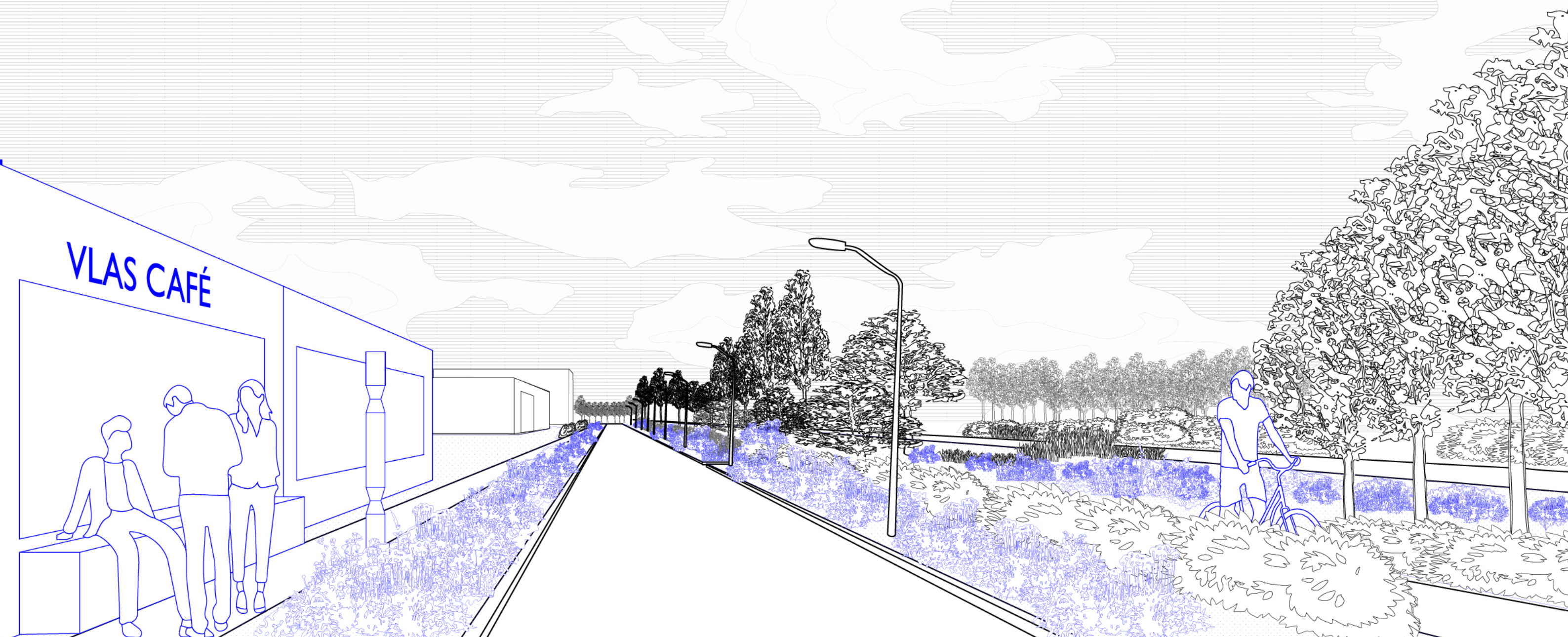
GRADUATION STUDIO REPORT
BARBARA DE MEIJER
4850734
METROPOLITAN ECOLOGY OF PLACES SERIES

Weaving Flax Fiber into the Territorial Fabric

A spatial design exploration on the potential role of flax in a circular biobased building sector in the Netherlands



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Author: Barbara Anna Eva de Meijer
Student number: 4850734

Supervisors
First Mentor: Alexander Wandl - Environmental Technology and Design
Second Mentor: Birgit Hausleitner - Urban Design

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TU Delft BK Bouwkunde

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METROPOLITAN ECOLOGIES OF PLACES SERIES

Abstract

Shifting to a circular biobased building sector is imperative to address pressing environmental challenges while meeting societal needs. The construction sector, responsible for a significant portion of global carbon emissions, faces the additional demand of constructing and refurbishing millions of houses by 2050. To achieve sustainability goals set out in the Dutch National Circularity Programme, the Dutch Government has allocated €200 million to transition to a circular biobased building sector, with flax emerging as a promising candidate, especially for fiber reinforced composites, due to its technical properties and suitability for Dutch climate and soil conditions. However, strategies on the spatial integration of a flax value chain do not exist yet.

This thesis addresses the research question: "How could a flax-based value chain be spatially facilitated to sustainably contribute to a circular biobased building sector?" Drawing upon theory on circular and biobased economies, the research investigates the potential applications of flax, the historical evolution of the flax industry, and the spatial, environmental, and socio-economic dimensions of a circular flax supply chain.

By formulating concrete scenarios and backcasting from desired outcomes, the study envisions future trajectories for the flax value chain and lays the groundwork for informed decision-making and strategic planning. A suitability analysis is performed to optimize land use and allocate functions of the flax value chain geographically, resulting in a national plan for the Netherlands. Furthermore, the use of a pattern language, stuctured along the flax value chain, provides a structured and systemic approach to understanding and modifying the system and translates research insights into tangible design interventions.

Lastly, the thesis extends beyond theoretical frameworks to practical implementation, by the application of the pattern language in the case of Lelystad, Flevoland. Through iterative design processes, spatial frameworks emerge as instruments for sustainable land-use optimization and system modification.

In conclusion, while flax emerges as a promising component of a circular biobased building sector, its role is just one part of the broader transition. Acknowledging uncertainties and complexities, and the need for environmental resilience, the research underscores the necessity for adaptable spatial design strategies and continued interdisciplinary collaboration and research to navigate the evolving landscape of the biobased built environment.

Key Words: Flax based value chain, Circular Biobased Building Sector, Systemic Design, Pattern Language, Lelystad

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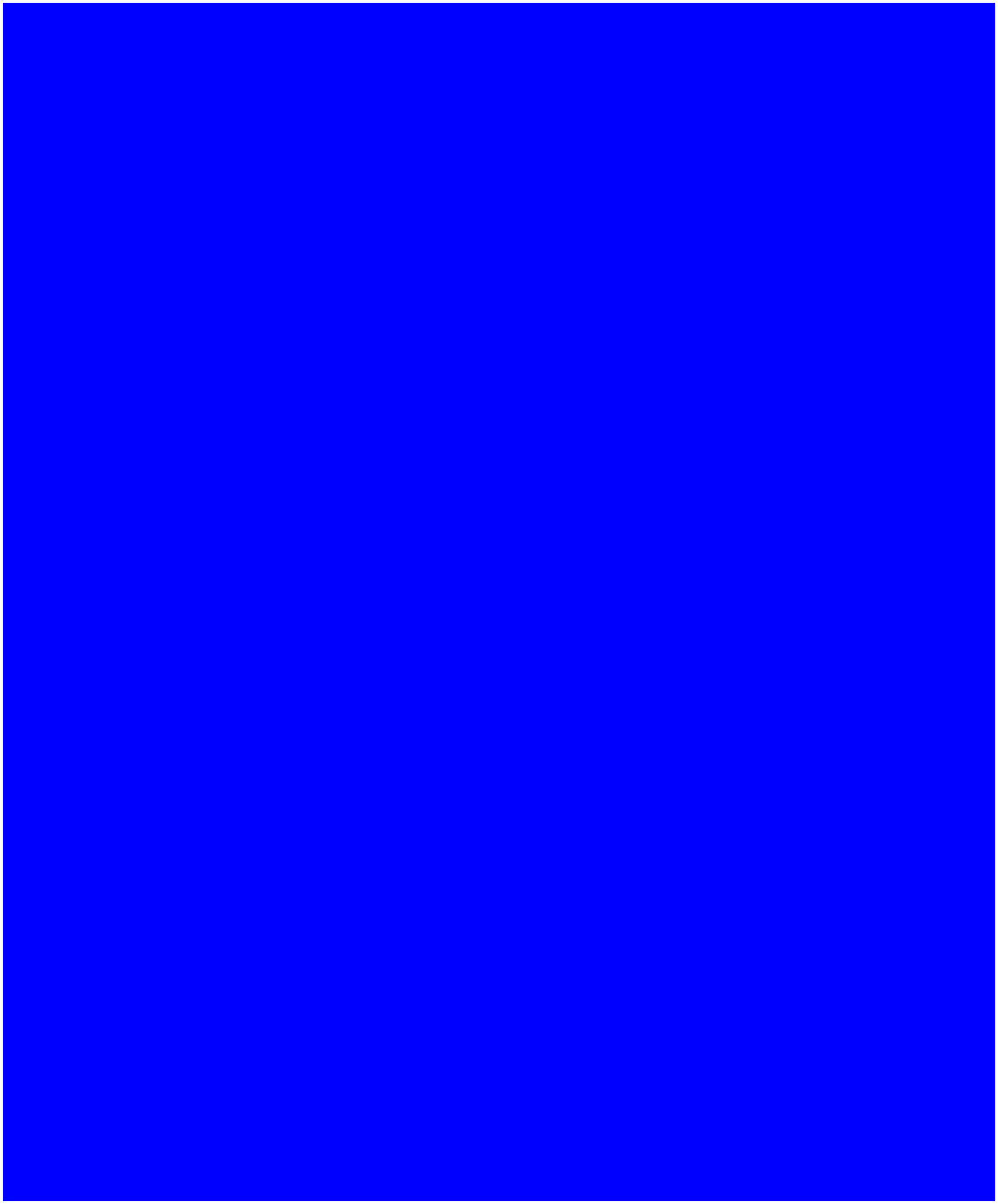


Chapter 1

Introduction: Shifting to a Circular Biobased Building Sector

Shifting to a circular biobased building sector

"The use of raw materials around the world causes 90% of the global loss of biodiversity, 90% of the world's water shortage, and 50% of greenhouse gas emissions. We cannot achieve the climate goals if we do not have a circular economy. " (Ministry of Infrastructure and Water Management, 2023).

To meet the goals set out in the climate agreement and the Dutch National Circularity Programme, various sectors have to transition to more sustainable and circular practices. One of those sectors is the construction sector, which, with the manufacturing of materials, accounted for 11% of global energy and process-related carbon dioxide emissions in 2018 (IEA, 2019) and accounts for 8% of dutch CO2 emissions. However, this sector faces the additional need to build 1 million houses before 2030, potentially an extra 1 million before 2050, as well as the need to refurbish 7 million existing houses (Ministry of the Interior and Kingdom Relations et al., 2023).
If we keep building the way we do now, the 'CO2 budget for the Dutch construction sector' will be exceeded in 2027 (see fig.1) (Copper8 et al., 2023). Therefore, there is a need for a radical change in the way we build.

On the 8th of November 2023, the Dutch Government published the program 'Nationale Aanpak Biobased Bouwen' (National Approach to Biobased Building). The government has allocated €200 million to transition to a circular biobased building sector. The main objective of the National Approach to Biobased Building is to contribute to national goals of CO2 reduction, nitrogen reduction, circular economy, nature and biodiversity, and spatial quality. Biobased building offers a transition to a more sustainable building sector, as well as more sustainable agricultural practices (Ministry of the Interior and Kingdom Relations et al., 2023).

