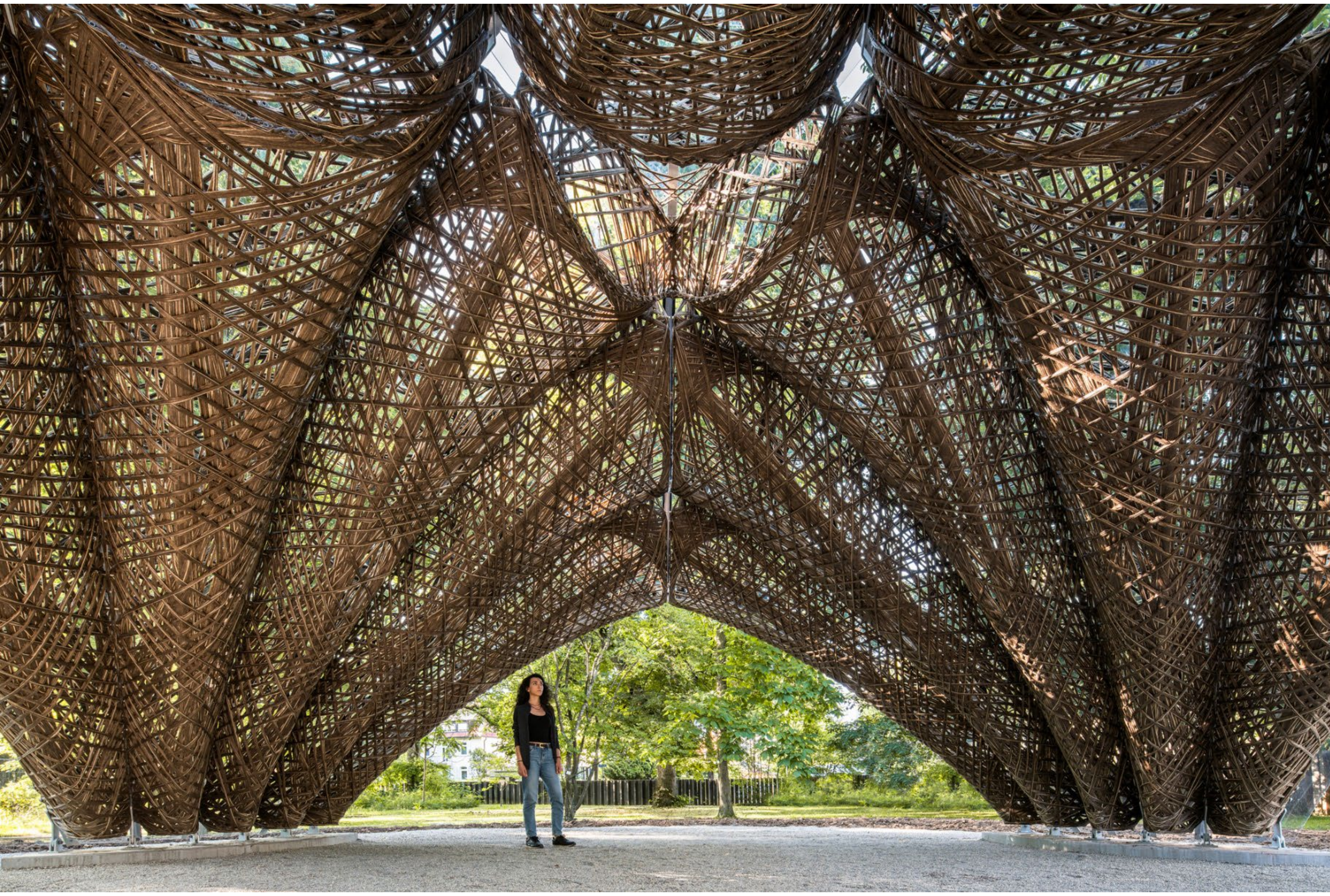
A NEW VISION ON LIGHT WEIGHT STRUCTURES WITH THE USE OF FIBROUS ARCHITECTURE



LivMats Pavilion 2021, Botanic Garden Freiburg, Germany

Courtesy of the Institute for Computational Design and Construction (Prof. A. Menges)
Institute of Building Structures and Structural Design (Prof. J. Knippers)

Showcases the use of flax fibers using the Coreless Filament Winding (CFW) fabrication technique and illustrates the potential of fibrous structures as light weight loadbearing building elements which expresses a new architectural language

Ruben Tjebbe Steinfort
5675138
Architectural Engineering Graduation Design Studio
7 November 2023

TU Delft Delft University of Technology

[This page has been left empty deliberately]

Personal Information

Name:	Ruben Tjebbe Steinfort
Student no.	5675138

Studio

Architectural Engineering Design

Design Tutor: Stephan Verkuijlen

Research Tutor: Mo Smit

Argumentation of choice of the studio:

The combination of engineering and architecture has always captivated me, and I'm eager to be at the forefront of architectural innovation using cutting-edge methods and materials that may shape the architectural language of tomorrow.

Focus

Context: Northeast-Groningen

Technology: Make

Design Program: Digitization

Contents

Keywords

BIOBASED

A material intentionally made from substances derived from living (or one-living) organisms.

BIOMIMICRY

The design and production of materials, structures, and systems that are modelled on biological entities and processes [OED].

COMPUTATIONAL DESIGN

A field that involves the use of computer algorithms, simulations, and data analysis to support and enhance the design process (Arup, 2023).

CORELESS FILAMENT WINDING (CFW)

Coreless filament winding (CFW) is an advanced method of filament winding which eliminates the need for a mandrel by winding fiber around a series of anchor points thus enabling the creation of multiple geometries within a single fabrication setup [Prado et al. 2014].

DEMATERIALIZATION

The reduction of the quantities of materials needed to serve a function in which it aims to lower life cycle energy requirements by reducing material and resource inputs [Wernick et al., 1996].

FIBROUS (FIBER) ARCHITECTURE

Fibrous elements with primarily tensile capacity, which are embedded in a matrix material that holds them in their relative positions.

ROBOTIC FILAMENT WINDING (RFW)

An industrial robot that is equipped with a feed and deposition system for placing fibers impregnated with resin along the major stresses directions of complex shape parts.

TECTONICS

The Science or art of construction, both in relation to use and artistic design.

General Problem statement

One of society's most pressing environmental issues is the rising demand for new structures and infrastructures. However, rather than reducing the overall amount of material utilized, innovations in the building industry have been concentrated on lowering the cost of materials through standardizing the manufacturing processes, resulting in significant waste, pollution, and gas emissions. This trend[1], illustrated in figure 1, resulted in a slight increase in efficiency in the building industry, but in comparison with the manufacturing industry and the overall growth of the total economy the building industry is falling behind.

A need for an increase in resource efficiency of structures and the productivity of our building processes is a key for the future of the industry. According to INJArchitects lightweight constructions are from an ecological, social and cultural standpoint beneficial to our society. Due to less waste material, feasibility to disassemble and recycle or compost and the necessitate production and assembly results in increased employment (INJ, 2023).

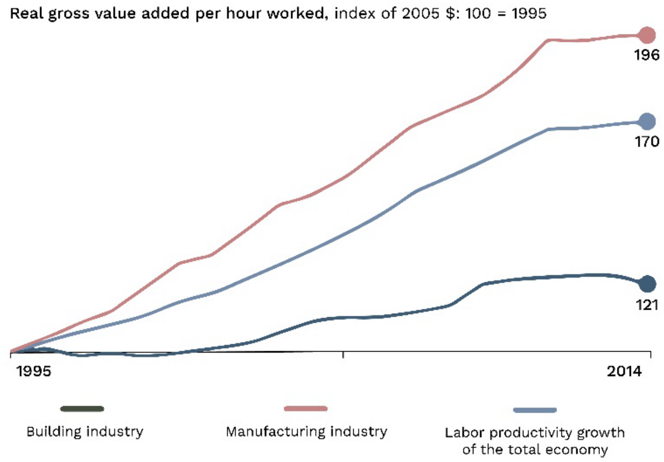


Figure 1: The inefficiency of the building industry illustrated in comparison with the manufacturing industry and the labor-productivity growth of the total economy

Although steel has been an efficient material to use in light weight structures the introduction of steel in the industrial revolution has started the exhaustion of our planet and therefore new materials need to be researched thoroughly to capture CO2 in the production of the material instead of depleting it in the atmosphere. Light weight structures can also be constituted from fibrous materials for example, such as: carbon-, glass- and most interestingly flax fibers. These materials have firstly, higher tensile strengths than steel (1000-2000 Mpa for flax fiber, 3000-4000 Mpa for carbon fiber and 550 Mpa for steel[2]). Secondly, they are lighter than steel with a lower density (1530 kg/m^3 for flax fiber, 1750 kg/m^3 for carbon fiber and 7800 kg/m^3 for steel). Thirdly, emit less CO2 in the air in relationship to their density during production (carbon fiber: 8,10 kg/CO2 eq/kg and steel 1,77 kg/CO2 eq/kg) and for flax this results in an absorption of CO2 of approximately 14,8 kg/C02 eq/kg per hectare per year (yield depended). Additionally, flax grows about 100 cm in a 100 days and can be combined over the year with other crops due to the low soil depletion[3]. Lastly, research has shown that flax fibers can be harvested on soils in North-Western Europe (Vleesschouwers, 2020) and therefore concluding with the stated arguments flax may be the most potent material for light weight structures.

