Furthermore, the energy needed to produce a product is kept and utilized through the use of its leftovers. Through material investigations, this thesis shows how leftovers from forestry, agriculture and groundwork have a wide range of qualities which has resulted in surfaces with diverse attributes. The materials have been overall minimally transformed from their state as a leftover, which assigns them with a sense of naturalness. In the investigation of transforming local natural leftover materials to surface materials more than fifty samples were made.

2. How can architecture, through the use of materials, invite wellbeing, create perceptions and compose narratives?

A search for how materials affect the human has been made through this thesis. First of all, the connection to human health and wellbeing has been pursuit. As discussed by Day (2002) the reality of homes today is that few breath clean air and according to World Health Organization (2010) many materials created by humans emit unhealthy amounts of toxins. Research has been made throughout this thesis on how to use organic, non-toxic adhesives. Meeting for example NSR, working with organic non-toxic adhesives, gave a basis for the possibilities of creating surface material free from harmful emissions. Consequently, all the material samples made as fibre boards are bonded with starch, cellulose based residue or with its own lignin. Because of the samples having a range of qualities, they will be perceived differently. The samples are different in for example colour, roughness, homogeneity and texture. Through the design of different sequences this thesis has aimed to showcase how they can be sensed and understood differently. Especially; privacy, vibrance, nature of space and light has been explored. It has furthermore been showcased that, not only different perceptions can be formed through materiality, but also different spatialities. Research from amongst other Norsk Treteknisk Institutt (2016) shows that recognition of a material's origin is recorded as an important aspect of a material's property. Recognition has in this thesis been explored through a notion of storytelling, where for example a surface made from conifer needles could evoke thoughts of being in a forest or reeds of time by the sea. Not only recognition but the smell of a material or knowledge about its origin means the material holds a story. This thesis hopes to inspire how storytelling through materials can spark conversations as well as a greater understanding and insight of the travel that the material, and all surrounding materials, have made.

Reflection

This thesis does not give right or wrong answers nor a proposed solution to the global issues of diminishing natural resources, global warming and health problems. It rather seeks, explores and tries to expand visions. The importance lies in an idea of daring to explore.

What became clear as this thesis developed was that no straight line could be drawn between the material samples' accomplishment, meaning quick answers of which were useful and successful were not given. The samples did not turn out good or bad, appealing or not appealing, successful or not successful, but merely emerging on scale of perception. Therefore, the thesis has seen a potential in nearly all its material samples.

Since the number of ways the collected raw materials could be combined was overwhelming, the choice of content in the experiments had to be limited due to time limits. The choices were based on research and desired outcome. A plan was made with expected experiments and recipes to go along, but many were made as a result of the previous or to test out an idea. Reflecting upon this, the method of choosing material content for the samples could have been more structured. However, more structure would perhaps have taken away some of the creativeness and even reflecting back on it, exploration and spontaneity was to some extent required in order to explore new ideas that it entailed. The lack of proper equipment for most of the samples, except the ones made in the hydraulic press, may have prevented possibilities of a greater success of the physically as well as aesthetically qualities of the samples.

The collection of raw materials has formed the outcome of the samples conducted in this thesis. Due to the time of year being at the end of winter and the time limit of collection, the raw materials could have been more extensive and of other kinds if it were during other circumstances. This refers especially to the ones originating from agriculture. Examples are stems, straw and stalk from agriculture such as tomato stems, corn stems and flaxseed straw. These are materials that were considered to have great potential when starting out this thesis, due to their high content of fibre and sturdiness. This would however be available during the end of the harvest season.