One of the crops that often gets put forward to play an important role in a future biobased building sector is flax, due to its tehnical properties and since the climate in the Netherlands is very suitable for growing flax. Flax is not a new crop in Dutch agriculture, as it has already been cultivated for many years for linen applications in the textile industry (van den Oever et al., 2023).

This thesis explores how a flax-based value chain could be spatially facilitated to sustainably contribute to a biobased building sector.

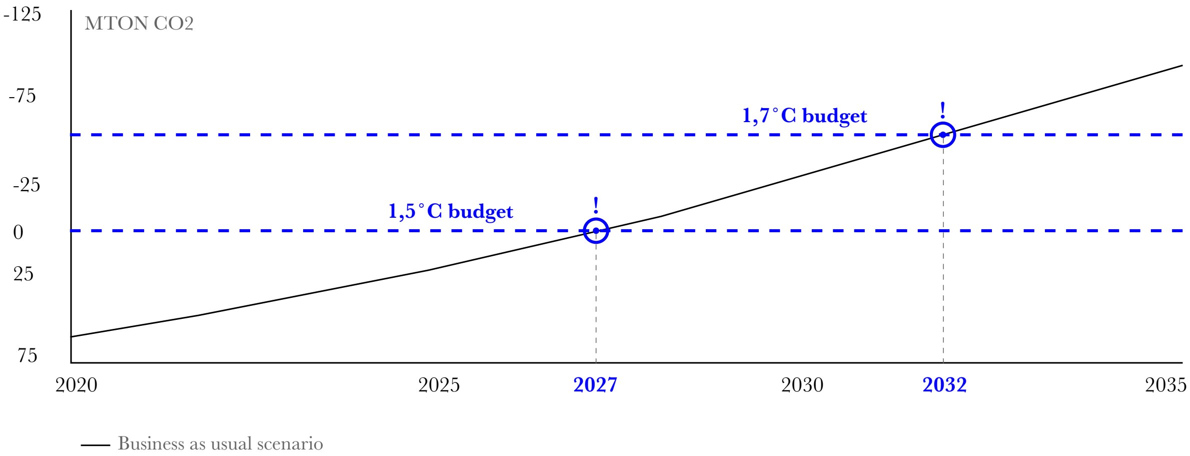


Fig. 1 CO2 budget Dutch Construction Sector adapted from (Copper8 et al., 2023, p.4)

Fig. 2 Growing building materials in Noord-Brabant (Brabant.nl, 2023)

Chapter 2

Problem Field

Societial Challenges

Biobased Building Sector: The solution?

Flax: *Linum Usitatissimum*

Obstacles on the Road

Problem Statement

Societal Challenges

Our society is confronted with numerous challenges today. Many of these challenges are related to stress that is put on the earth's planetary systems, caused by unsustainable human behavior over the past decades. The construction and agricultural sectors have played and play a notable role in this, as they are both heavily reliant on conventional practices and materials, which are unsustainable. The identified challenges encompass;

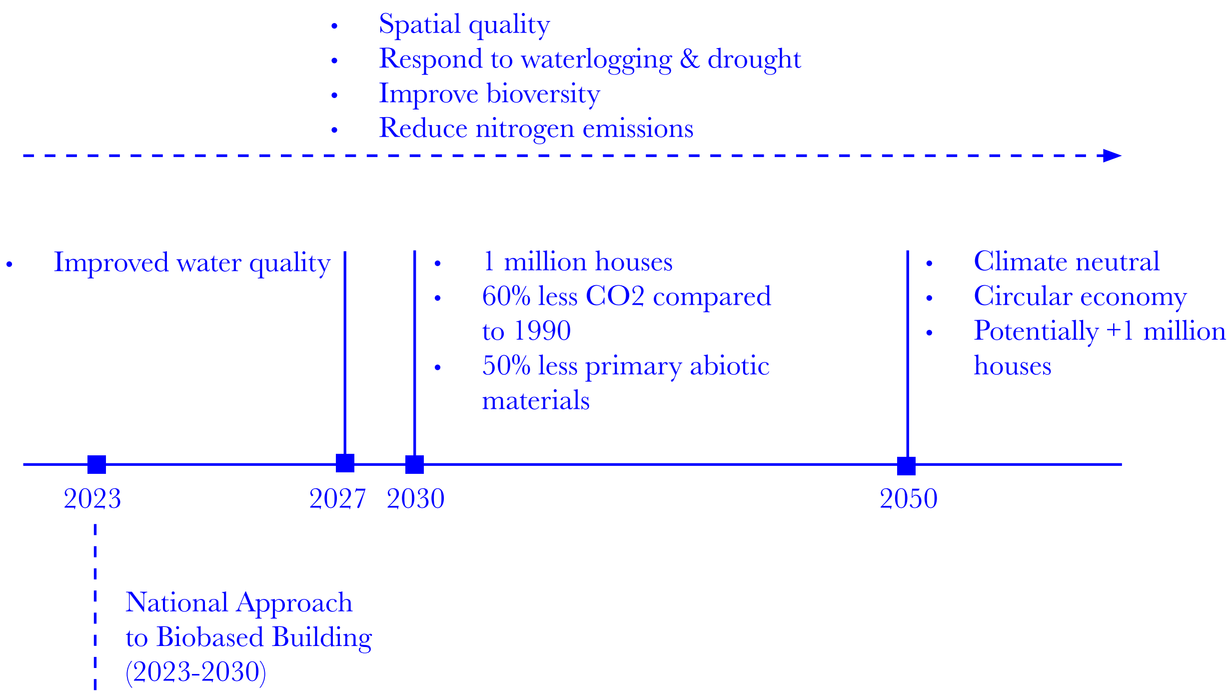


Fig. 3 Societal challenges on timeline

Reducing CO2 emissions

The Netherlands aims to be climate neutral by 2050, meaning that the greenhouse gas emissions should not exceed the amount that is stored, resulting in a net zero emission. In 2030 the Netherlands should emit 60% less CO2 compared to 1990. By 2035 the reduction should be 70% and by 2040 80%. Each sector has to actively do its part to achieve this result (Rijksoverheid, 2021). Actions to achieve a net zero emission include reducing emissions and increasing opportunities for carbon capture storage. In the building sector, the industrial processes of the production of building materials emissions are mainly responsible for the emissions (Ministry of the Interior and Kingdom Relations et al., 2023).

Circular Economy

The Dutch Government stated the ambition to achieve a circular economy by 2050 and to be halfway by 2030. The guiding target for 2030 is to use 50% less primary abiotic raw materials. For the building sector this requires a substantially different way of building and using different materials (Ministry of the Interior and Kingdom Relations et al., 2023).

Nitrogen Reduction

Emissions of nitrogen oxides and ammonia have been too high in the Netherlands for decades. This results in a high concentration of nitrogen oxides in the air, which is harmful for public health, and in excessive dry and wet deposition of nitrogen oxides and ammonia in the soil and vegetation which is harmful to nature. When too much nitrogen enters nature, it fertilizes and acidifies the soil, leading to the death of some plants and resulting in a loss of biodiversity (Ministry of Agriculture, Nature and Food Quality, 2023). In the EU, agreements have been made regarding the protection of natural areas. These are the Natura 2000 areas. Out of the

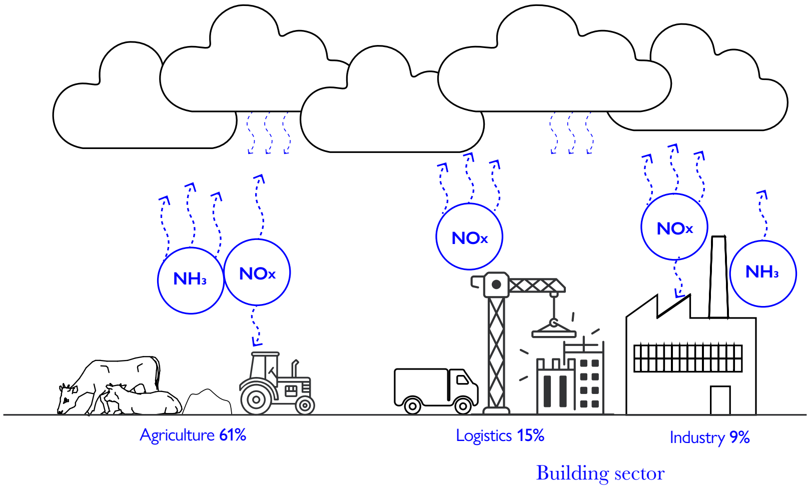


Fig. 4 Dutch nitrogen emissions. adapted from (Copper8 et al., 2023, p.24)

162 Natura 2000 areas in the Netherlands, 128 are sensitive to nitrogen. To protect these natural areas, several sectors need to reduce their nitrogen emissions.

Ammonia mainly comes from livestock manure and chemical fertilizers, which are used in the agriculture sector (Ministry of Agriculture, Nature and Food Quality, 2023).
Nitrogen emissions in the construction sector occur at the construction site (NOx), during the production phase in factories (NOx and NH3), and during transportation (mainly NOx) (Copper8, Metabolic, NIBE & Alba Concepts, 2023).

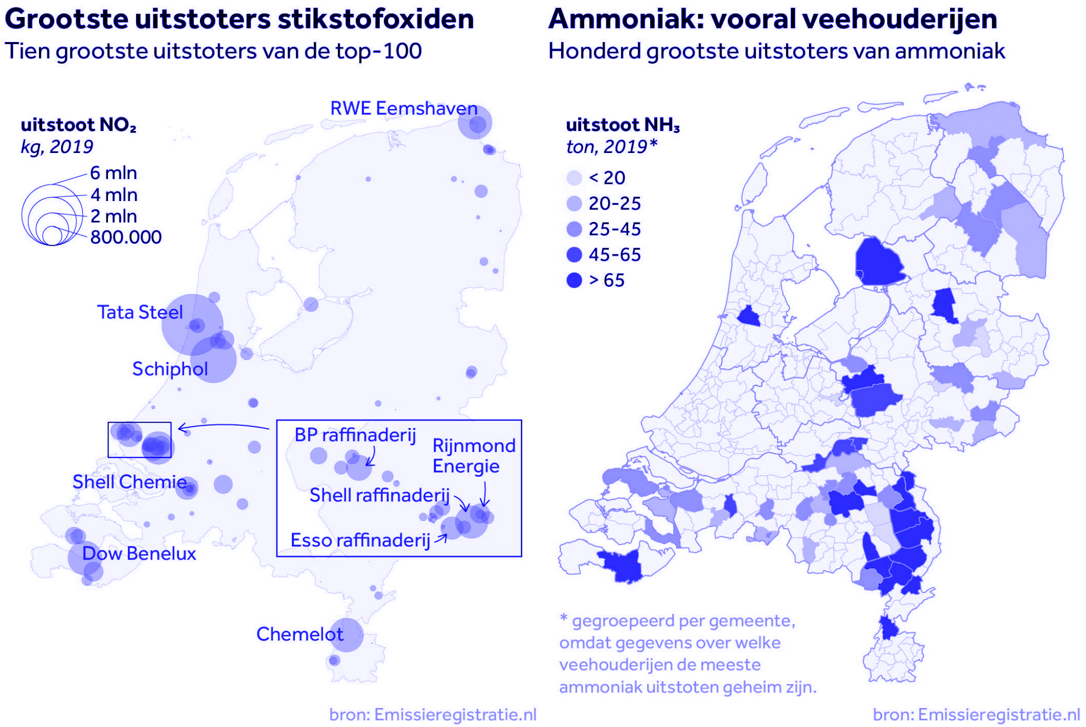


Fig. 5 Biggest NO2 and NH3 emitters 2019 (Emissieregistratie.nl)

Biodiversity & Soil and Water Quality

Intensive monocultural agriculture practices that use pesticides and other methods to maximize the yield put pressure on biodiversity. The ambitions for the restoration of biodiversity are laid out in the birds and habitats directive (Ministry of Agriculture, Nature and Food Quality, 2023). The use of nutrients in current agricultural practices negatively affects the groundwater and surface water quality. By 2027 the Netherlands must comply with 'de kaderrichtlijn water (KRW), a quality standard for the chemical and ecological quality of groundwater and surface water (Ministry of the Interior and Kingdom Relations et al., 2023).