Additionally, the manufacturing industry has been capable of increasing their production efficiency due to the large quantities it can produce with minimal variations. The building industry mostly relies on the variations in end products and therefore can't utilize the same manufacturing techniques. As Jan Knippers, Professor at the Institute of Building Structures and Structural Design on the University of Stuttgart, states: "we as architects and engineers have to develop our own fabrication processes adapted for the needs of architectural and building construction". A technique that utilizes the material characteristics of fibers, such as Flax, is Robotic Filament Winding (RFW) or Coreless-Filament Winding (CFW).

Lastly, the technique results in material efficient structures that are based on natural principles using biomimicry and therefore can be an innovative alternative in the construction industry.

1 Source: GGCD-10; national statistical agencies of Turkey, Malaysia, and Singapore; OECD, Rosstat; US Bureau of Economic Affairs; US Bureau of Labor Statistics; WIOD; World Bank; McKinsey Global Institute analysis

2 Source: matweb; material property data; https://www.matweb.com/

3 Source: allianceflaxlinenhemp; https://allianceflaxlinenhemp.eu/en/flax-growing-expertise

Fibrous structures using Flax fibers

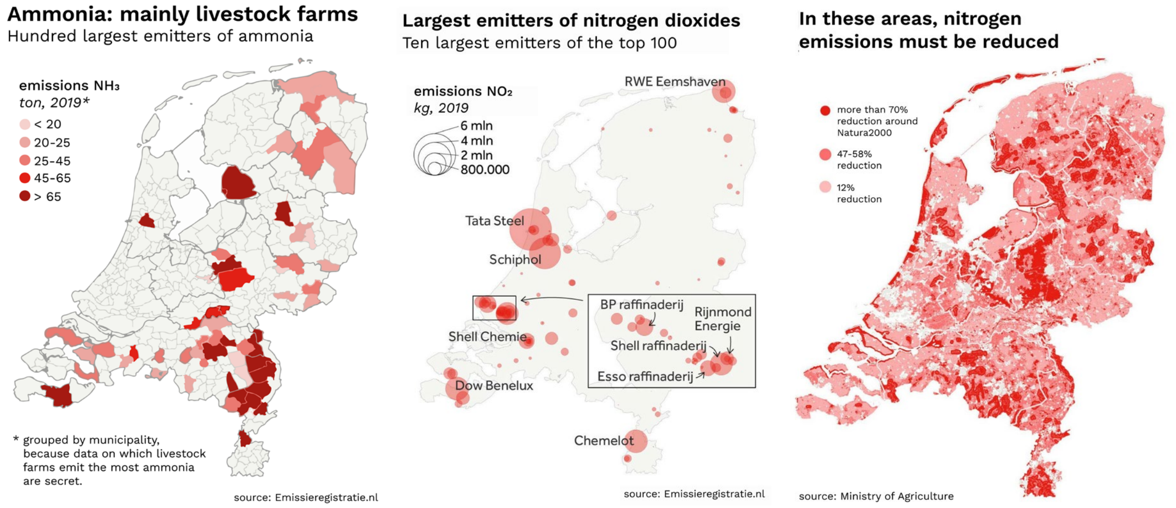
Courtesy of The Institute for Computational Design and Construction (ICD) and The Institute of Building Structures and Construction (ITKE)

General Problem Statement:

The urgent environmental challenge of increasing demand for structures has led to a focus on cost reduction rather than material reduction in the building industry. This trend has improved efficiency slightly but lags behind other industries. Resource efficiency and productivity are vital for the industry's future. Experts advocate lightweight constructions for ecological, social, and cultural benefits. While steel, historically efficient, poses environmental concerns, fibrous materials like flax offer higher tensile strength, lower density, and reduced CO_2 emissions or even absorption of CO_2 during production. Flax's rapid growth and compatibility with crop rotation makes it a promising material. Lastly, the technique of Robotic Filament Winding (RFW) shows promise for material-efficient, biomimetic structures, offering an innovative alternative in construction.

Context Problem Statement

The Netherlands, among other European countries, face a major nitrogen crisis, shown in figure 3, which is the result of the ever going expansion of the livestock industry, the building industry and in general industrialization. The crisis has stagnated building production nearby Natura 2000 regions (Ministerie van Binnenlandse Zaken en Koninkrijkrelaties, 2019) and approximately 3000 livestock farms need to extensify, switch, innovate, move or quit their businesses (Rijksoverheid, 2023). This can be the result of the lack of innovation in both industries stated in the general problem statement.



a *b* c

Figure 3: Ammonia and Nitrogen emission in The Netherlands (translated)

Focusing on the Northern part of the Netherlands, a region known for its country side and extensive farm industry, socio-demographic problems have arisen in the last couple of decades. The rural regions cope with shrinking population numbers, shown in figure 4 (CBS, 2022), an immigration of young adults that move to urban settlements, like Amsterdam, which causes an aging population composition, illustrated in figure 5 (CBS, 2022).

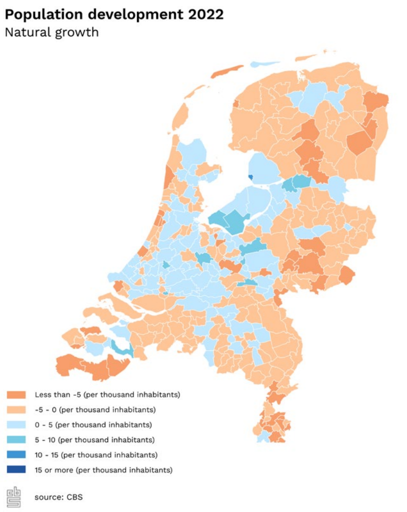


Figure 4: Northern Netherlands faces a demographic decline in natural growth CBS, 2022

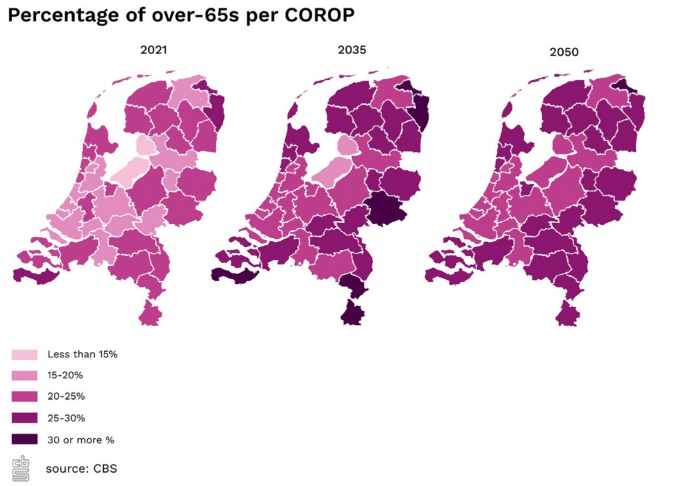


Figure 5: Additionally the Northern region has an aging problem CBS, 2022

The agriculture industry faces also a crisis in which, according to (Bakker, 2021), 41% of the agricultural business, approximately 16.000 businesses, don’t have a successor. The pressure on the industry from society has taken a toll on the farmers and it’s future prospects. Therefore young adults don’t seem to have clear prospects and ambitions from the government. As Van der Plas, the forewoman of the Dutch political party BBB, states:

"Farmers in the Netherlands produce cleaner and more sustainably than elsewhere in the world and yet some parties do not hesitate to portray farmers every day as environmental polluters, animal abusers and poison injectors".

The possibilities for further modernization of the industries of farming and building can be a gamechanger which can result in more young adults stepping into the business of these industries. Therefore on a socio economic basis young adults would be more willing to stay in the rural regions if there are more opportunities for them to prosper. This would result in a more well balanced age population composition and can give the region an economic boost. Additionally, a possibility can arise to combine both transitions of the farming and building industries by letting them work together. To create a circular economy whereby farmers can harvest crops that can be used as biobased building materials in the building sector. Such a biobased material can be for example: Flax, a fiber that can be grown on clayish soils which the Northern part of the Netherlands mostly consists of.

Historically seen, the province of Groningen, in the Northern part of The Netherlands, had a flourishing flax industry in the 1950’s (Brouwers, 1957). The province of Groningen wants to bring back this industry back by reintroducing flax fields (Hofslot, 2023).