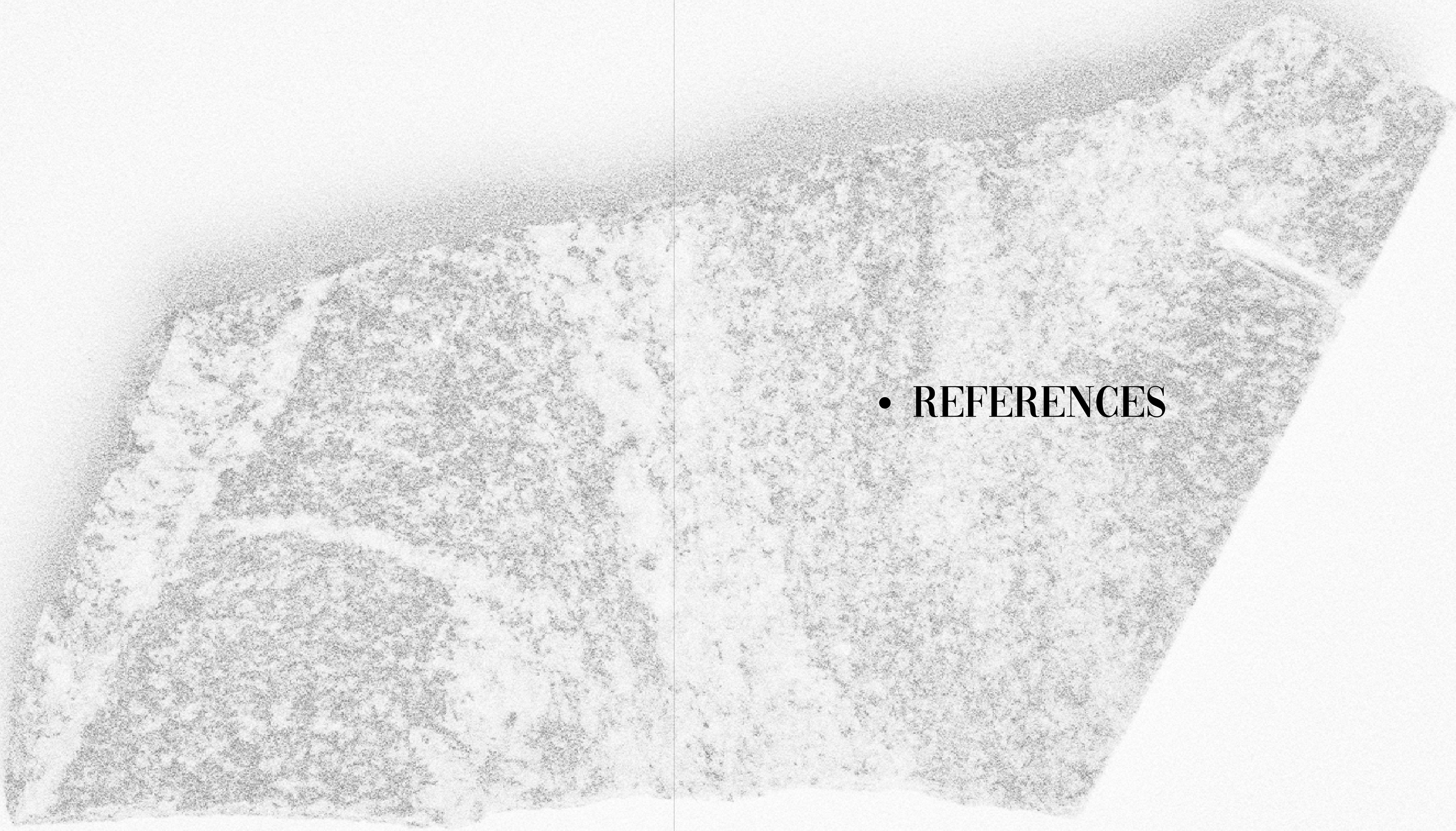
In order to create and explore a variety of spatialities using the conducted material samples, some materials had to be added along the process to reach a desired range of characteristics. The investigations of stone, wood as well as the painted samples therefore came late in the process. Paint was investigated both to highlight its natural and designed textures, as well as creating lighter materials to choose from.

Struggling with a line between interior architecture, where surface materials are added to a space and architecture, were the materials shapes the space, this thesis aims for the latter.

This thesis taps into ongoing research on building materials of natural leftover materials, and adds a level of architectural perception to the discussion. It hopes to inspire creative thinking and broaden the mindset of what leftover resources are. To develop this research further could be to investigate physical properties of the materials, as well as dive deeper into natural adhesives and additional raw materials.

This thesis hopes to have acquired its goals of inspiring in a transition towards circular design and a change of the concepts of raw materials and waste. It emphasizes the importance of materials connection to health and wellbeing as well as being at the forefront of current global goals such as Goal 12 from United Nations 2030 Agenda for Sustainable Development; responsible consumption and production. This goals is, for instance, about promoting resource and energy efficiency, providing green jobs, a better life quality for all, decreasing degradation as well as minimizing air, water and soil pollution. It aims to at "doing more and better with less" (United Nations). By utilizing leftover resources this thesis directly aims to find a solution to material consumption. It shows how, through prolonging life cycles, jobs can be created and how there is a connection between wellness of nature and that of human. This thesis is a testament to a longing of not only doing less bad and using less, but to also do good and create beauty of less. Lastly, this thesis meets its aim of following Goal 12 of; "educating consumers on sustainable consumption and lifestyles" (United Nations) as this thesis makes an attempt to literally bring leftover resources to the surface. Materials that most often are foreseen, forgotten and unvalued are instead given room in an exposed application to tell the story of how consumption means a product leaves behind remains. Furthermore, natural surfaces hopefully prosper an equal relationship between human and nature, where nature and its resources are valued.

As a reflection on what role the architect has, this thesis has been of great value to its authors and hopefully also as an inspiration to others. The construction industry faces a future challenge of urbanization and population growth, that is without enough resources at the pace and way of today. The future role of the architecture should, with favor, hold responsibility and creativity. In order to meet for instance goal 12 from United Nations, it can be argued that architects need to dare to be innovative, along with a dialog and collaboration with for example engineers, politicians, contractors and users. More specifically to its authors, this thesis has been inspirational in that sense that humbleness and creativity can go hand in hand in architecture. When letting go of presumed ideas of what is usually done, curiosity has arisen which feels like something to keep striving for.