Anticipating Waterlogging & Drought

As a result of more extreme weather (excessive rainfall or a lack of rainfall), rising groundwater levels, groundwater extraction, soil subsidence and accelerated drainage, the Netherlands is facing increasing waterlogging and drought. This has a negative impact on nature and biodiversity, crop yields and water quality (Ministry of the Interior and Kingdom Relations et al., 2023).

Housing Demand

The Netherlands faces a shortage of housing. There is the need to build 1 million houses before 2030, potentially an extra 1 million before 2050, combined with the need to refurbish 7 million existing houses (Ministry of the Interior and Kingdom Relations et al., 2023).
It is not possible to meet this demand and also reduce the use of raw materials and carbondioxide and nitrogen emissions, if we keep using the conventional materials and practices. However, by better utilization of the existing housing stock, approximately 50,000 homes can be realized without any construction interventions until 2030 (Copper8 et al.,2023).

Spatial Quality and Quantity

All these societial challenges have a significant spatial impact, while space is scarce. To connect and coördinate the different challenges while also achieving spatial quality requires an integral approach and multiscalar design thinking (Raad voor Cultuur & College van Rijksadviseurs, 2020).

Biobased Building Sector: The Solution?

In the published program ‘National Approach to Biobased Building’ (Ministry of the Interior and Kingdom Relations et al., 2023), biobased building is presented as one integral solution that can connect the earlier posed societal challenges:

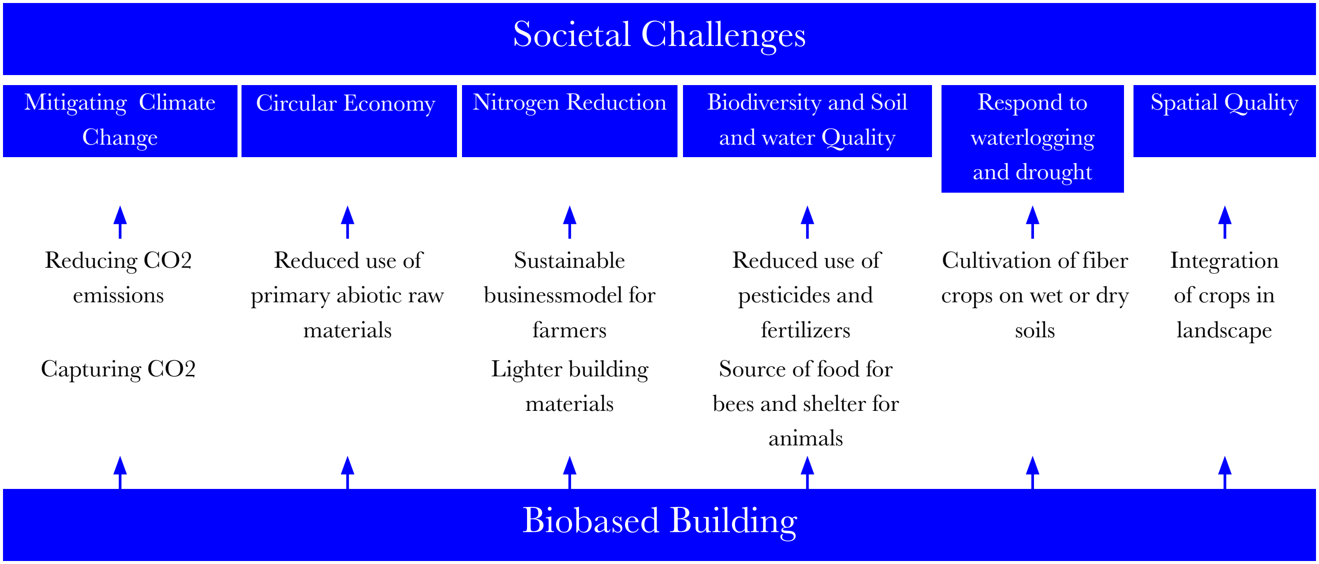


Fig. 6 The societal contribution of the cultivation, processing and application of bio-raw materials in construction (Translated and adapted from Ministry of the Interior and Kingdom Relations et al., 2023, p.90)

The definition that is used for biobased building materials according to the EN16575:2014 is 'a material that consists at least for 70% out of renewable mass'. It can be assumed that this definition will change in the future, and a larger percentage will have to be biomass once this becomes more feasible. Ideally, the material is so pure that after demolition, disassembly or renovation, it can be used again for the manufacturing of building materials or be brought back into nature without any harm (Ministry of the Interior and Kingdom Relations et al., 2023).

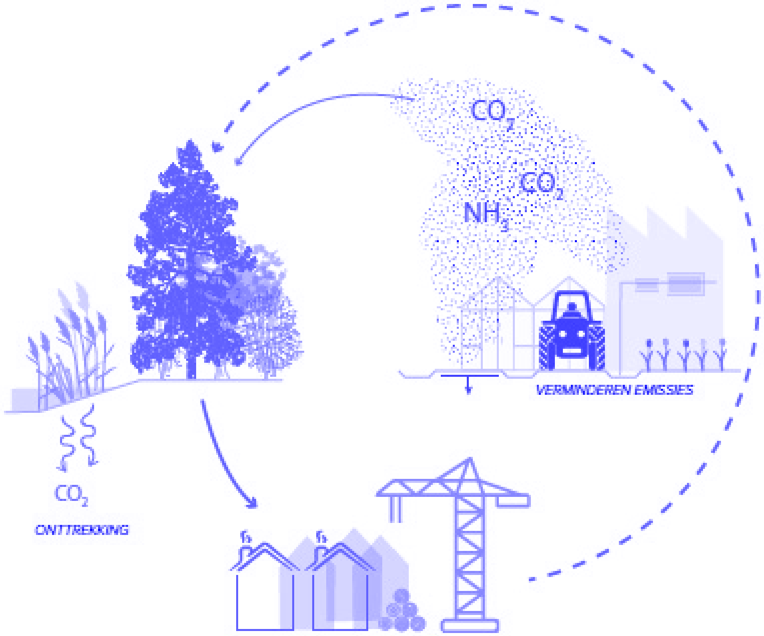


Fig. 7 Principle of Circular Biobased Building Sector
(BOOM Landscape & De Natuurverdubbelaars, 2022, p.5)

Flax: *Linum Usitatissimum*

Flax, scientifically known as 'Linum Usitatissimum' , which translates to 'common' or 'useful' flax, has been around for centuries and is known for its bast fiber for linen in the textile industry. Flax was the first textile produced and fragments of linen textiles stemming from 36.000 BC were discovered in a cave in Caucasia (Alliance for European Flax-Linen & Hemp, n.d.).

North Western Europe (Province of Zeeland to Normandy) has a rich history in the flax industry and still plays a significant part in the industry to this day. "Actually, bast fibre flax grown in this region is considered the highest quality flax fibre in the world" (van den Oever et al., 2023, p.20). Flax is an annual crop, that gets sown in the end of march, flowers in june and gets harvested around 100 days after sowing. However, flax is currently only cultivated on a very small scale. The harvesting and processing of fiber flax is focussed on the extraction of the long bast fiber. Nonetheless, the whole plant can be used, and no parts need to go to waste. The crop has a wide variety of potential applications, but it has received more attention in the Netherlands lately because it is expected to play a role in a more sustainable agricultural and biobased building sector. Examples of applications in the building sector include insulation material, sheet material and reinforcement for composites, which can be created with industrial processing (Leendertse et al., 2020).

"..., bast fibre flax grown in this region is considered the highest quality flax fibre in the world"

- (Van den Oever et al., 2023, p.20)

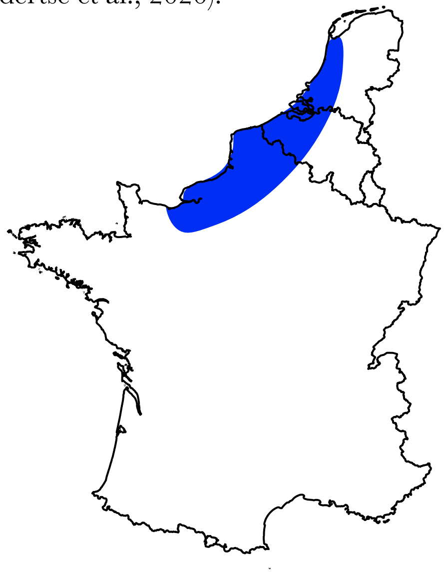


Fig. 8 North Western Europe Flax Region (Adapted from Alliance for European Flax-Linen& Hemp, n.d.)

Fig. 9 Flax Drawing (Freepik, n.d.)