Lastly as previously was mentioned has the agricultural sector a bad image of harming the environment due to the large amount of nitrogen emissions. One of the Natura 2000 zones that is in great danger is The Wadden area in the North of Groningen. It is a habitat where a lot of breeding birds come over in the spring to lay their eggs and therefore the area is of great importance for a bigger ecosystem (Krap S, Straathof (DLG), Sleeking, Verlaat (DLG), & Janssen, 2017). Flax can also be potent to break free of this image. The material has a low emission of nitrogen on the environment, it extracts carbon dioxide from the atmosphere and flora and fauna prosper very well in the landscapes (CLM, 2020).

What if the building- and farming industry join forces to grow biobased materials in regional landscapes that can be used for the building industry. By creating a pilot project that showcases the possibilities with the use of flax fibers can benefit the Northern region of The Netherlands greatly.

A region plagued by the disastrous earthquake problems that were the result of the long lasting tunnel vision of the Dutch government that saw Groningen only as a profitable region for their gas fields. Now is the time for the region to showcase its potential as a key factor in combating the nitrogen crisis in the agricultural sector and as a mayor player to fulfill the need for building materials.

By doing so we can recreate a synergy not only between farmers, builders and the inhabitants, but with nature itself.

The Natura 2000 region of the Wadden coast of Groningen, The Netherlands.

Illustrating the fragile habitat of a variety of bird- and plant species
that are harmed by the nitrogen deposition.

Context Problem Statement:

The Netherlands, like several European countries, confronts a significant nitrogen crisis resulting from the continuous expansion of the livestock, construction, and industrial sectors. This crisis has led to a slowdown in construction projects near Natura 2000 regions and necessitates about 3,000 livestock farms to adapt or cease their operations. The lack of innovation in these sectors exacerbates the problem. Focusing on the Northern Netherlands, demographic challenges have emerged, including a declining population and an aging demographic due to urban migration, causing socio-economic issues. The agriculture industry also faces succession problems. A potential solution lies in modernizing these industries, promoting youth involvement, and exploring synergies between farming and construction, particularly using biobased materials like Flax. Such innovations can address the nitrogen crisis and enhance economic prospects in the region while fostering environmental sustainability.

THEME

SUB-THEMES

Materiality of Flax

- What are the characteristics of (flax) fibers that need to considered for using fibers for structural purposes of building elements?

From crop to product to raw material

- How are flax fibers harvested, produced and finalized to be used in building elements and how can they be reused?

Robotic Filament Winding (RFW) and Coreless Filament Winding (CFW) with (Flax) Fibers

- How can the fabrication technique of Robotic Filament Winding (RFW) also known as Coreless Filament Winding (CFW) be used with flax and other types of fibers to utilize the characteristics of the material the most optimal?

Structural possibilities of Fibrous structures

- Which archetype structures can be made from fibrous structures?

Modularity possibilities

- How can flax fiber building elements be made modular so that a range of building elements can be created and result in more adaptable designs in its life cycle and afterlife?

Dematerialization

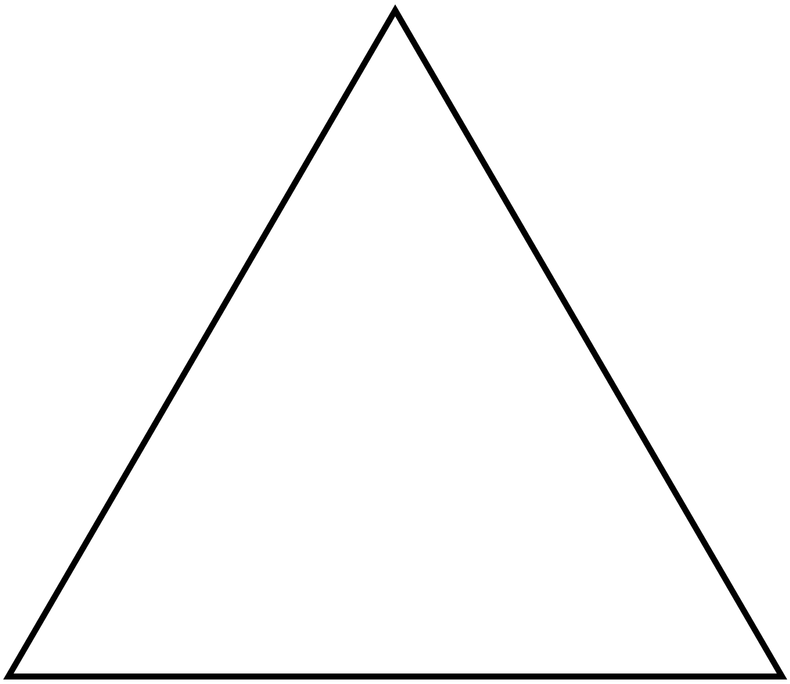
- In comparison with conventionally made building elements how much (fiber) material can be saved with the idea of dematerialization?

Tectonics of Flax

- How do these fibrous materials and techniques alter the way we are connected to our living environment and what is this kind of new architectural language?

Technique

Robotic Filament Winding (RFW) or Coreless Filament Winding (CFW) using (Flax) Fibers



Context

Northeastern Netherlands

(Groningen)

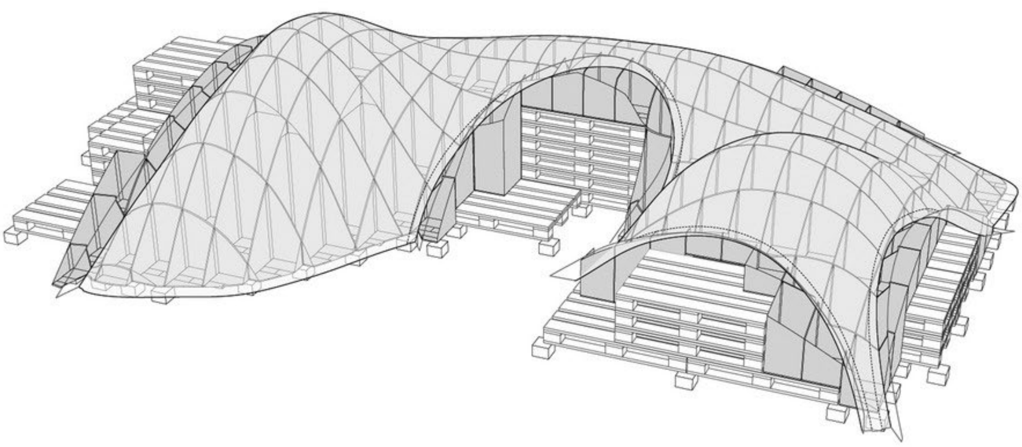
Use / Program

Farm structures (Farmers and as a showcase for the harvesting, production and end product cycle)

Overall Design Objective

In this project the outcomes of the thematic research on the building material Flax, with a combination of other fibrous materials, such as carbon fibers and glass fibers, that is conducted on a micro level in which structures, characteristics, strengths and weaknesses of the material are analyzed, will be used. Additionally, by doing so the most suitable building structures that use the full potential of the material can be chosen and integrated into the design process.

The design project focuses on the farm of the future which is constructed using Robotic Filament Winding Techniques (RFW) and Coreless Filament Winding Techniques (CFW) and is constituted out of fibrous structures. The aim of the project is to design a farm which is incorporated into the Groninger landscape and uses regional sources, such as Flax. Therefore, potent fibrous structures that are constituted from the thematic research are explored and integrated into the design. The goal, firstly, is to design various potent layout which is the most suitable for the required infrastructure for flax farm activities and to promote a smooth workflow and efficiency between the facilities. Secondly, in the architectural design a space for community engagement, education and events is desired to showcase the full potential of flax as building material and to educate and inspire people. Lastly, the ambition is to explore the transformative impact of this new architectural language on the connection between humans and their living environment.



Design Hypothesis

The flax farm of the future, that is constituted from fibrous structures and which is constructed using Robotic Filament Winding Techniques (RFW), will have a positive impact on the layout, the efficiency of the required facilities and translates into a new architectural language that has a transformative impact on the relationship between humans and their environment and ultimately showcases the full potential of the use of flax in Architecture.

Design Sub-Questions:

- Which materials and construction techniques, both historically and contemporary, have been used to accommodate different farm typologies in The Netherlands and abroad?

- What are the geographical and climatic characteristics of the site, in the Groninger landscape, that needs to be considered, and how do they influence the design?

- What infrastructure is required for flax farm activities, including storage, processing, production and packaging and which layout is the most suitable to use in the design to promote a smooth workflow and efficiency between the facilities?

- How can the architectural design of the farm include spaces for community engagement, education and events to showcase the potential and the production cycle of Flax?

- How do these materials and techniques alter the way we are connected to our living environment and result in a new architectural language?

This hypothesis suggests a study of the materials and construction methods employed in different farm typologies, in The Netherlands and around the world, both historically and contemporary. It also acknowledges the importance of understanding the geographical and climatic characteristics of the Groninger landscape in shaping the design. Furthermore, the hypothesis calls for a review of the infrastructure required for flax farming activities and the potential for creating educational facilities or visitor centers to showcase flax production. Ultimately, the hypothesis highlights the transformative impact of chosen materials and techniques on the relationship between humans and their environment, aiming to identify a new architectural language specific to flax farm typologies.