• REFERENCES

Literature

Berge, B. (2009). *The ecology of building materials.* Amsterdam/Boston/London: Elsevier/ Architectural Press.

Browning, W. D., Ryan, C. O. & Clancy, J. O. (2014). *14 Patterns of Biophilic Design.* New York: Terrapin Bright Green llc.

Carson, L. R. (1962). *Silent Spring.* New York: Houghton Mifflin Company

Compton, M. & Shim, R. (2015). *The Social Determinants of Mental Health.*Washington, DC: American Psychiatric Publishing.

Day, C. (2002). *Spirit & place.* Oxford: Architectural press, Butterworth-Heinemann.

GXN et al. (2018). *Building a Circular Future (3rd edition).* Copenhagen: GXN.

Geiser, K. (2001). *Materials matter, towards a sustainable materials policy.* Cambridge: The MIT Press

Hall, T. & Dunér, K. (eds.). (1995). *Svenska hus: Landsbygdens arkitektur - från bondesamhället till industrialismen.* Stockholm: Carlssons bokförlag.

Hebel, D., Wisniewska, M. & Heisel, F. (2014). *Building from Waste, Recovered Materials in Architecture and Construction.* Basel: Birkhauser Verlag AG

Kellert, S. R., Heerwagen, J. H. & Mador, M. L. (2008). *Biophilic design.* Hoboken: John Wiley & Sons, Inc.

Khatib, J. M. (eds.). (2016). *Sustainability of Construction Materials.* Cambridge, United Kingdom: Woodhead Publishing (Elsevier Ltd.)

Lacy, P. & Rutqvist, J. (2015). *Waste to wealth: The circular economy advantage.* New York: Palgrave Macmillan.

McDonough, W. & Braungart, M (2013). *The Upcycle, Beyond Sustainability - Design for Abundance.* New York: Melcher Media.

Nriagu, J. O. (1992). *Gaseous Pollutants: Characterization and cycling.* New York: John Wiley & Sons, Inc.

Papanek, V. (2009). *Design for the real world, Human Ecology and Social Change.* Chicago: Academy Chicago Publishers.

Salunkhe, D. K. & Kadam, S. S. (eds.). (1998). *Handbook of vegetable science and technology: production, composition, storage and processing.* New York: Marcel Dekker

Walther, J. (2014). *Earth's Natural Resources.* Burlington: Jones & Bartlett Learning.

Wheeler, S. (2004). P*lanning for sustainability: creating livable, equitable, and ecological communities.* London: Routledge.

Web sources

Artnet Worldwide Corporation. (2018). *Joseph Cornell.* Retrieved 2019-05-06 from http://www.artnet.com/artists/joseph-cornell/

Bauder, J. (2013). *Cereal crop residues and plant nutrients. Montana State University Communications Services.* Retrieved 2019-03-08 from http://www.montana.edu/cpa/news/wwwpb-archives/ag/baudr230.html

Boverket. (2017). *Bygg- och fastighetssektorns uppkomna mängder av avfall.* Retrieved 2018-11-25 from https://www.boverket.se/sv/byggande/hallbart-byggande-och-forvaltning/miljoindikatorer--aktuell-status/avfall/?fbclid=IwAR0cNUlCDV1_DSdSiAoaHt1XSLvlN0yOkS9QomZLpcVZqT29PM-HzIadjXY

Claytec. (2018). *Downloads - CLAYTEC Greentech 700 (PDF).* Retrieved 2019-05-09 from https://www.claytec.de/en/products/downloads_en

Clayworks. (2019). *Natural clay plaster wall finishes.* Retrieved 2019-03-20 from https://clay-works.com/

Clayworks. (2019). *Product descriptions.* Retrieved 2019-05-09 from https://clay-works.com/product-descriptions/

Dictionary.com. (2019). *Well-being.* Retrieved 2019-05-06 from https://www.dictionary.com/browse/well-being

ECOboard. (2017). *How ECOBoards is made from Green.* Retrieved 2019-03-20 from https://ecoboardinternational.com/slider-info-page/

Engineering ToolBox. (2009). *Densities of Solids.* Retrieved 2019-05-09 from https://www.engineeringtoolbox.com/density-solids-d_1265.html

Engineering ToolBox. (2004). *Densities of Wood Species.* Retrieved 2019-05-09 from https://www.engineeringtoolbox.com/wood-density-d_40.html

Engineering Toolbox. (2003). *Specific Heat of common Substances.* Retrieved 2019-05-09 from https://www.engineeringtoolbox.com/specific-heat-capacity-d_391.html

Engineering Toolbox. (2003). *Thermal Conductivity of common Materials and Gases.* Retrieved 2019-05-09 from https://www.engineeringtoolbox.com/thermal-conductivity-d_429.html

FAO. (2018). *FAOSTAT - Data.* Retrieved 2019-03-18 from http://www.fao.org/faostat/en/?fbclid=IwAR1sCocTguXGnLNqjGLPG7w0zalcY1r8WNROh3g6R7t3NJGZH WWl75fVU_A#data