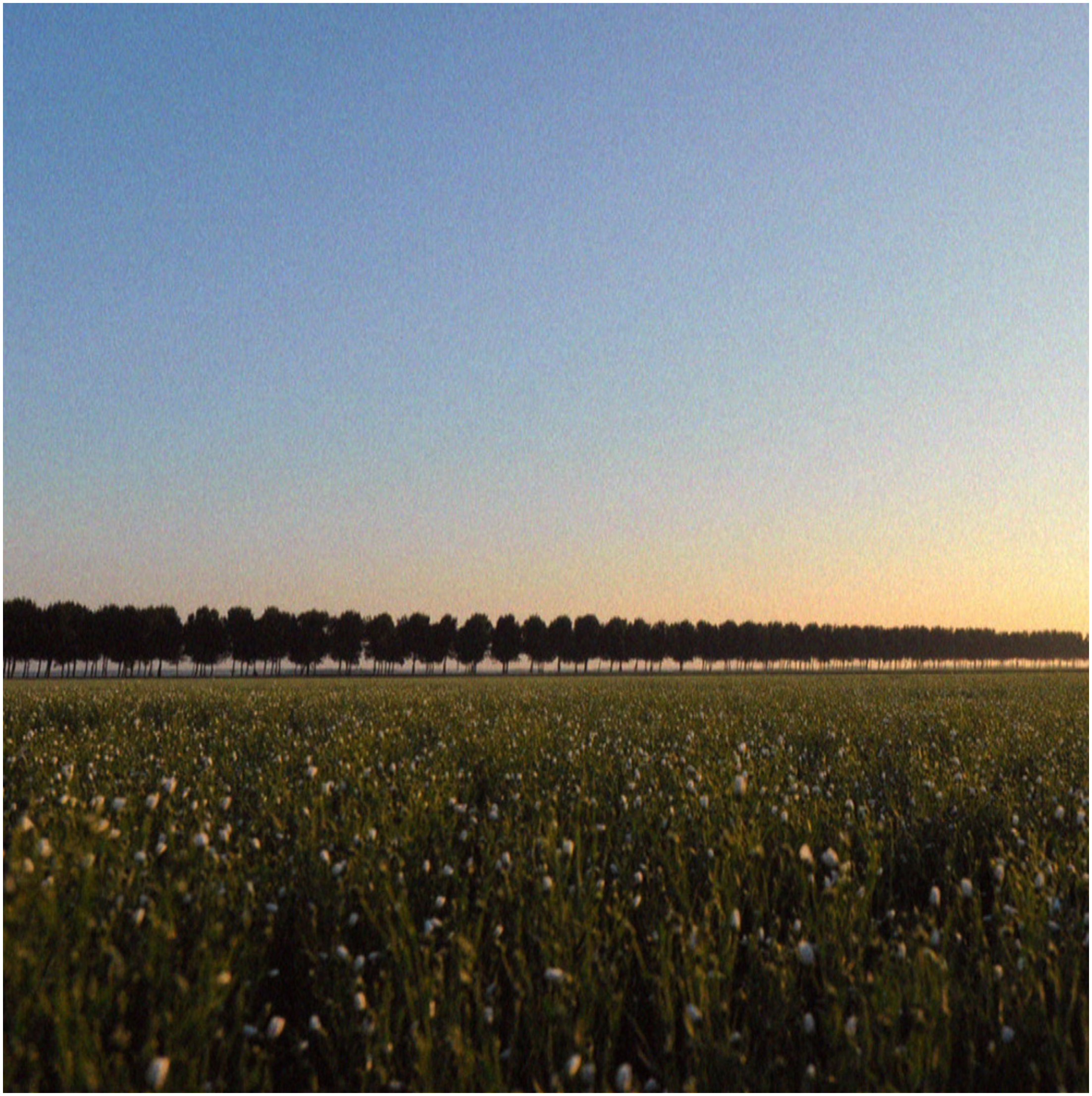


Fig. 10 Flax field (Picture byRoel van Tour in ‘a flax project’ by Christien Meindertsma)

Fig. 11 Flowering Flax Field (Picture byRoel van Tour in ‘a flax project’ by Christien Meindertsma)

Obstacles on the Road

The Market is not ready yet

There is not a solid supply chain for biobased building materials yet. Farmers do not produce a lot of fiber crops yet, and are not to do so, since demand is still limited. Processors run into the same problem, due to limited demand and supply they can't make a business case out of it (Ministry of the Interior and Kingdom Relations et al., 2023). Flax has has the advantage compared to other fiber crops that there is already an existing chain for flax processing for the textile industry and residual streams are used for the construction sector on a small scale, but for larger scale sustainable application in the construction industry, steps still have to be made. There is also some scepticism on the growth of flax in the biobased industry as the biobased industry can not (yet) financially compete with the linnen industry for the fibers (BOOM Landscape & De Natuurverdubbelaars, 2022). For upscaling the market for biobased building materials, monitoring of the market and stimulating actions are required (Ministry of the Interior and Kingdom Relations et al., 2023).

Limited Knowledge

There is still a lack of experience and knowledge on biobased building among architects and developers, which results in lacking demand. For the case of flax, the cultivation and processing also requires quite some expertise and specific machinery (BOOM Landscape & De Natuurverdubbelaars, 2022).

Competition with other materials

Currently biobased building materials are often still more expensive than traditional building materials. Therefore, there is still not enough demand for farmers or processing companies to see a business case in it. However, the expection is that the prices for biobased building materials will go down the coming years, because of the funding (Copper8 et al., 2023).
Flax competes with synthetic and cotton fibers in the textile industry, with synthetic fibers and hemp fibers for composites and other crops for insulation and sheet material.

Spatial Claim

Creating the infrastructure for a biobased building material value chain from cultivation to processing and production to assembly the building site requires space, while space is scarce. In the published program 'National Approach to Biobased Building' (Ministry of the Interior and Kingdom Relations et al., 2023), an intended output for 2030 is to have 50.000 ha dedicated to cultivation of fiber crops for the building sector. o connect and coördinate the different challenges while also achieving spatial quality requires an integral approach and multiscalar design thinking (Raad voor Cultuur & College van Rijksadviseurs, 2020).

Problem Statement

Our society is confronted with numerous challenges today. Many of these challenges are related to stress that is put on Earth's natural systems, caused by unsustainable human behavior over the past decades. The construction and agricultural sectors have played and play a notable role in this, as they are both heavily reliant on conventional practices and materials, which are unsustainable. These challenges encompass reducing CO2 and nitrogen emissions, achieving a circular economy, higher biodiversity, improving soil and water quality, anticipating waterlogging and drought, the need to build 1 million houses before 2030, potentially an extra 1 million before 2050, combined with the need to refurbish 7 million existing houses, while also creating spatial quality (Ministry of the Interior and Kingdom Relations et al., 2023).

To meet the goals set out in the climate agreement and the Dutch National Circularity Programme, various sectors have to transition to more sustainable and circular practices. Research indicates that biobased building materials could very well replace conventional building materials and could also form an integral solution to the posed societal challenges (Ministry of the Interior and Kingdom Relations et al., 2023). One of the crops that shows great potential is flax, as it has various potential applications due to its technical properties, the climate and soil in the Netherlands are very well suited for growing high-quality fiber flax, and the Netherlands has a long-standing tradition of growing flax for the textile industry (van den Oever et al., 2023). However, the transition to a biobased and flax-based building sector is struggling to take off. A possible reason is the complex nature of implementing a full value chain for biobased building materials. It includes setting clear goals, coordination, matching supply and demand and making it economically viable for stakeholders in the supply chain, as now biobased building materials are often still more expensive than traditional building materials (Ministry of the Interior and Kingdom Relations et al., 2023). In the case of flax, it requires expanding the existing value chain for the textile industry to create a local circular flax value chain for the building industry, which requires space, expertise, and special machinery (van den Oever et al., 2023).

Recently the 'National Approach to Biobased Building' was published (Ministry of the Interior and Kingdom Relations et al., 2023), and €200 million was reserved to build up several biobased building value chains. Research needs to be done on how a flax-based value chain could be spatially facilitated to sustainably contribute to a circular biobased building sector.

Chapter 3:

Theory

Circular Economy
Biobased Economy
Socio-Ecological Metabolism
Pattern Language

Theory

As emerged from the problem field, the Netherland aims to be fully circular by 2050 and to be halfway by 2030, using 50% less primary abiotic raw materials. The concept of the circular economy has emerged as a response to the growing recognition of the finite nature of resources and the need for sustainable development. The transition towards circularity has become a prominent theme in policy innovations, urban strategies, and sustainability visions (Marin & De Meulder, 2018).

Complementing the circular economy framework is the biobased economy, which offers a sustainable alternative to conventional materials and practices, with significant spatial implications. As highlighted in the problem statement, the transition to biobased building materials, such as those derived from flax, holds promise for addressing environmental challenges while meeting societal needs.

This thesis researches how a flax-based value chain could be spatially facilitated to sustainably contribute to a circular biobased building sector. Therefore, this research draws upon theory on the circular economy and the biobased economy, especially on their relation to space, to inform the development of practical solutions and a holistic approach.

Circular Economy

Circularity has received growing attention among both scholars and practitioners. However, most studies on designing for a circular economy have been theoretical and conceptual, often embedded in an economic growth-oriented paradigm that emphasizes recycling over reducing and reusing (Marin & De Meulder, 2018). Moreover, they often overlook broader social, cultural, and political dimensions (Paul, 2022) as well as the spatial aspects of this transition, which remain largely unexplored in the literature (Dokter et al., 2020; Marin & De Meulder, 2018).

Transitioning to a circular economy requires a systemic transformation that takes place in the physical world and operates in a field of complex multi-actor, multi-level, and multi-dimensional processes (Marin & de Meulder, 2018). For a circular flax value chain, circularity operates on the level of materials and components and buildings as assemblies, but it also operates in space through different scales (The Circular Built Environment Hub, n.d.).
A circular economy requires space for reparations, sharing, recycling, the processing of (bio) raw materials, and the necessary transport infrastructure (Rood & Evenhuis, 2023).

The Circular Built Environment (CBE) concept expands on the notion of circularity by emphasizing the importance of closing resource loops at various spatial-temporal levels. It aims to transition cultural, environmental, economic, and social values towards a sustainable way of living, thereby enabling society to live within the planetary boundaries. This integrated approach highlights the interconnectedness of different aspects of sustainability within the built environment, underscoring the need for holistic solutions in achieving circularity."(The Circular Built Environment Hub, n.d.).

Biobased Economy

The European Commission's defines the bioeconomy as an economy which prodcues biological renewable materials, and uses residual streams of biomaterials, to converted into value added products (European Commission, 2012). Facing a future shortage of primary abiotic raw materials and the need to reach the climate goals, biomass is expected to be the main future feedstock to produce materials (Langeveld et al., 2010). In the National Circular Economy Programme 2023-2030 (Ministry of Infrastructure and Water Management, 2023), four measures to make use of raw materials more circular are presented, pointing out the need for biobased materials:

1. Reducing raw material usage by reducing production and purchase
2. Substituting primary raw materials with secondary raw materials (recycled materials) and biobased materials
3. Extending product lifetime through reuse and repair
4. High-grade processing: closing the loop by recycling materials

Thus, a biobased economy is required to achieve a circular economy, but it is not inherently circular, as often assumed. James (2022), criticizes how recent published approaches still instrumentalize nature to serve economic growth, and reduce nature to a set of ecosystem services. He also underscores the need for a more holistic approach to a circular (and biobased) economy, in which not only the economy is the main focus, but social and ecological dimensions are also integrated. Because a 'circular' and 'biobased' flax value chain, does not automatically ensure a 'sustainable' value chain. Bio-based building materials often materials perform better than traditional materials in mitigating climate change and abiotic resource use. However, impacts on ecology and resilience to the changing landscape as a result of climate change should also be taken into consideration (Le et al., 2023).
This thesis draws on these notions by advocating for a more holistic approach to resource management, recognizing the metabolic interactions between human activities and natural systems. This approach not only stimulates the sustainability of the flax-based value chain but also addresses environmental and social issues in the construction and agricultural sectors.