Reflection on the relevance

The constitution of a new farm typology of the future which combines harvesting, production and showcasing of the possibilities of flax can have great effects on the way we built our new light weight structures. Additionally, a connection with the Groninger landscape can be made in the design and can therefore give farm architecture a new place in Groningen.

Different fibrous materials, such as: carbon fiber, glass fiber and most recently flax fiber have been used for these light weight structures. By connecting the necessary characteristics of a material that are needed for light weight structures to its source, the soils, a true sustainable building cycle can be achieved.

From a socioeconomic standpoint the design research can have great effects on the image that has been portraited on the farm industry the last couple of decades. A new image can be resulted whereby a circular economy can be created, but also in the built environment itself with new farm typologies of the future which co-exist with nature and truly protect the natural environment.

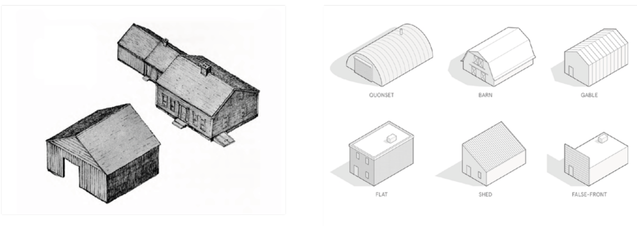
Flax fiber extraction

Illustrating the technique used to extract flax fibers

Design Research Methodology

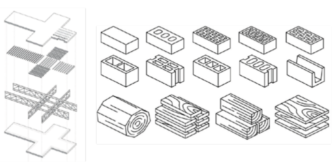
In the design research stage various research methods will be conducted to utilize the outcomes of the thematic research, which was more general by nature, to make the design context based. Firstly, the chosen typology: “farms” will be investigated from a historical and contemporary perspective to inspect the various materials and structures used in the past and present. This will be done by literature review and case study analysis (qualitative). Secondly, the context of the Groninger landscape will be analyzed on geographical and climatic characteristics that need to be considered for the design. This will be done by context analysis which is comprised of field research and literature study (qualitative). The required infrastructure for flax farm activities, including storage, processing, production and packaging are analyzed through case study analysis, literature study and predominantly Research by Design which aims to create various layouts which can be the most suitable to use in the design to promote a smooth workflow and efficiency between the facilities (qualitative).

Farm Typologies



Historically

Contemporary



“Which materials and construction techniques, both historically and contemporary, have been used to accommodate different farm typologies in The Netherlands and abroad?”

Investigation of the various types of materials and structures that have been used for various farm typologies through the centuries.

Using case study analysis materials and structures will be investigated.

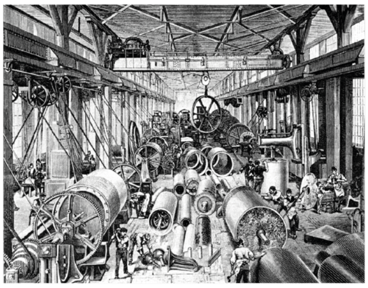
“What are the geographical and climatic characteristics of the site, in the Groninger landscape, that needs to be considered, and how do they influence the design?”

Investigation of the geographical and climatic characteristics of the site in Groningen.

Using context analysis based on field research and literature study.

Additionally, preliminary designs will be created using Research by Design and analyzed with (computational) simulations. To find out how flax fiber building elements can be made modular Research by Design is used and prototypes will be created. How to incorporate community engagement and educational possibilities in the architectural design of the farm typology various case studies will be analyzed, literature study conducted and through Research by Design several options will be designed for the integration in the design.

Lastly, to get a better understanding from an architectural perspective how these fibrous materials, techniques and structures alter the way we are connected to our living environment and which could result in a new architectural language empirical research of the impact is used (qualitative).



"What infrastructure is required for flax farm activities, including storage, processing, production and packaging and which layout is the most suitable to use in the design to promote a smooth workflow and efficiency between the facilities?"

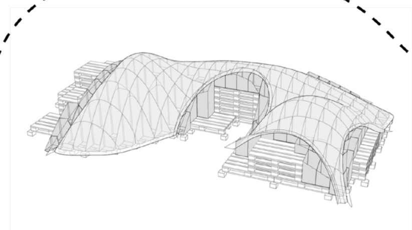
Investigation of the required infrastructure and exploration of the most suitable layout.

Using case study analysis, literature study and predomintanly Research by Design.

"How can the architectural design of the farm include spaces for community engagement, education and events to showcase the potential and the production cycle of Flax?"

Investigation and exploration of the implementation of community engagement possibilities in the design of the farm typology"

Using case study analysis, literature study and Research by Design.



Possible vision on farm typologies of the future

"How do these materials and techniques alter the way we are connected to our living environment and result in a new architectural language?"

Investigation of the impact of the chosen techniques and materials on our lives.

Using empirical research the impact of the fibrous architecture will be investigated.

Thematic Research Objective

The main objectives of the thematic research are the in depth analysis of the fibrous material of Flax and several other types of fibers, such as Carbon and Glass, used with the Coreless-Filament Winding (CFW) techniques. Additionally, the structural potential of Flax fibers will be researched. The fundamental idea behind this research is to start with the material—fibers—in order to create the final architectural masterpiece. This principle works the other way around than conventional building methods used with biobased or non-regenerative materials which don't have the material as it's starting point.

Characteristics

By studying the characteristics, the harvesting-, production- and end cycle of Flax and lastly the techniques used to create fibrous structures the full potential of the material and it's natural structures can be found for architectural purposes. To conduct a comprehensive comparison with other non-renewable materials, such as concrete, steel, carbon- and glass fibers various performance indicators have been formulated. These performance indicators are categorized in: Structural behavior, Fire behavior, Thermal behavior, Moisture behavior, Production cycle, Aesthetics and Sustainability.

Structural behavior will be analyzed with the topics of tensile- and compression strength, flexibility and elongation, durability and weight and density. The fire behavior is analyzed on fire resistance and retardance. Moisture absorption and moisture resistance are analyzed in both wet and dry conditions to evaluate the moisture behavior of the material. Thermal behavior is evaluated on the aspects of thermal insulation and conductivity. On the production cycle the material, structure and techniques are evaluated on the aspects of processing efficiency and costs. The aesthetics of flax is analyzed to evaluate the potential of esthetically appealing structures. Lastly, sustainability is evaluated on the aspects of biodegradability, eco-friendliness, UV resistance and chemical resistance. From the aspect from the above architectural structures will be found that can be used in the architectural and building industries.

The production/biological cycle of Flax

The cycle of flax will be investigated thoroughly by focusing on the aspects of harvesting, production, the use in design and it's afterlife. Therefore a critical look on the cycle will result in the categorization in which cycle the material and its techniques are part of. One of these models that describes the biological and manufacturing cycles is the butterfly model, shown in figure 6. Additionally, the alterations of the material are researched, for instance the types of epoxy's used and if there are biobased alternatives which could result the material to be even more sustainable in the end of life phase.

Fabrication Techniques

From there on the fabrication techniques of Robotic Filament Winding (RFW) and Coreless-Filament Winding (CFW) are analyzed. Both these techniques use fibers and most recently also Flax fibers. The advantages are analyzed on the basis of dematerialization, disassembly and modularity.

Computational Design of Fibrous structures with the use of Biomimicry

Lastly, in the thematic research computational design will be investigated how this can help create structures using nature-based principles (biomimicry).