Från Sverige. (2017). *De fyra vanligaste sädesslagen – vete, havre, korn och råg.* Retrieved 2019-03-08 from https://fransverige.se/konsument/vilka-varor-marks/svenska-ravaror/spannmal/

Government of Canada. (2016). *Insect repellents.* Retrieved 2019-03-08 from https://www.canada.ca/en/health-canada/services/about-pesticides/insect-repellents.html

GXN. (2018). *Circle house.* Retrieved 2018-11-25 from https://gxn.3xn.com/project/circle-house

GXN. *Biological House.* Retrieved 2018-11-25 from https://gxn.3xn.com/project/biological-house

Järki. (2018). *JÄRKI FAKTA 19: Vassmöjligheter*. Retrieved 2019-03-12 from https://www.slu.se/globalassets/nyhet-kalend/2018/jarki_isku_19_a3_sve_web-002.pdf

Lendager group. *Upcycle house*. Retrieved 2018-11-25 from https://lendager.com/en/architecture/upcycle-house-en/

Leonard, A. (2007). *Story Of Stuff, Referenced and Annotated Script*. Retrieved 2019-03-18 from https://storyofstuff.org/wp-content/uploads/movies/scripts/Story%20of%20Stuff.pdf

MaterialDistrict. (2013). *Yosima*. Retrieved 2019-03-20 from https://materialdistrict.com/material/yosima/

Nationalencyklopedin. (2019). *Cirkulär ekonomi*. Retrieved 2019-05-03 from http://www.ne.se/uppslagsverk/encyklopedi/lång/cirkulär-ekonomi

Nationalencyklopedin. (2019). *Gips*. Retrieved 2019-05-01 from http://www.ne.se/uppslagsverk/encyklopedi/lång/gips

Nationalencyklopedin. (2019). *Halm*. Retrieved 2019-03-08 from http://www.ne.se/uppslagsverk/encyklopedi/lång/halm

Nationalencyklopedin. (2019). *Hampa*. Retrieved 2019-05-05 from http://www.ne.se/uppslagsverk/encyklopedi/lång/hampa

Nationalencyklopedin. (2019). *Jordbruk*. Retrieved 2019-03-10 from http://www.ne.se/uppslagsverk/encyklopedi/lång/jordbruk

Nationalencyklopedin. (2019). *Material*. Retrieved 2019-01-30 from http://www.ne.se/uppslagsverk/encyklopedi/lång/material

Nationalencyklopedin. (2019). *Skogsbruk*. Retrieved 2019-03-10 from http://www.ne.se/uppslagsverk/encyklopedi/lång/skogsbruk

Nationalencyklopedin. (2019). *Tatami*. Retrieved 2019-05-13 from http://www.ne.se/uppslagsverk/encyklopedi/lång/tatami

Naturvårdsverket. (2018). *Bygg- och rivningsavfall*. Retrieved 2019-03-12 from https://www.naturvardsverket.se/Miljoarbete-i-samhallet/Miljoarbete-i-Sverige/Uppdelat-efter-omrade/Avfall/Bygg--och-rivningsavfall/

Organoid. *Solutions*. Retrieved 2019-03-20 from https://www.organoids.com/en/products/solutions/

Prade, T. Svensson, S. Tufvesson, L. (2017). *Skördad våtmarksvegetation renar vattnet bättre från närsalter! SLU Partnerskap Alnarp och Biosystem och teknologi*. Retrieved 2019-03-12 from http://pa.ltj.slu.se/janlars/partnerskapalnarp/uploads/faktablad/866.pdf

ProEarth. (2016). *The Answer to Delhi's Air Pollution lies in Sustainable Farming and Agro Waste Management*. Retrieved 2019-05-06 from http://www.proearth.in/answer-delhis-air-pollution-lies-sustainable-farming-agro-waste-management/

RECYCLING.COM. (2019). *Waste Hierarchy: Lansink's Ladder*. Retrieved 2019-05-03 https://www.recycling.com/downloads/waste-hierarchy-lansinks-ladder/

SkogsSverige. (2019). *Trä och träindustrin*. Retrieved 2019-03-10 from https://www.skogssverige.se/tra-och-traindustrin

SVT Nyheter. (2018). *Torkan kan ge brist på foder i åratal*. Retrieved 2019-03-08 from https://www.svt.se/nyheter/lokalt/uppsala/torkan-kan-ge-brist-pa-foder-i-aratal

Trafikverket. (2017). *Om bygget*. Retrieved 2019-03-12 https://www.trafikverket.se/nara-dig/Vastra-gotaland/projekt-i-vastra-gotalands-lan/Vastlanken---smidigare-pendling-och-effektivare-trafik/Fragor-och-svar-om-Vastlanken/bygget/

Trafikverket. (2018). *Västlänken*. Retrieved 2019-03-12 https://www.trafikverket.se/nara-dig/Vastra-gotaland/projekt-i-vastra-gotalands-lan/Vastlanken---smidigare-pendling-och-effektivare-trafik/