Chapter 4:

Research Design & Method

Conceptual Framework
Research Questions and Aims
Analytical Framework
Methods

Conceptual Framework

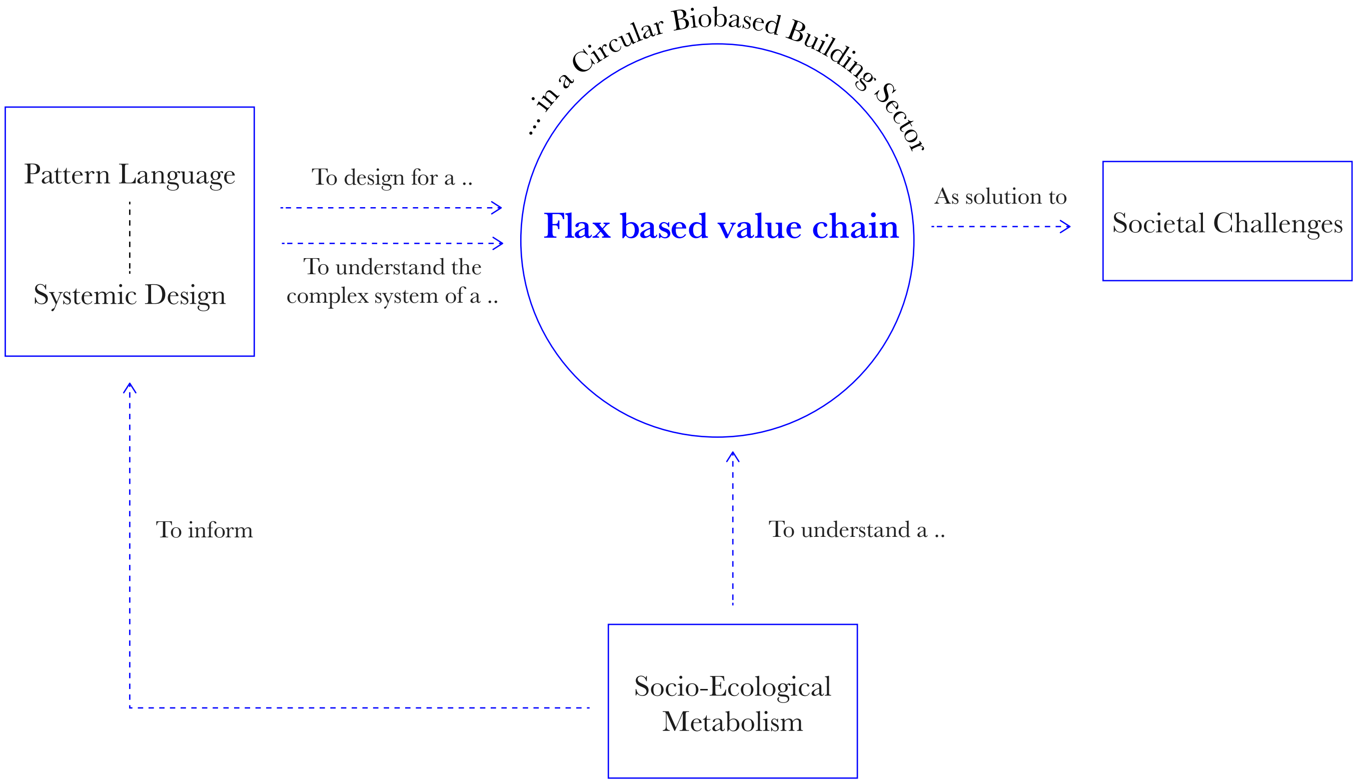


Fig. 12 Conceptual Framework

Research Questions and Aims

Research Question:

How could a flax based value chain be spatially facilitated to sustainably contribute to a circular biobased building sector?

Sub-Questions:

1. What are the potential applications of flax and what are the required processes to come to the products?

Aims: To identify the various and most promising potential applications of flax and the required processes to lay the foundation for the systemic design of the future flax value chain.

2 What are the spatial, environmental and socio-economic dimensions of the flax industry and how has it developed over time?

Aims: To understand the context and the industries' evolution to enable informed future decision-making and design.

3. What are spatial principles, environmental and socio-economic requirements for a sustainable circular flax supply chain?

Aims: To define the spatial conditions needed to ensure a sustainable circular flax supply chain.

4. How could a circular flax supply chain be sustainably integrated in the territorial context of the Netherlands and how does it influence the landscape and built environment?

Aims: To explore how the design interventions can be implemented in such a way that they align well with the country's existing landscape and infrastructure and how it could influence the landscape and built environment.

5. How can alternative spatial futures be assessed?

Aims: To evaluate the design to do policy recommendations and suggestions for further research.

Analytical Framework

Problem statement

Research Question

How could a flax based value chain be spatially facilitated to sustainably contribute to a biobased building sector?

Sub-Questions

1. What are the potential applications of flax and what are the required processes to come to the products?

2. What are the spatial, environmental and socio-economic dimensions of the flax industry with its relation to other industries and how has it developed over time?

3. What are spatial principles, environmental and socio-economic requirements for a sustainable circular flax supply chain?

4. How could a sustainable and circular flax supply chain be integrated in the territorial context of the Netherlands and how does it influence the built environment?

5. How can alternative spatial futures be assessed?

Fig. 13 Analytical Framework

Outcomes

Methods	Outcomes
LR	Application / processing scheme
LR, AS, FA, MA	Diachronic Analysis Systemic sections Trade map
RD, LR, PL, SA, FT, BS	Scenarios Systemic section Suitability Analysis Pattern Language
MA, PL, SD, RD, FT	Strategic map 2030 Examplary Projects
LR, EV	Evaluation

- SD Systemic Design
- LR Literature Review
- FA Flow Analysis
- MA Mapping
- PL Pattern Language
- RD Research by Design
- FT Field Trip
- SA Suitability Analysis
- BS Backcasting Scenarios
- EV Evaluation
- AS Archival Studies

Methods

LR Literature Review

Reading and reviewing scientific literature to develop a theoritcal and conecptual framework and to create an understanding of the flax industry, and other theories that appear to be relevant during the pattern development and design process.

MA Mapping

Visualizing and connecting research, observations and spatial structures. Mapping through different scales is used to get a spatial understanding of the problem. It is also used during the design phase to analyse how different design interventions interact with their surroundings.

SD Systemic Design

Integrating systems thinking and design thinking to approach the complex challenges of implementing a circular flax value chain.

PA Policy Analysis

Collecting and analysing policy documents and strategic agendas to determine governmental goals or restrictions regarding implementing a biobased building sector.

FA Flow Analysis

Mapping the flows related to the Dutch flax industry in a systemic section and on map to understand how these flows relate to space and to inform later decision making on where to intervene to create a sustainable circular biobased building sector.

RD Research by Design

Projecting various design interventions on the context to analyse how they interact with eachother and the existing context and to explore alternative spatial futures.

PL Pattern Language

Originating from Christopher Alexander in 1977, pattern language offers a structured approach to understanding and controlling complex systems in spatial design. By breaking down complexity into comprehensible patterns adaptable to various conditions, pattern language facilitates coherent design solutions.

FT Field Trip

Once strategic locations for interventions have been chosen, visiting the area can help create a better understanding of the social and spatial conditions of the context.

SA Suitability Analysis

Analysing land use suitability by formulating decision criteria, overlaying maps and ranking the suitability of land for a certain land use. This method, by McHarg (1969) helps to optimize the benefits of an area.

AS Archival Studies

Analysing and reviewing archival documents and pictures to create an understanding of the flax industry in relation to space and the environment in different periods of time with diferent context.

BS Backcasting Scenarios

Looking backwards from a generated desired future and create strategy on how this future can be achieved. It involves analysing and experimenting with different ways to achieve this future. The scenarios used are derived from the 'National Approach to Biobased Building' (Ministry of the Interior and Kingdom Relations et al., 2023) which shows a desired future for 2030 and a study by Wageningen University & Research (van den Oever et al., 2023) that shows the potential demand for flax in 2050.

EV Evaluation

Formulating evaluation criteria to assess the designed alternative futures in order to compare the different scenarios and point out potential trade-offs.

Theoretical Framework

Socio-Ecologcial Metabolism

The challenges encountered within the construction and agricultural sectors are deeply intertwined with socio-ecological systems. Taking a socio-ecological metabolism perspective, it becomes evident that achieving circularity extends beyond merely closing material loops; it entails understanding and managing the broader systems in which these loops are embedded. Recognizing the metabolic interactions between human activities and natural systems is essential for devising sustainable solutions. Therefore, this thesis uses the concept of socio-ecological metablism to understand the social and ecological implications of implementing a flax value chain, as well as analysing how the socio-ecological context interacts with the metabolic flax chain in other ways.

Using flax for building materials can be seen as an exchange between nature and society. According to the socio-ecological metabolism concept, the metabolic is represented by five actions: appropriation, transformation, circulation, consumption and excretion (Molina & Toledo, 2018).These five actions take not only the input and output into acount, but the circulations within society as well.

Appropriation is the first moment of exchange between nature and society, and this action is carried out by an 'appropriation unit', in the case of the flax value chain, this concerns the harvesting of flax by farmers.
The process of transformation implies all changes induced on the products extracted from

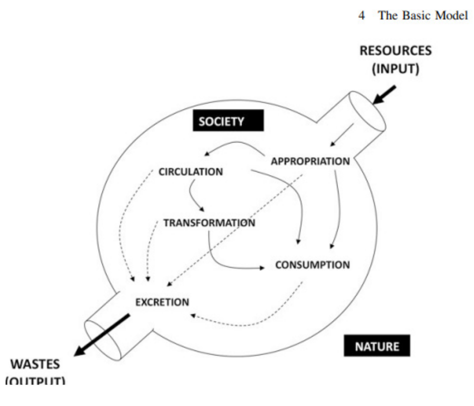


Fig. 14 General diagram showing the metabolic processes and the relation between society and nature (Molina & Toledo, 2018, p.62)

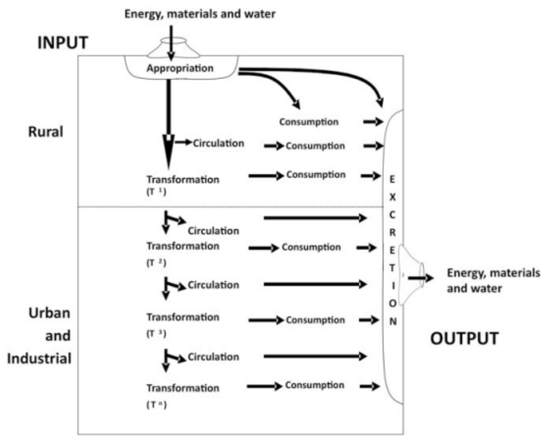


Fig. 15 Diagram showing the relations of the five main functions of social metabolism in rural, urban and industrial sectors (Molina & Toledo, 2018, p.63)

nature. For the flax textile this includes the first processing in which the different components of the plant are extracted and the further processing required to manufacture the final materials. Circulation and consumption happens when different appropriation units exchange materials, transformed or not. In the flax value chain, different components of the plant get circulated, to either be directly 'consumed' or further processed.
Excretion, the act of disposing the material, happens when it is no longer used.