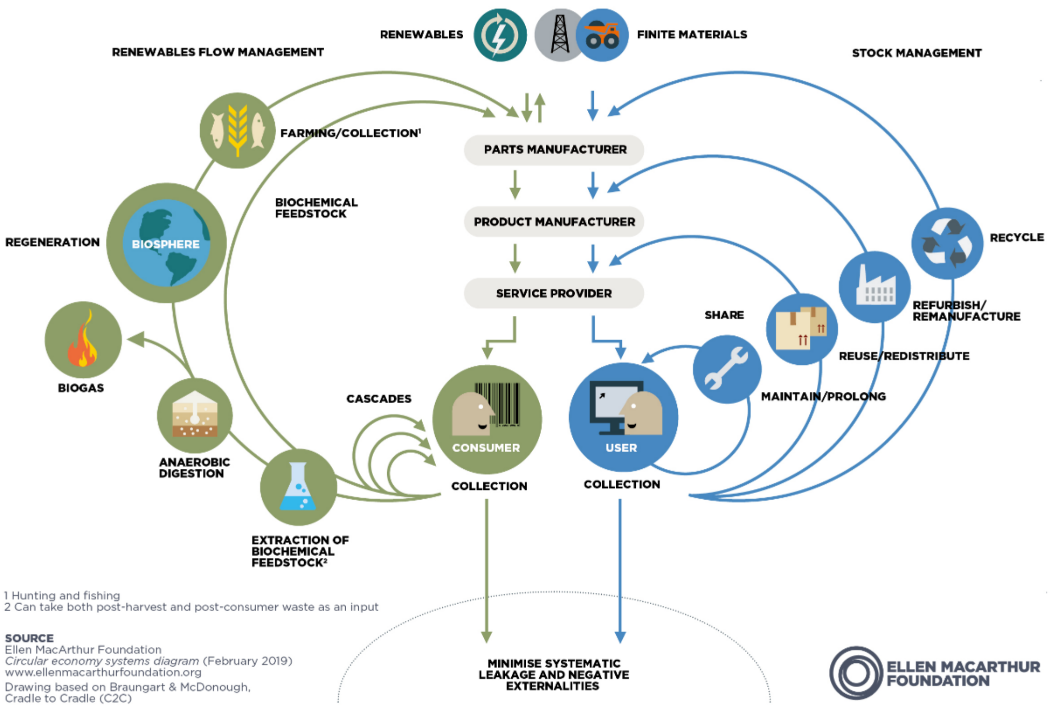


Figure 6: Butterfly Model

The research theme is related to the general problem statement and overall design question, because the study results in an extensive outcomes for structural and architectural purposes of (flax) fibers and the production technique of Robotic Filament Winding or Coreless-Filament Winding. Which result in lightweight fibrous structures that reduce material waste, are made from regenerative materials and can be produced very efficiently. Resulting in an alternative material and structure for architectural typologies which use lightweight structures and are normally constructed from non-regenerative materials, such as steel and concrete.

Research Question:
How do you create light weight structures using Robotic Filament Winding techniques (RFW) from (flax) fibers from regional landscapes into modular design elements that can be used in programs which utilize large open spaces in architecture whereby tectonics, dematerialization and modularity are taken as starting points?

Research Sub-Questions:

- What are the characteristics of (flax) fibers that need to be considered for using fibers for structural purposes of building elements and in which forms can these fibrous structures that are exerted on axial compression be translated?

- How are flax fibers harvested, processed, and finalized so that they can be utilized as building materials, and how does this relate to the biological and/or production cycle that includes the afterlife of the material, as in the case of the butterfly model?

- How can the fabrication technique of Robotic Filament Winding (RFW) also known as Coreless Filament Winding (CFW) be used with flax and other types of fibers to utilize the characteristics of the material the most and result in structures that use dematerialization, disassembly and modularity?

- How can computational design help with creating fibrous structures that utilize dematerialization and are optimized for the shapes needed for the program using nature-based principles (biomimicry)?

Reflection on the relevance

The thematic research is relevant due to the high level of innovation it can bring to the building industry. From a scientific point of view the in depth analysis of the fibrous material, flax, and its structural purposes to create light weight structures and thereby reduce material waste, increase building efficiency and speed play a big role in the innovation it can bring. The translation of the techniques of robotic filament winding and coreless-filament winding into architectural purposes which can be used in various building programs: such as: temporary and portable structures, sports facilities, such as sport halls, green houses, shelters, exhibition and event pavilions, large atriums or train station canopies can benefit the architectural field as well. The combination of the biobased material and the robotic technique result in more material and production efficiency whereby less material is wasted. From a societal perspective the synergy between farmers (harvest), builders (production) and residents (living) can strengthen the cohesion in society. Lastly, from an economical and environmental perspective the combination of the biobased material and the robotic techniques can create prosperity, reduces the environmental impact of the industries and creates a consciousness in society that we truly can work with the environment instead of depleting it for our own purposes.

From architectural point of view, a new architectural language may be discovered due to the fibrous structures and aesthetics of the material and structure.

Coreless Filament Winding (CFW) using Flax fibers

Courtesy of The Institute for Computational Design and Construction (ICD) and The Institute of Building Structures and Construction (ITKE)

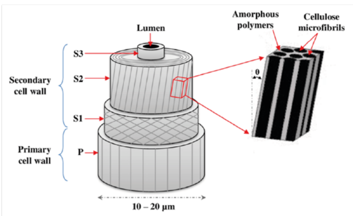
Thematic Research Methodology

In this study several research methods will be used to conduct research on the material characteristics, production and biological cycle, fabrication techniques and finalization of different building element designs.

Through literature study the material characteristics and by case-study analysis the use of (flax) fibers in the building industry are researched historically and in contemporary architecture (quantitative). The harvesting, production and finalization cycle will be analyzed through literature study (quantitative) and interviews with several experts from the field, such as Machiel Bakx, owner of Energiegames, which focusses currently on connecting builders with farmers to create biobased building materials from locally harvested crops (qualitative). The findings will result in essential information which will be bind into a set of design tools that will be used in the next stage of Research by Design (qualitative).

The robotic techniques used for these fibrous structures, which are Robotic Filament Winding (RFW) and Coreless-Filament Winding (CFW), are analyzed using literature study and interviews with different experts in the field and from different universities. Lotte Krijnen and Lizzy Louer, both PhD students from the University of Eindhoven which research structural optimization and lightweight axial compressive elements made with the Robotic Filament Winding technique will be conducted. Prof. Jan Knippers, from the University of Stuttgart (ITKE), will be possibly interviewed to gather information on the Coreless-Filament Winding technique and engage an open conversation of the future of fibrous structures in the field of Architecture. Additionally, Moritz Doerstelmann, Professor of the

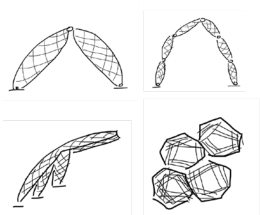
Material Characteristics



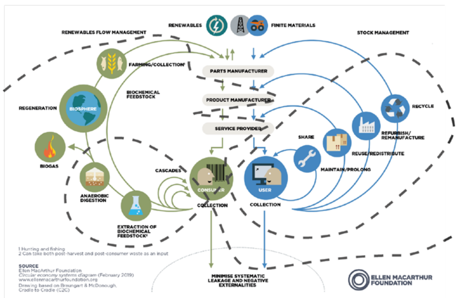
"What are the characteristics of (flax) fibers that need to be considered for using fibers for structural purposes of building elements and in which forms can these fibrous structures that are exerted on axial compression be translated? "

Investigation of the characteristics of different fiberous materials, such as: carbon-, glass-, hemp-, wool- and specifically flax fibers and in which forms these fibrous structures can be translated.

Using literature study, case study analysis and conducting several interviews with professors or PhD students from different Universities and experts from the field.



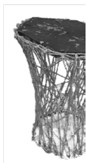
Biological/Production Cycle



"How are flax fibers harvested, processed, and finalized so that they can be utilized as building materials, and how does this relate to the biological and/or production cycle that includes the afterlife of the material, as in the case of the butterfly model?"

Investigation of the production and biological cycle of Flax to analyze where flax belongs in the butterfly model

Using literature study and conducting several interviews with professors or PhD students from different Universities and experts from the field.