Träguiden. (2017). *Skogsindustri*. Retrieved 2019-03-12 from https://www.traguiden.se/om-tra/materialet-tra/skogsbruk/skogsbruk/skogsindustri/

UN. (2018). *68% of the world population projected to live in urban areas by 2050, says UN*. Retrieved 2018-11-21 from https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

UNenvironment. *Food and food waste*. Retrieved 2018-11-21 from https://www.unenvironment.org/explore-topics/resource-efficiency/what-we-do/sustainable-lifestyles/food-and-food-waste

UN. (2015). *World population projected to reach 9.7 billion by 2050*. Retrieved 2018-11-21 from http://www.un.org/en/development/desa/news/population/2015-report.html

UN. (n.d.). *Goal 12: Ensure sustainable consumption and production patterns*. Retrieved 2019-05-10 from https://www.un.org/sustainabledevelopment/sustainable-consumption-production/

Vandalorum. (2018). *Wasteland – från avfall till arkitektur 16.6 2018 - 20.1 2019*. Retrieved 2018-11-25 from http://www.vandalorum.se/sv/wasteland

WWF. (2018). *Uncovering sand mining's impacts on the world's rivers*. Retrieved 2019-03-18 from https://wwf.panda.org/our_work/water/?333451/Uncovering-sand-minings-impacts-on-the-worlds-rivers

Reports

FAO. (2011). *Global food losses and food waste – Extent, causes and prevention*. Rome: FAO

IPBES. (2018). *Summary for policymakers of the assessment report on land degradation and restoration of the Intergovernmental Science - Policy Platform on Biodiversity and Ecosystem Services*. Bonn: IPBES

IPBES (2019). *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (advance unedited version)*. Paris: IPBES

Magnusson, T. (2015). *Skogsbruk - mark och vatten*. Skogsstyrelsen

Naturvårdsverket. (2018). *Avfall i Sverige 2016*. Stockholm: Naturvårdsverket

Norsk Treteknisk Institutt. (2016). *Building materials and well-being in indoor environments*. Oslo: Norsk Treteknisk Institutt.

Rode, C. et al. (2005). *Moisture Buffering of Building Materials, BYG·DTU R-126*. Department of Civil Engineering, Technical University of Denmark. Nordic Innovation Centre: proj. nr.: 04023

UNEP. (2011). *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication - A Synthesis for Policy Makers.* UNEP.

World Health Organization. (2010). *WHO guidelines for indoor air quality: selected pollutants.* Copenhagen: World Health Organization

WWF. (2016). *Living Planet Report 2016. Risk and resilience in a new era.* Gland, Switzerland: WWF International.

Articles

Bahrudin, F. Aurisicchio, M. (2018). *Is this wallet made of real leaves?: A Study of the Emotions Evoked by Sustainable Materials.* Linköping: Norddesign

Basta, H. A., El-Saied, H. & Gobran, R. H. (2004). *Formaldehyde-Free Environmentally Friendly Composites Based on Agricultural Waste. I. Novel Adhesive System.* Polymer-Plastics Technology and Engineering, 43(3), 745-777, doi: 10.1081/PPT-120038063

Cabeza, L. F., Castell A., Rincón L., Pérez G. & Vilariño V. (2014). *Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review.* Renewable and Sustainable Energy Reviews, 29. 394–416. http://dx.doi.org/10.1016/j.rser.2013.08.037

Ferrández-García et al. (2012). *Panels made from giant reed bonded with non-modified starches.* BioResources, 7(4), 5904-5916.

Goodbun, J. & Jaschke, K.. (2012). *Architecture and Relational Resources: Towards a New Materialist Practice.* Architectural Design, 82(4), 28-33. https://doi.org/10.1002/ad.1424

Jean, T. (2014, Dec) *What the house of tomorrow can teach us today.* Mechanical Engineering, 136(12), 30-37.

Jarraya, I., Fourmentin, S., Benzina, M., & Bouaziz, S. (2010). *VOC adsorption on raw and modified clay materials.* Chemical Geology, 275(1-2), 1-8. doi:10.1016/j.chemgeo.2010.04.004

Joye, Y. (2007). *Architectural Lessons From Environmental Psychology: The Case of Biophilic Architecture.* Review of General Psychology, 11 (4), 305–328. doi: 10.1037/1089-2680.11.4.305

Kelly, T. J., Smith, D. L. & Satola, J. (1999). *Emission Rates of Formaldehyde from Materials and Consumer Products Found in California Homes.* ENVIRONMENTAL SCIENCE & TECHNOLOGY, 33(1), 81-88. doi: 10.1021/es980592+

Nicklas, M.H. & G.B. Bailey (1996). *Analysis of the Performance of Students in Daylit Schools.* Raleigh: Innovative Design.