Analyzing the flax value chain with this method helps find ways to make these networks more circular along different sectors and across various scalles. It also helps showcase how changes might affect society and the environment.

Pattern Language

To understand the complex system of integrating a flax value chain, to modify the system and to translate the insights of the research into practical solutions, the use of pattern language is proposed. In 1977 Christopher Alexander developed an 'archetypical language' , called 'pattern language'. A method to understand and possibly control complex systems in spatial design, but also to function as a design tool that can build something functionally and structurally coherent (Salingaros, 2008). This method acknowledges complexity, but breaks it down in comprehendible blocks of knowledge or solutions, called patterns, translatable to a wide range of conditions. Patterns are basically built up out of a hypothesis, theory supporting this hypothesis and a practical implication solution, clarified by a sketch or example (Rooij & van Dorst, 2020), thus functioning as a bridging tool between research and design.

Each pattern is linked to one or more other patterns, through themes or level of scales. The 'pattern field' can be seen as a framework that describes the organization of the relations between the patterns. Through this organization, a hierarchy can be created. The pattern field helps you see relations between different design interventions. Two patterns may function independently, complement eachother or potentially even compete with eachother (Salingaros, 2018).

Urban environments are complex systems, and spatially facilitating a circular flax value chain is a complex task, requiring knowledge from different sectors and technologies and on different scales. To achieve circularity, a pattern language can be used as an instrument for interdisciplinary mediation (Hausleitner et al., 2020). Pattern language offers systemic design a structured approach for ideating solutions and organizing design principles and solutions. Socio-ecological metabolism informs the development of pattern language by providing insights into the underlying ecological and social processes that shape design outcomes.

Planning Graduation Year

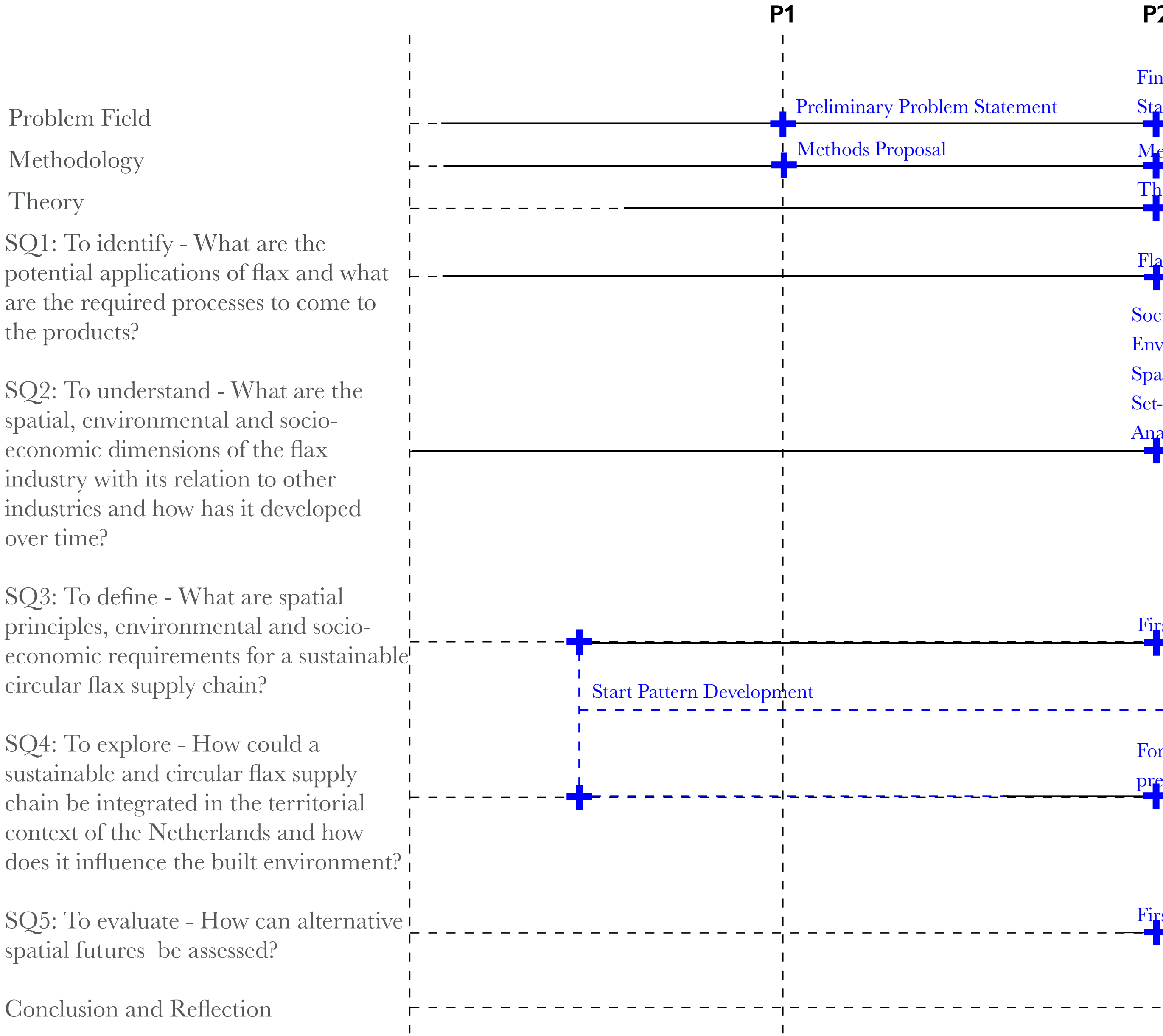
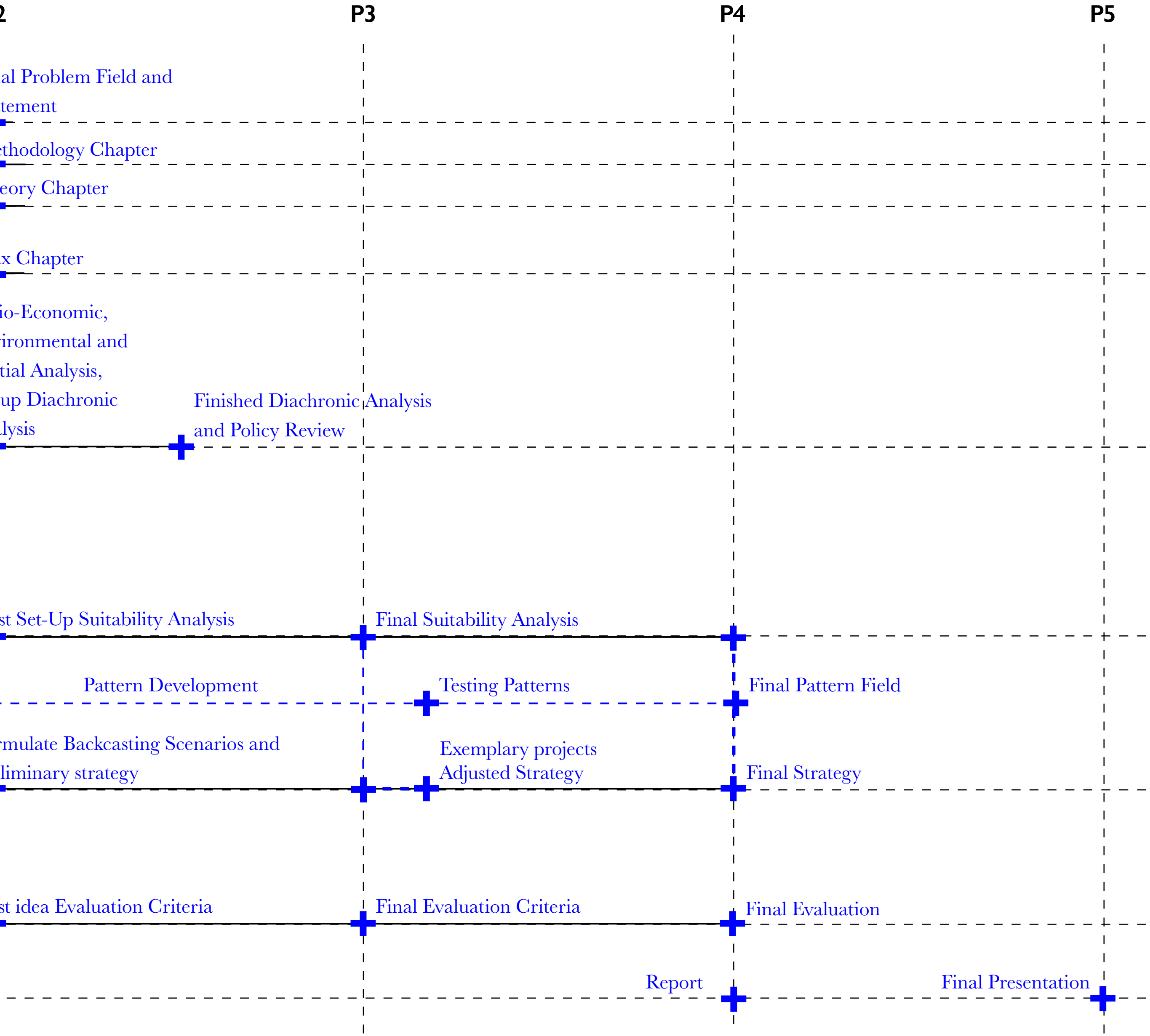


Fig. 16 Planning Graduation Year



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Chapter 5:

‘Linum Usitatissimum’: Very Useful Flax

What are the potential applications of flax and what are the required processes to come to the products?

Flax Components and Processing

Flax is an annual plant and the whole plant can be harvested and used. In France, Belgium, and the Netherlands the focus of flax production has been mostly on the fashion and household textile market. The plant's main products are the bast fiber, which is known to be amongst the strongest fibers and used to spin into yarn, and (lin)seeds (Nunes, 2017).

The process from harvesting to product application is labor intensive and it requires multiple steps. Figure 18 shows a schematic overview of the process with its products.