Prototypi
architectu
element

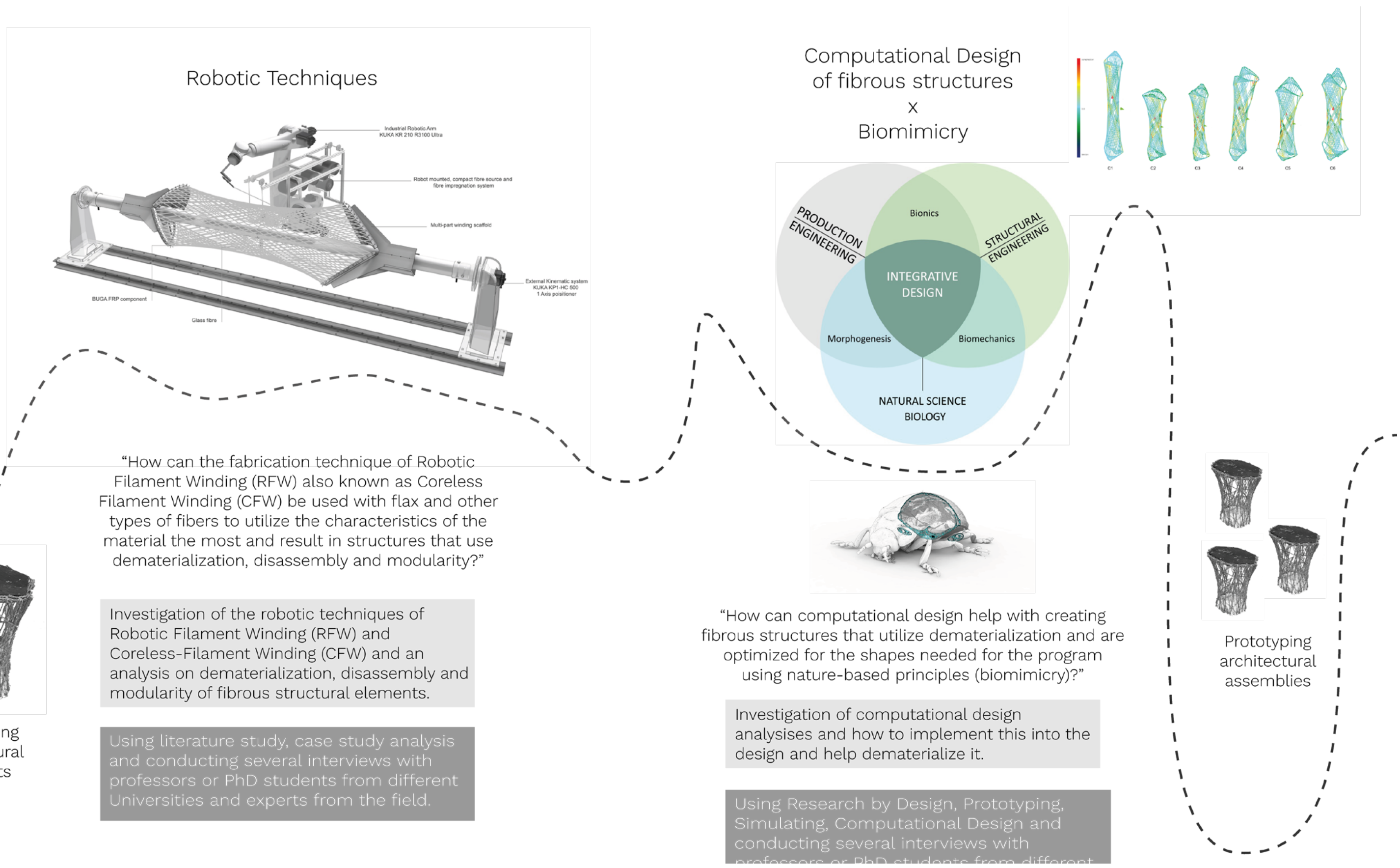
Ruben Tjebbe Steinfort

University of Stuttgart (ICD) and owner of FibR, a construction company that creates load-bearing elements, facades, and interiors using architectural fiber composite structures, will be interviewed to get more insight in how to work with the material and upscale the approach to other types of building elements.

Knowledge on computational design for the creation of fibrous structures will be gathered through literature review and interview(s) with several experts (qualitative). Daniël Jansen, a PhD student from the TU Eindhoven, focusses on the Robotic Winding technique combined with computational design on nature based principles. With a combination of computational and generative model simulation and Research by Design information is collected from these models to eventually create a huge variety of potential designs for fibrous structured building elements.

Prototyping will be used to conduct research in the physical realm to test the different designs that have been made in the previous stage of research by design and simulation (qualitative).

The prototypes will be designed and constructed through the principles of RWF and CFW techniques and will be tested on the performance indicators that have been listed in the thematic research objectives paragraph (qualitative). The structural behavior will be tested with a press to analyze the characteristics of the physical strength (qualitative). Fireproofing capabilities will be tested through destructive fire testing with the use of small- or bench scale testing to analyze the fire behavior of the material and structure (qualitative). The energy consumption of the material will be analyzed through literature study (quantitative).



Research Plan

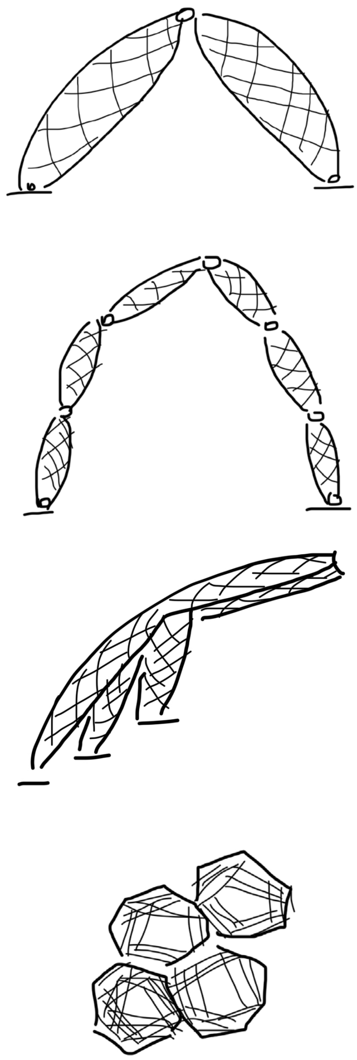
Generative design of The livMats Pavilion

Courtesy of The Institute for Computational Design and Construction (ICD) and The Institute of Building Structures and Construction (ITKE)

Expected results of thematic research and design implementation

The expected results from the thematic research are a better general understanding of how to design and construct customizable, distinctive and sustainable fibrous flax structures, potentially leading to replication and upscaling. Therefore, other designers can utilize the findings of the thematic research for their chosen program.

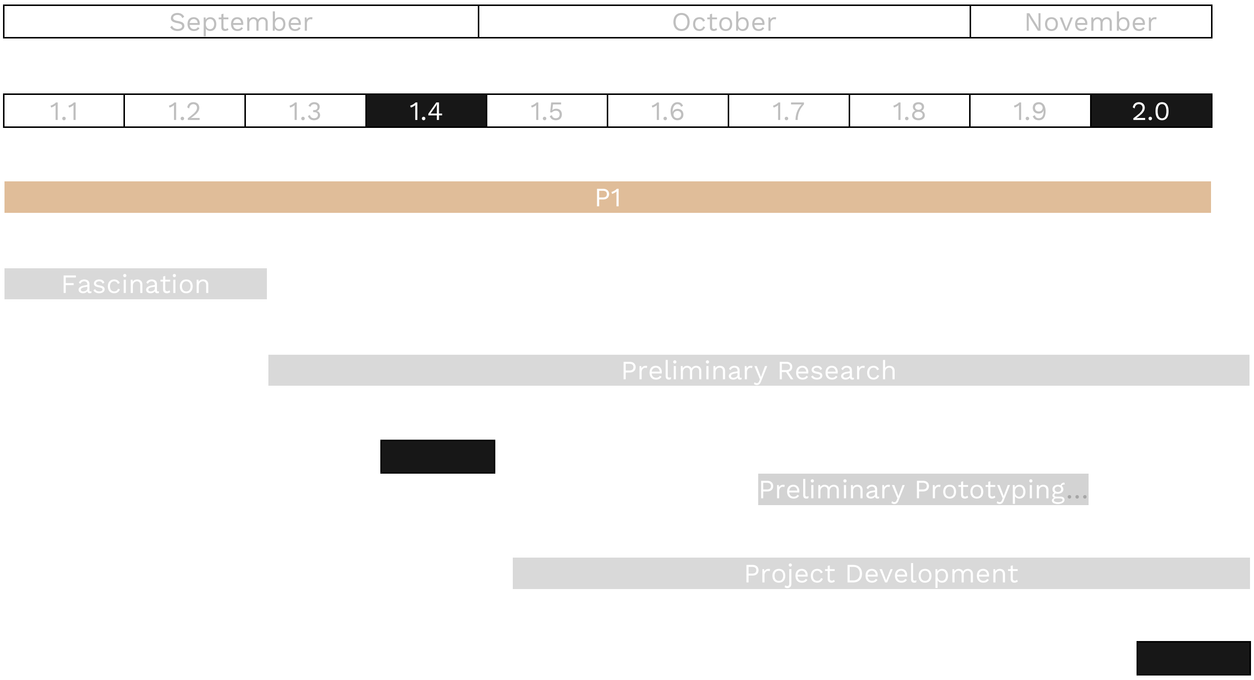
Lastly, it is expected that the general results from the thematic research will be implemented and adapted for the chosen program: of Farms of the Future in the design phase. This will be adapted for the structures and applications of the program and will finally result in a comprehensive design for the Farm of the Future which incorporates an integration into the harvested landscape, an efficient layout and an optimization between the required facilities. Lastly, to create a true showcase project possibilities of community engagement and education are integrated into the design to inspire people how to work and live with flax.