Salem, M. Z. M., Böhm. M., Srba, J. & Beránková, J. (2012). *Evaluation of formaldehyde emission from different types of wood-based panels and flooring materials using different standard test methods.* Building and Environment, 49, 86-96. doi:10.1016/j.buildenv.2011.09.011

Sauerwein, M., Karana, E., & Milano, P. (2017). *Revived Beauty: Research into Aesthetic Appreciation of Materials to Valorise Materials from Waste.* Sustainability, 9(4), 529. http://doi.org/10.3390/su9040529

Simonson, C. J., Salonvaara, M., Ojanen, T. (2002). *The effect of structures on indoor humidity – possibility to improve comfort and perceived air quality.* INDOOR AIR, 12(4), 243-251. doi: 10.1034/j.1600-0668.2002.01128.x

Qu, F., Zhu, L., & Yang, K. (2009). *Adsorption behaviors of volatile organic compounds (VOCs) on porous clay heterostructures (PCH).* Journal of Hazardous Materials, 170(1), 7-12. doi:10.1016/j.jhazmat.2009.05.027

Que, Z. L., Wang, F. B., Li, J. Z., & Furuno, T. (2013). *Assessment on emission of volatile organic compounds and formaldehyde from building materials.* Composites Part B: Engineering, 49, 36-42.

Images

Images with no source are taken by the authors to this thesis.

Image 1. NASA. (n.d.). *On top of the world [photography]*. Retrieved 2019-05-05 from https://unsplash.com/photos/_SFJhRPzJHs

Image 2. Förster, M. (n.d.). *HD Photo [photography]*. Retrieved 2019-05-08 from https://unsplash.com/photos/1nbpbEaNKr8

Image 3. United Nations. (n.d.). *Goal 12 [graphic material]*. Retrieved 2019-05-15 from https://www.un.org/sustainabledevelopment/news/communications-material/

Image 5. Bogdanov, Y. (n.d.). *Ridgefield, United States [photography]*. Retrieved 2019-05-10 https://unsplash.com/photos/uXg6mSTWfr4

Image 6. GXN. (n.d.). *Biological house [photography]*. Retrieved 2019-05-10 from https://gxn.3xn.com/project/biological-house

Image 7. Ecoboardinternational. (n.d.). *ECOBoard-151-300x225 [photography]*. Retrieved 2019-05-10 from https://ecoboardinternational.com/ecoboard-standard-2/

Image 8. Clayworks, photograph Nicholas Worley. (n.d.). *2043 Clayworks natural clay plaster architecture interior design inspiration (Clay house by Simon Astridge) [photography]*. Retrieved 2019-05-10 from https://clay-works.com/?gallery=london-flat-2

Image 9. Claytec. (n.d.). *CLAYTEC - Greentech 700 [photography]*. Retrieved 2019-05-10 from https://www.claytec.de/de/produkte/lehm_trockenbau/claytec-greentech-700_pid213

Image 10. MaterialDistrict. (n.d.). *Yosima [photography]*. Retrieved 2019-05-10 https://materialdistrict.com/material/yosima/

• APPENDIX

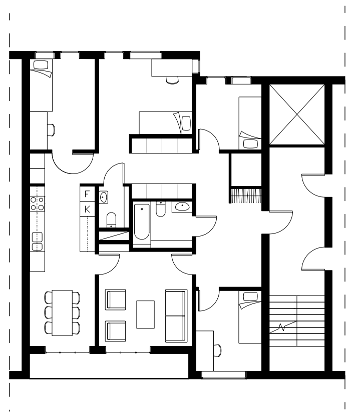
FLEXIBILITY AND ADAPTABILITY

In the process of designing the apartment, great focus has been on creating a flexible and adaptable layout. In the drawings to the right, several layouts of more or less the same apartment as the one on page 179 are shown.

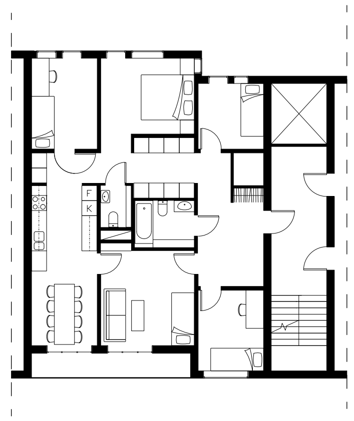
In these drawings, the same apartment is shown with different number of rooms. Also, two different kitchen solutions are shown.

Furthermore, the apartments are variously furnished, to allow for a different number of people living there, in different constellations.

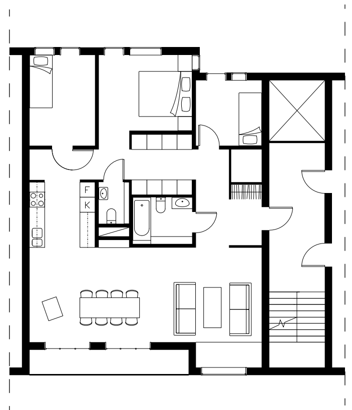
These drawings display an exploration of how to create an apartment design suitable for several living (and material) situations.