When flax gets harvested it gets pulled out of the ground to keep the fibers as long as possible, simultaneously it gets rippled, which means the seeds get separated from the rest of the plant (De Bont et al., 2008). After harvesting, the plant has to ret, a rotting process during which the fibers are released from the stem (Vreeke et al, 1991). In the Netherlands, the method of dew retting is mainly applied (De Bont et al., 2008), which happens on the field over the course of three to five weeks, depending on the amount of rainfall (Brancheorganisatie Akkerbouw, 2005).The retted flax gets baled and transported to processing facilities. Here, the plant goes through the process of breaking and scutching, a mechanic process that separates the fibers from the woody stem. This results in long and short fiber bundles, shives, and dust. The byproducts get distributed to various customers, due to a wide range of possible applications (De Bont et al., 2008). To prepare the fibers for spinning, the long fiber bundles get combed. This process is called 'hackling', and is used to separate the bundles by removing the weak links between the technical fibers. More short fibers and dust also come free in this part of the process. With each processing step, the tensile strength of the fibers increases (Van den Oever et al., 2000).

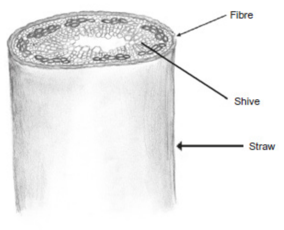


Fig. 17 Flax Stem
(Nunes, 2017,p.3)

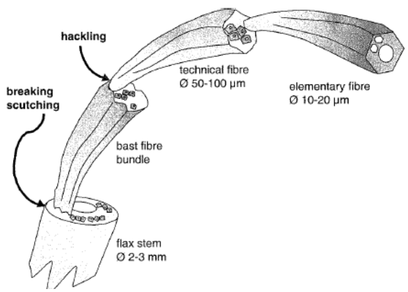


Fig. 18 Schematic plot of a flax stem down to an elementary flax fibre.(van den Oever et al., 2000,p.3)

The hackled flax then can be spun into yarn, which can then be woven into fabric. However, there are no spinning facilities in the Netherlands and the broken and scutched flax mainly gets exported to china to be made into clothing (van den Oever et al., 2023).

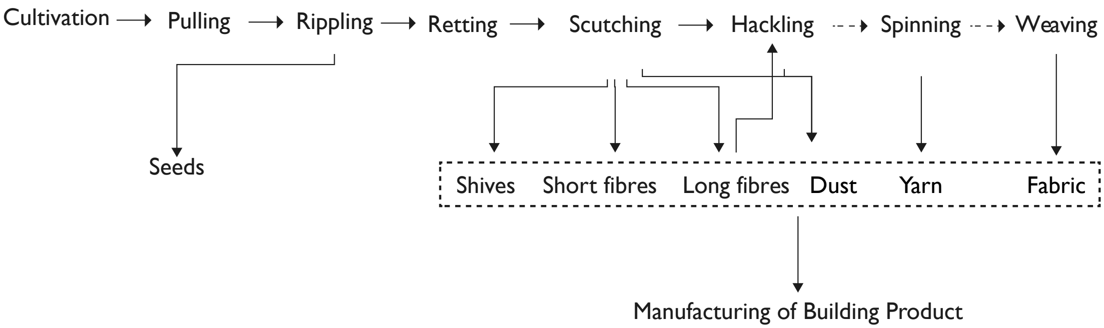


Fig. 19 Scheme of flax processing

Fig. 20 Flax components (ABN AMRO,2023,p.7)

Potential applications

Flax in North Western Europe is mainly grown for its long fiber, which is used to make linen for the textile industry (van den Oever et al., 2023). But it has a wide variety of possible applications. This section aims to give an overview of which parts of flax can be used for certain construction applications, to compare flax' charachteristics to other crops and to evaluate for which purpose flax can best be used.

Flax Construction Applications

Long fibres
- Technical textile (wall and floor coverings)
- Fibre-reinforced composites
- Load bearing structure

Short fibres
- Non woven textiles (acoustic and thermal insulation)
- Fibre-reinforced composites

Seeds
- Linseedoil
- Natural paint
- Linoleum

Shives
- Chipboards
- Plaster
- Reinforcement for composites

Dust
- Biogas

Fig. 21 Flax Construction Applications scheme

Fig. 22 Flax Pavillion (IntCDC, Universität Stuttgart / Robert Faulkner)

Fig. 23 Flax Insulation (bouwmaat.nl, n.d.)

Fig. 24 Flax Pavillion with biobased composite facade, including flax fibers (Studio MarcoVermeulen, 2013)

Scalable Construction Applications	Crops
Composites	Flax and Hemp
Blow-in Insulation without intensive processing required	Miscanthus - Hemp - Grain Straw
Blow-in Insulation from secundary stream	Flax shives - Hemp shives
Insulation wool from main crop	Hemp
Insulation wool from secundary stream	Hemp short fibers - Flax short fibers
Sheet Material Interior without binding materials	Miscanthus - Hemp shives - Flax shives - Horticulture secundary streams
Sheet Material Interior/Exterior with binding materials	Miscanthus - Hemp shives and short fibers - Flax shives and short fibers
Bales for prefab facades and walls	Miscanthus - Hemp - Grain straw

Fig. 25 Scalable Construction Applications (Building Balance, 2023)

Exploring the diverse applications

Adressing the demand for building materials, secundary streams from the flax value chain, like the shives and short fibers, can be used to make insulation material. It would not make sense to expand the cultivation area of flax for insulation applications, since replacing 50% of insulation demand with flax would require 40,800 ha of cultivation land, which is approximately 20 times larger than the current land dedicated to flax cultivation and there are multiple other suitable crops, like Miscanthus, Hemp, Grain straw and Reed, that require less processing, expertise and machinery and that are less expensive (Building Balance, 2023).

However, flax shows potential to be applied in composites, with diverse applications ranging from facade panels to bridge components. Fiber reinforced composites get applied in the constructior sector because of their high strength and stiffnes. Flax and hemp bast fiber have an advantage to the other crops because of their strong reinforcing properties. Recent research revealed that flax based composites retain their original strength and durability, even after reshaping, showcasing its potential for reuse in a circular economy (Ghosh, 2023). The strength of the natural fibers is still lower compared to glass fibers, but the structure may be improved by developing technology (van den Oever et al.,2023).

In a study by WUR (van den Oever et al., 2023) , they also introduce the concept of 'sequential cascading' : "long fibres may be first used in textiles (product level 4), in a second and third life the fibres could be used as insulation material (level 3) and composites (level 2), and finally the composite can be used for energy production (level 1). "

The livMatS Pavillion, which can be found in the botanical garden of the university of Freiburg in Germany, and was created by an interdisciplinary team of architects and engineers at the university of Stuttgart, is the first ever load bearing structure made of robotically wound flax fiber (University of Stuttgart, n.d.).While the immediate adoption of flax load-bearing structures on a large scale seems unlikely now, it shows the remarkable potential of flax and it shows a glimps of what we might expect from flax as technology advances and biobased building starts to play a bigger role.

Chapter 6:

State of the Art: A Flax Industry

What are the spatial, environmental and socio-economic dimensions of the flax industry and how has it developed over time?

Spatial Dimensions

The current flax supply chain with its final application in the built environment, can roughly be divided into the sections agro, industry (flax), industry (textile), industry (building materials),

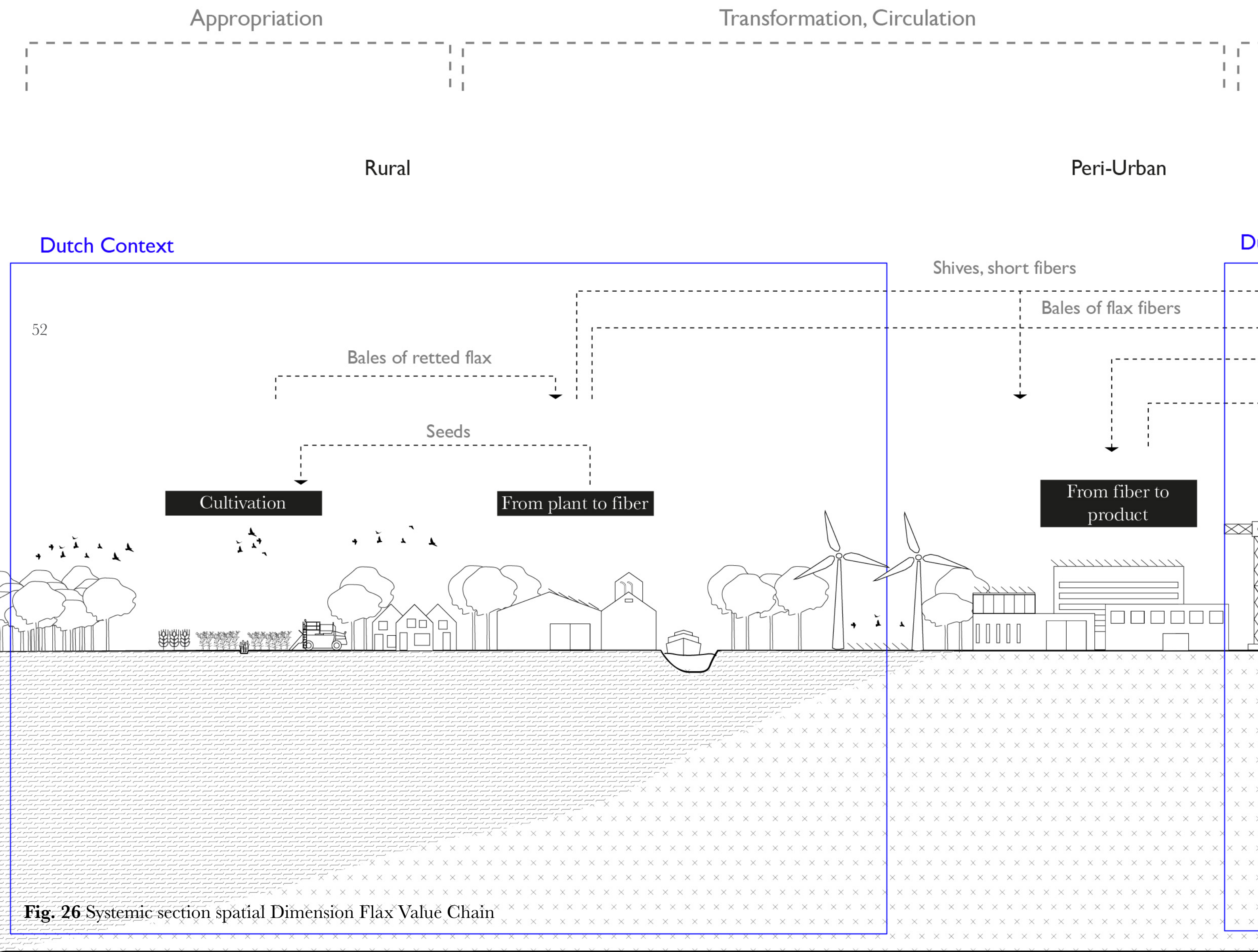
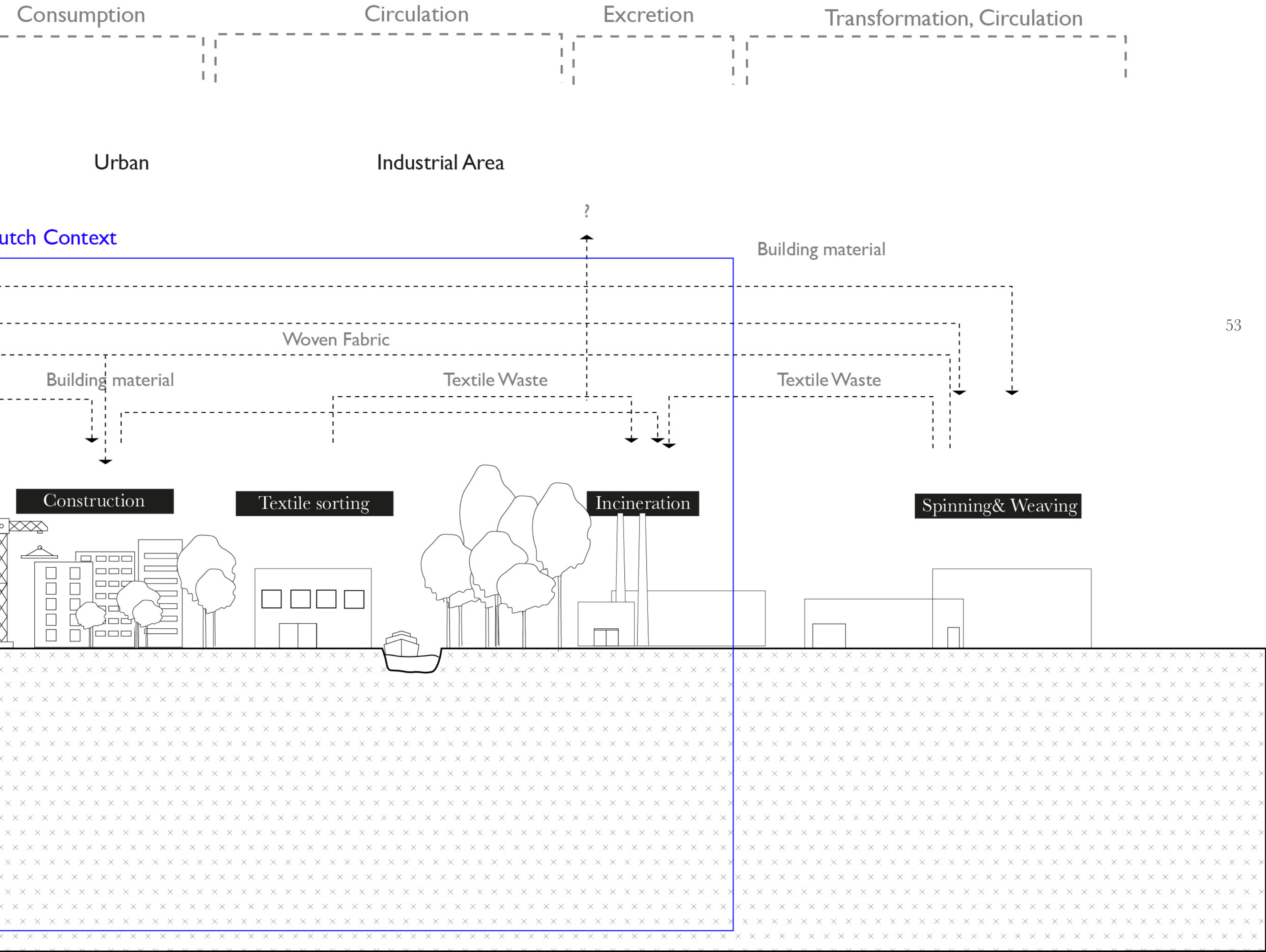