Preliminary prototyping with Flax fibrous structures

Steinfort, R.T. (2023), Prototype of a Flax fibrous structure, Delft

Planning



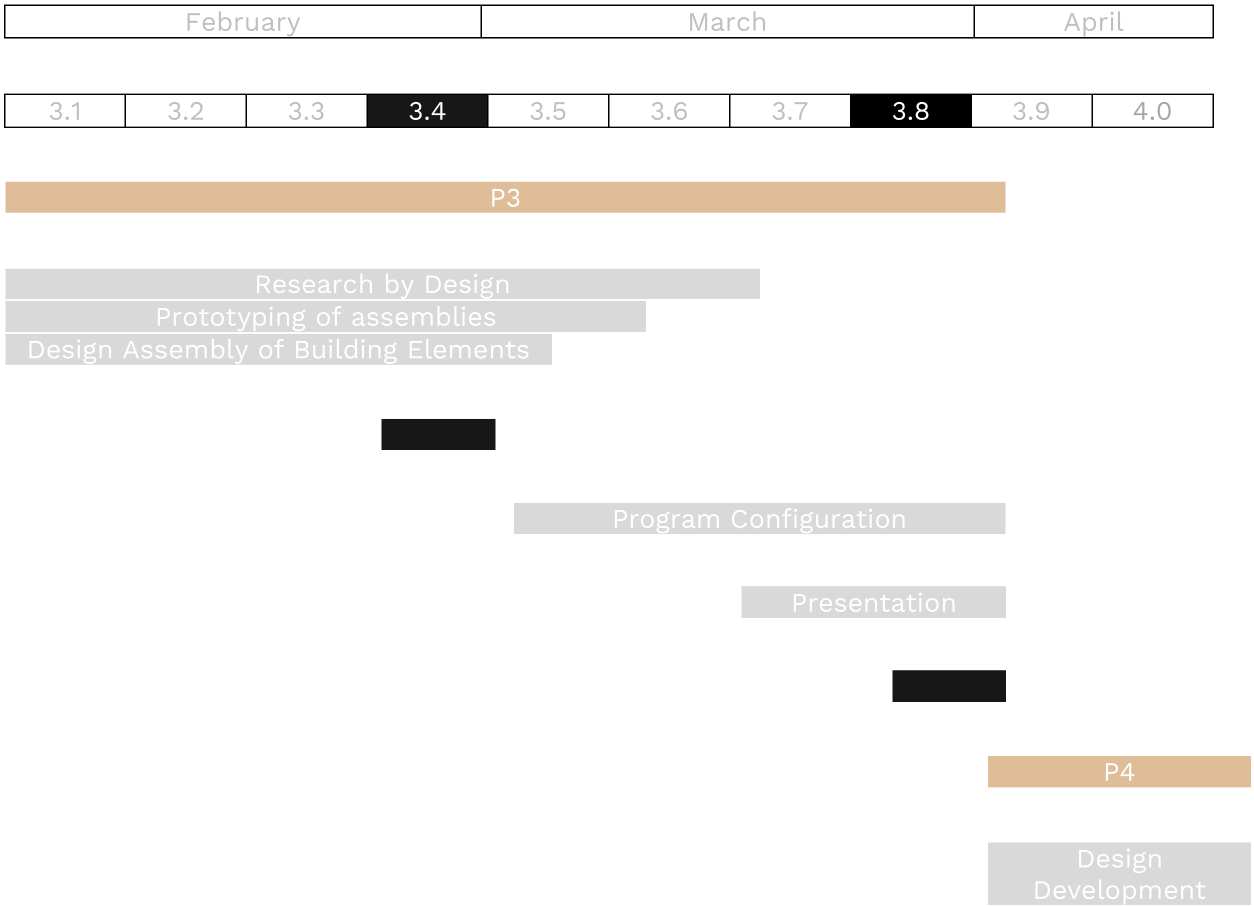
* 1.4 P1 I Concept Research Plan

* 2.0 P1 I Final Research Plan

* 2.6 P2 I Research transformation to Design tools

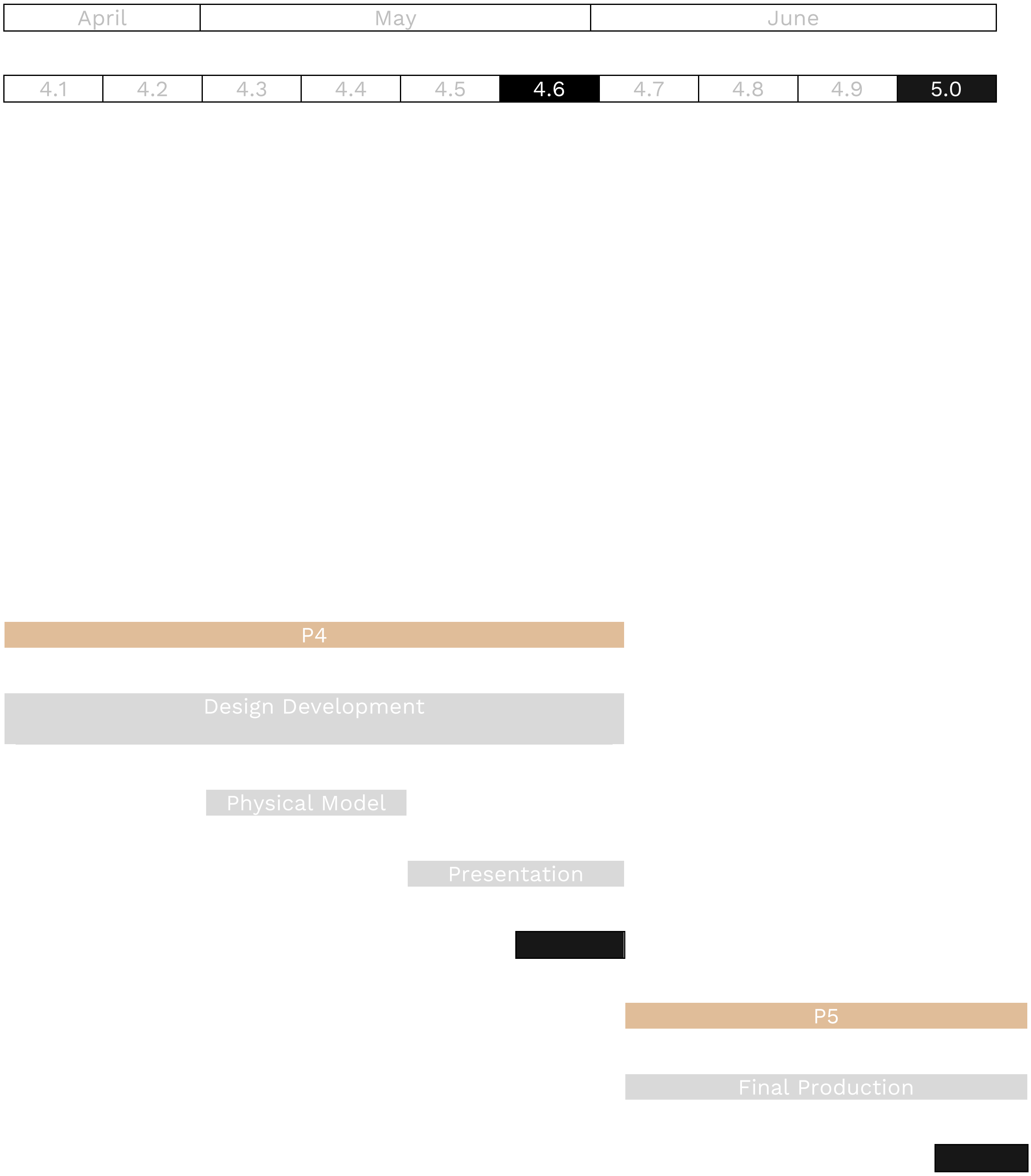
* 3.0 P2 I Final Research

Planning



* 3.4 P3 I Preliminary Concept Design

* 3.8 P3 I Concept Design



* 4.6 P4 I Final Design

* 5.0 P5 I Final Products

Literature

Radkar, S. S. (2018). *Potential Applications of Flax Fibers.* Fargo, North Dakota: North Dakota State University of Agriculture and Applied Science.

Agricultural Map of The Netherlands. (2023). Retrieved from Themasites.pbl: https://themasites.pbl.nl/atlas-regio/kaarten/?gm-b=1596110641718,true,1;1595921285002,true,1

Akram, M. (2017, June 21). *New approach to architectural construction.* Retrieved from iaacblog: https://www.iaacblog.com/programs/fiber-dynamics-2/

Allianceflaxlinenhemp.eu. (2023). *Alliance for European Flax-Linen & Hemp*. Retrieved from https://allianceflaxlinenhemp.eu/en

Amziane, S., & Sonebi, M. (2016). *Overview on bio-based building material made with plant aggregate.*

Amziane, S., & Sonebi, M. (2016). *Overview on Biobased Building Material made with plant aggregate.* Rilem Tech Lett.