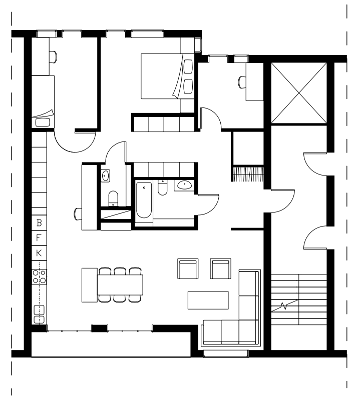
Five room apartment 1
Furnished for four people
1:300



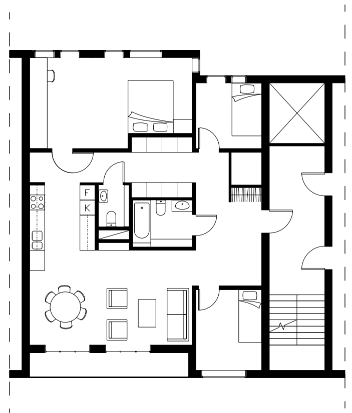
Five room apartment 2
Furnished for six people
1:300



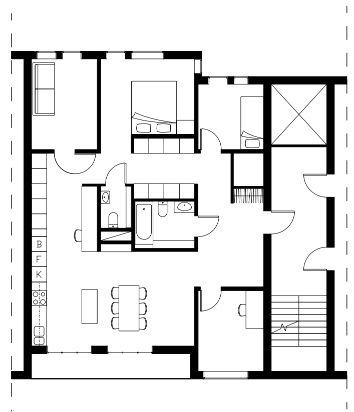
Three room apartment 1
Furnished for five people
1:300



Three room apartment 2
Furnished for three people
1:300



Three room apartment 3
Furnished for four people
1:300



Four room apartment 1
Furnished for four people
1:300

MEETINGS AND STUDY VISITS

Tommie Månsson Research Engineer, Architecture and Civil Engineering	*30/01/2019* Chalmers University of Technology
Paula Wahlgren Associate Professor, Architecture and Civil Engineering	*30/01/2019* Chalmers University of Technology
Mats Torring Head of New Ventures at Stena Metall AB	*25/01/2019* Stena Recycling, Gothenburg
Shea Hagy Project Manager, Architecture and Civil Engineering	*25/01/2019* Chalmers University of Technology
Lasse Lind Architect, head of consultancy at GXN	*29/01/2019* Office of GXN, Copenhagen
Lin Tan Project Administrator, Architecture and Civil Engineering	*01/02/2019* Chalmers University of Technology
Quan Jin Researcher, Architecture and Civil Engineering	*07/02/2019* Chalmers University of Technology
Ida Toll Retail Design & Development Manager at Nudie Jeans	*12/02/2019* Nudie Jeans office, Gothenburg
Rodrigo Arvidsson CEO at Oceanbryggeriet	*13/02/2019* Oceanbryggeriet, Gothenburg
Mahmood Hameed Academic adviser and Project Leader at NSR	*14/02/2019* NSR, Helsingborg
Torleif Bramryd Post retirement professor at Lund University	*14/02/2019* NSR, Helsingborg
Abhijit Venkatesh PhD Student, Polymeric Materials and Composites	*18/02/2019* Chalmers University of Technology

COLLECTING MATERIAL: THE ROAD TRIP - DAY 1

14th-15th February a road trip in South of Sweden was made to collect materials to the investigations.

14th of February

Derome, Veddige, Varberg

Picking up bark, saw dust, wood chips and wood shavings.

NSR/Vera Park, Helsingborg

Meeting with Dr Mahmoud Hameed and Torleif Bramryd. They work with how to utilize wood waste and adhesives developed from organic residues to produce environmentally friendly chipboards, without any formaldehyde emissions. Experiments have been done on a smaller scale and they are now looking into how Gunnarshögs Gård's residual products can be a raw material in the making of a new adhesive. We came in contact with NSR though Gunnarshögs Gård, with whom we planned a visit the following day. It was very interesting to hear about how these attempts are being researched and how relevant it is to develop new materials with lower embodied energy and high carbon storage that are free from toxins. It confirmed the potentials of materials of interest to our thesis, for example the pressing mass from rapeseed oil.

Oatly, Landskrona

Picking up fibre remains from the production of liquid oat products. Today it becomes feed for pigs on farms in the area. The solid fibre remains are about 20 tons a day.

Nordic sugar, Eslöv

Intention was to pick up beet pulp, but it was unfortunately not available. Instead we got Betfor, which is made of mostly dried beet fibre and some molasses, this is however a feed for horses and is not seen as residue.

The car packed with collected materials.


Nordic sugar's factory in Eslöv.


Field of hibernated rape plants.


Samples of fibre board and soap made by NSR.

COLLECTING MATERIAL: THE ROAD TRIP - DAY 2

15th of February

Österlen Hampa, Tomelilla

Stopping at Thomas Jacobsson's farm to pick up fibres from hemp and pressing mass from hemp oil production (from first year's batch). Thomas is one of few farmers in Sweden cultivating hemp, he also takes an active part in promoting hemp as a building material.