Arkell, H. (2019, Augustus 22). *Plexus: The Space of Man by Hannah Arkell.* Retrieved from https://issuu.com/hannaharkell/docs/issu_upload-compressed

Arup. (2023). *Computational Design*. Retrieved from Arup: https://www.arup.com/services/digital/computational-design

Bakker, K. (2021, Januari 14). *'Gebrek aan jonge boeren is een groot probleem'*. Retrieved from Boerenbusiness: https://www.boerenbusiness.nl/agribusiness/artikel/10890648/gebrek-aan-jonge-boeren-is-een-groot-probleem

Blog libeco. (2018, Januari 15). *Extracting Flax Fibers*. Retrieved from Blog libeco: https://blog.libecohomestores.com/the-linen-craft/extract-flax-fiber/

Brouwers, A. (1957). *DE VLASSERIJ IN HET NEDERLANDS VAN DE EERSTE HELFT DER TWINTIGSTE EEUW.*

CBS. (2022). *Regionale bevolkings- en huishoudensprognose 2022-2050*. Retrieved from CBS: https://longreads.cbs.nl/regionale-prognose-2022/vergrijzing/

CBS. (2022). *Waar groeit of krimpt de bevolking?* Retrieved from CBS: https://www.cbs.nl/nl-nl/dossier/dossier-verstedelijking/waar-groeit-of-krimpt-de-bevolking-

CLM. (2020). *Bijdrage van vlas en hennep aan milieu- en klimaatdoelstellingen van het toekomstig EU-landbouwbeleid.* Culemborg: CLM.

De Natuurverdubbelaars. (2022). *ONTWERPEND ONDERZOEK BIOBASED (VER-)BOUWEN IN GROOT HAARZUILENS.*

(2022). *De urgente belofte van biobased bouwen.*

Energy Agency, I. (2021). *Global Energy Review: CO2 Emissions in 2021 Global emissions rebound sharply to highest ever level.* Retrieved from www.iea.org/t&c/

FibR. (2023). Retrieved from https://www.fibr.tech

Fibrous Tectonics: towards bio-based and bio-inspired architecture. (2022, November 10). Retrieved from jeccomposites.com: https://issuu.com/gsdharvard/docs/materialperformance

Harvard GSD. (2016, Juli 22). *Material Performance: Fibrous Tectonics & Architectural Morphology.* Retrieved from https://issuu.com/gsdharvard/docs/materialperformance

Hindmarsh, G. (1999). *Flax - The enduring fibre*. Retrieved from nzgeo.com: https://www.nzgeo.com/stories/flax-the-enduring-fibre/

Hofslot, G. v. (2023, September 13). *Bouwmateriaal, linoleum, papier. Vlas gedijt op Zernike Campus in Groningne. 'Dit gewas willen we heel graag terug hebben'*. Retrieved from Dagblad van het Noorden: https://dvhn.nl/economie/Vlas-gedijt-goed-op-de-Zernike-Campus-28636533.html

INJ. (2023, 3 27). *Lightweight Architecture: Innovate Materials and Construction Techniques*. Retrieved from INJ Architects: https://injarch.com/lightweight-architecture-innovative-materials-and-construction-techniques/

Jansen, D. (2023). *ROBOTIC WINDING*. Retrieved from Eindhoven University of Technology: https://www.tue.nl/en/research/research-groups/structural-engineering-and-design/roasd/robotic-winding

Keijsers, E., Dam, J., & Yılmaz, G. (2011). *Cellulose, een eindeloze bron van mogelijkheden.* Wageningen UR Food & Biobased Research.

Knippers, J., Solly, J., Koslowski, V., & Fildhuth, T. (2016, December). *MODULAR CORELESS FILAMENT WINDING FOR LIGHTWEIGHT SYSTEMS IN ARCHITECTURE.* Retrieved from ResearchGate: https://www.researchgate.net/publication/313421984_MODULAR_CORELESS_FILAMENT_WINDING_FOR_LIGHTWEIGHT_SYSTEMS_IN_ARCHITECTURE

Krap S, Straathof (DLG), Sleeking, Verlaat (DLG), & Janssen, V. (2017, 12). *PAS-gebiedsanalyse Waddenzee (001).*

Krijnen, L. P. (2023). *Numerical optimization and manufacturing of a bio-based 3D structure through robotic filament winding.* Eindhoven: Eindhoven University of Technology.

Kuma, T. (2015). *weaving carbon fiber pavilion designed by uni. of tokyo's T_ADs team*. Retrieved from designboom: https://issuu.com/gsdharvard/docs/materialperformance

Martins, V. C., Cutajar, S., van der Hoven, C., Baszynski, P., & Dahy, H. (2020, April 1). *FlexFlax Stool: Validation of Moldless Fabrication of Complex Spatial Forms of Natural Fiber-Reinforced Polymer (NFRP) Structures through an Integrative Approach of Tailored Fiber Placement and Coreless Filament Winding Techniques.* Retrieved from MDPI: https://www.mdpi.com/2076-3417/10/9/3278

Menges, A., Kannenberg, F., & Zechmeister, C. (2022, Juli 25). *Computational co-design of fibrous architecture*. Retrieved from Springerlink: https://link.springer.com/article/10.1007/s44223-022-00004-x

Ministerie van Binnenlandse Zaken en Koninkrijkrelaties. (2019, Juli 2). *Woningbouwplannen, stikstof en Natura 2000-gebieden overzichtelijk gemaakt door factsheet*. Retrieved from Volkshuisvestingnederland: https://www.volkshuisvestingnederland.nl/actueel/nieuws/2019/07/02/woningbouwplannen-stikstof-en-natura-2000-gebieden-overzichtelijk-gemaakt-door-factsheet

Minsch, N., Müller, M., Gereke, T., Nocke, A., & Cherif, C. (2018). *3D truss structures with coreless 3D filament winding technology.* Journal of Composite Materials.

Moritzdoerstelmann. (2023). Retrieved from http://moritzdoerstelmann.com/

Nehls, G. (2021, Augustus 12). *LIVMATS Biomimitec Flax Fiber Pavilion opens to the public*. Retrieved from Compositesworld: https://www.compositesworld.com/news/livmats-biomimetic-flax-fiber-pavilion-opens-to-the-public

Nieuwscheckers. (2021, Januari 28). *Vee-industrie neemt bijna helft Nederlandse grond in beslag*. Retrieved from Nieuwscheckers: https://nieuwscheckers.nl/vee-industrie-neemt-bijna-helft-nederlandse-grond-in-beslag-en-misschien-zelfs-meer/

NOS. (2022, Juli 10). *Het stikstofprobleem is echt nederlands uitgelegd in acht grafieken*. Retrieved from NOS: https://nos.nl/collectie/13901/artikel/2436073-het-stikstofprobleem-is-echt-nederlands-uitgelegd-in-acht-grafieken

Oxman, N. (2021). *Material Ecology.*

Prado, M., Dörstelmann, M., Schwinn, T., & Menges, A. (2014). Core-Less Filament Winding. *Robots in Architecture Conference 2014*. University of Michigan.

Quanjin, M., Rejab, M., Idris, M. S., Kumar, N. M., & Merzuki, M. (2019). *Robotic Filament Winding Technique (RFWT) in Industrial Application: A Review of State of the Art and Future Perspectives.* Retrieved from Semanticscholar: https://www.semanticscholar.org/paper/Robotic-Filament-Winding-Technique-(RFWT)-in-A-of-Quanjin-Rejab/c112b3244beaec60cf5bb2eef1ffca214a96ee3f

Rijksoverheid. (2023). *Aanpak piekbelasting*. Retrieved from Aanpakstikstof: https://www.aanpakstikstof.nl/aanpak-piekbelasting

Sandak, A., Sandak, J., Brzezicki, M., & Kutnar, A. (n.d.). *Environmental Footprints and Eco-design of Products and Processes Bio-based Building Skin.* Retrieved from http://www.springer.com/series/13340

Schlopschnat, C., Pérez, M. G., Zechmeister, C., Estrada, R. D., Kannenberg, F., Rinderspacher, K., & Knippers, J. (2023). *Co-Design of Fibrous Walls for Multi-Story Buildings.* Retrieved from De Gruyter: https://www.degruyter.com/document/doi/10.1515/9783111162683-018/html

Singh, P. (2022). *Physical and Mechanical Properties of Flax Fiber and its Composites.* Allahabad, India: Journal of Material Sciences and Engineering.

Soil map of The Netherlands. (2023). Retrieved from Storymaps.arcgis: https://storymaps.arcgis.com/stories/ba85aa49141040bda0d088da11cf518e

Tillema, T. (n.d.). *Vlas en hennep in Pekela*. Retrieved from deverhalenvangroningen: https://www.deverhalenvangroningen.nl/alle-verhalen/vlas-en-hennep-in-pekela

United Nations. (2018, May 16). *2018 Revision of World Urbanization Prospects*. Retrieved from UN: https://www.un.org/en/desa/2018-revision-world-urbanization-prospects

University of Stuttgart. (2022). *Fibrous Tectonics 2022*. Retrieved from ITKE.uni-stuttgart: https://issuu.com/gsdharvard/docs/materialperformance

Van Dam En Martien Van Den Oever, J. (n.d.). *Biocomposieten 2012 Catalogus biobased bouwmaterialen Groene grondstoffen.*

Verkenning, S. (n.d.). *Ruimte voor Biobased Bouwen.*

Vleesschouwers, B. (2020). *Dossier Vlasteelt.* Retrieved from www.inagro.be

Wernick, I., Herman, R., Govind, S., & Ausubel, J. (1996). *Materialization and Dematerialization: Measures and Trends.* Summer.