Gunnarshögs Gård, Hammenhög

A guided tour through the production of rapeseed and flaxseed oil. This farm produces cold pressed oils, which results in a higher amount of seed mass than the refined one. About 2/3 of the seed becomes leftovers when pressing cold pressed oil. After the tour we pressed our own oil, and then we got pressing mass from both rapeseed and flaxseed with us back home.

Seeds and residues from oil production.

Testing how to produce rapeseed oil.

Pressing of flaxseed oil and piles of residue.

Rapeseed oil before and after particle removal.

Field of Österlen hampa's previous year hemp cultivation.

COLLECTING MATERIAL: BARLEY

Collecting barley residue from Oceanbryggeriet.

Inside the factory of Oceanbryggeriet.

The raw material for beer, barley, before extraction.

COLLECTING MATERIAL: CLAY

Excavation of clay in central Gothenburg.

Collecting clay.

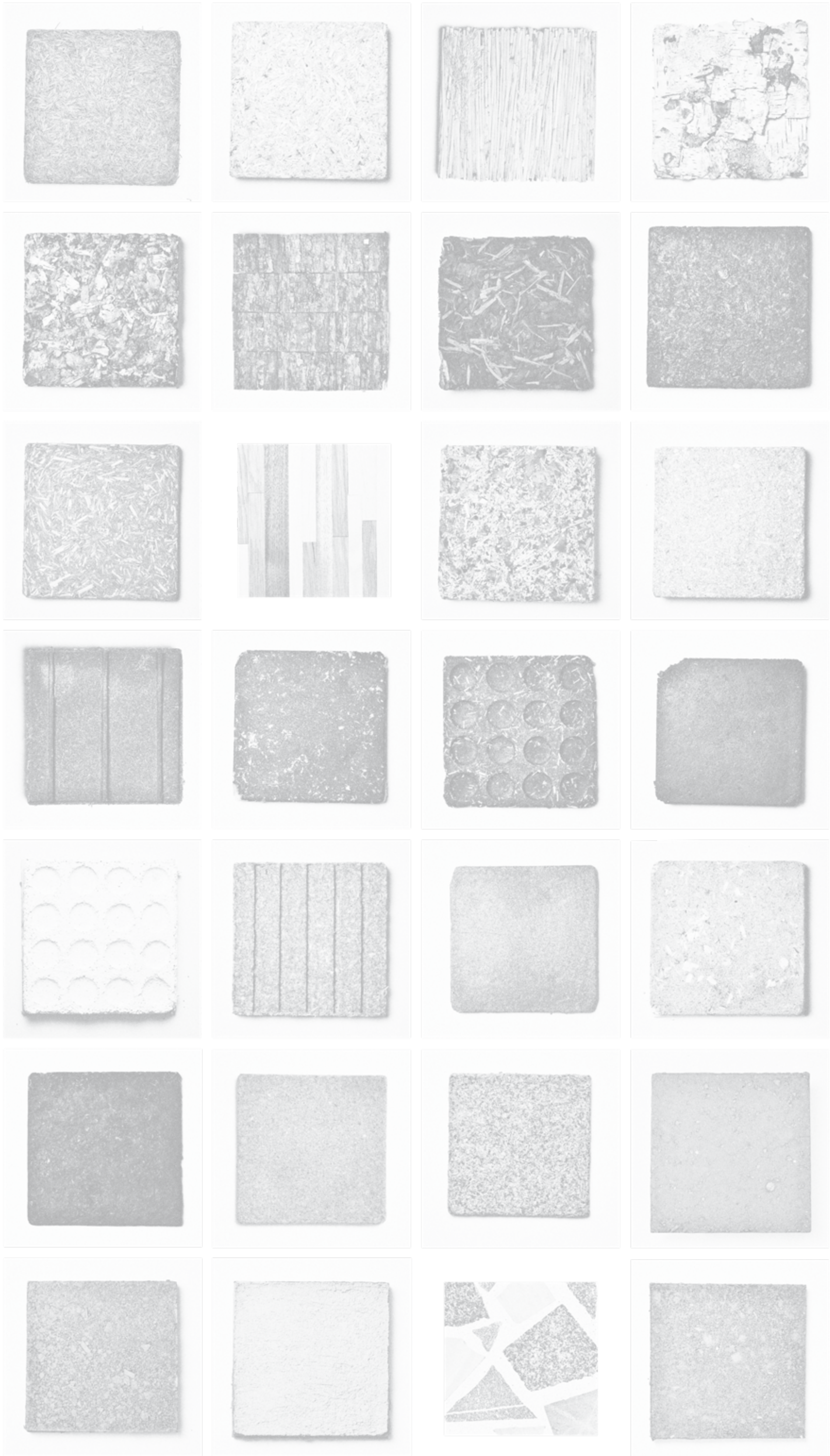
COLLECTING MATERIAL: STONE

Collecting leftover stone from Stencentrum's container.

Leftover pieces of stone from production of countertops, floor tiles and wall cladding.

COLLECTING MATERIAL: WOOD

Leftover pieces of wood at Svensson & Örn Snickeri AB.



CHALMERS

Master Thesis Spring 2019