Fig. 26 Systemic section spatial Dimension Flax Value Chain

construction and end-of-life. Currently there are no spinning facilities and barely any manufacturers that use flax to make building materials in the Netherlands.



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Spatial Dimensions Flax Value Chain

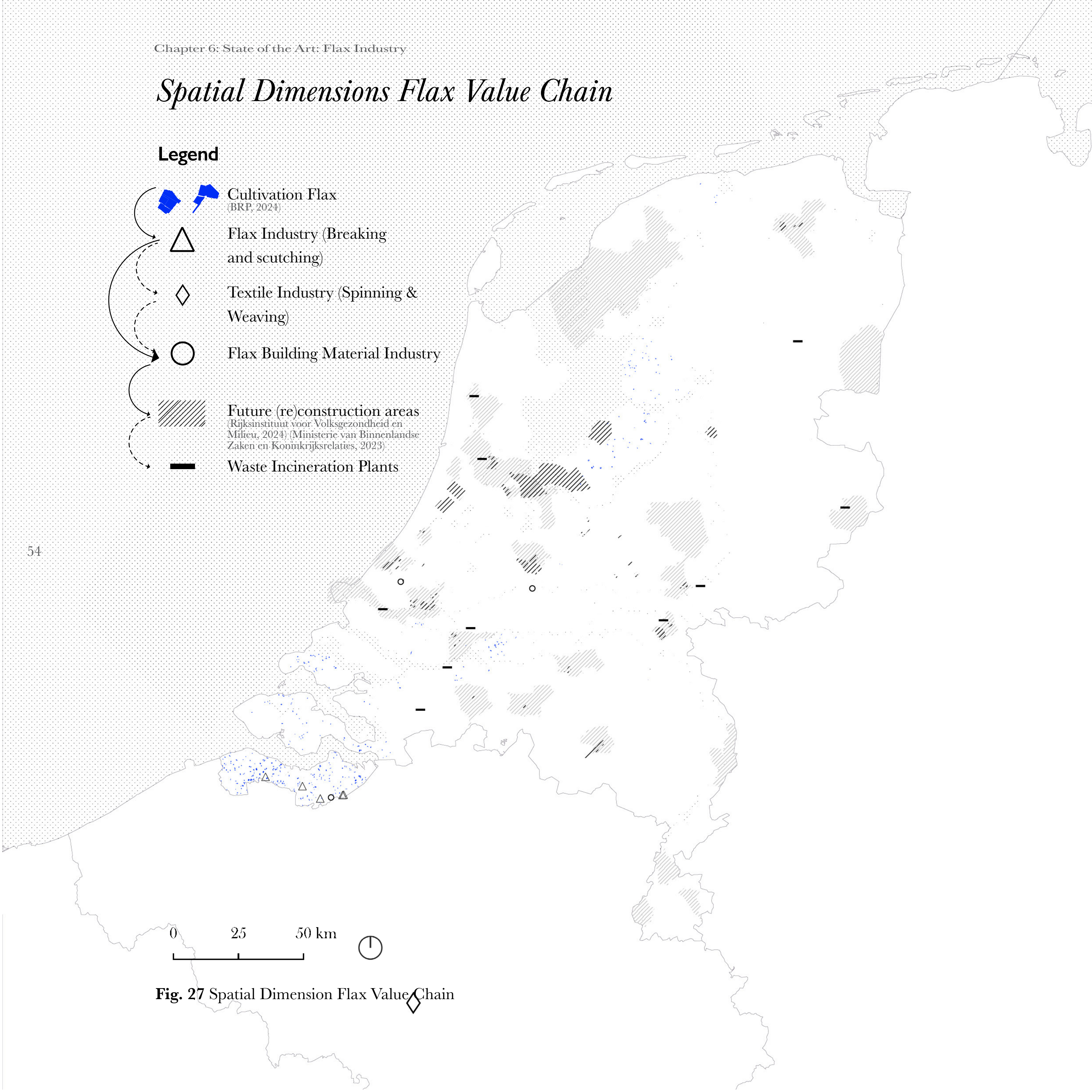


Fig. 27 Spatial Dimension Flax Value Chain

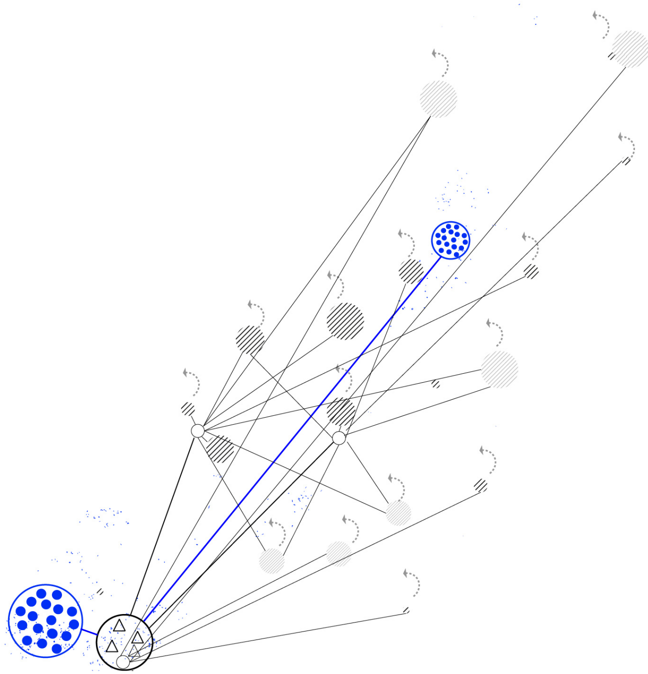


Fig. 28 Conceptualizations spatial Dimension Flax Value Chain

Conceptualization Flax Value Chain

Conceptualizing the spatial flax value chain enhances clarity on the geographical distribution of the different 'stations' of the value chain, the network becomes clear and it an create insight in where interventions to create a circular flax value chain could take place.

Two clusters of flax cultivation parcels can be recognized, a larger one in Zeeland and a smaller one in Flevoland. In Zeeland there is also a cluster of four companies that take care of the first processing of flax (scutching and hackling). There are no spinning facilities in the Netherlands, therefore most of the scutched flax gets exported to Belgium or China for a final application in the textile industry, but woven flax could also be used to create composites.

There are still very few companies that work on making building materials from flax in the Netherlands and they are a bit scattered. From these companies, the building materials would be transported to the construction locations. At end of the use in the construction sector, the materials leave the system (excretion), and are most probably largely incinerated (Velzing et al., 2021).

Agriculture

The cultivation of flax happens in the agricultural sector. Currently, flax cultivation only has a marginal spatial claim, with 2375 ha in 2023 (Centraal Bureau voor de Statistiek, 2023), but the spatial claim of flax cultivation has fluctuated through time (see figure 43).
The agricultural sector plays an important role in the flax supply chain, influencing the quantity and quality of the flax fibers produced. Central to this influence is the strategic selection of cultivation locations based on their ecological properties. Selecting suitable land for flax cultivation involves considerations of soil types, moisture-retention capabilities, and climate conditions (Vreeke et al., 1991).

Flax can only be grown on the same plot once every seven years, but it is very suitable to be integrated in a crop rotation with food crops. Integrating flax into crop rotation systems with food crops, has benefits for soil health and disease prevention. The seven-year rotation cycle for flax cultivation requires thoughtful land allocation strategies.

The cultivation process of flax is further described on the next pages.

Fig. 29 Agro dimension of flax value chain (Pictures from ‘a flax project’ by Christien Meindertsma)

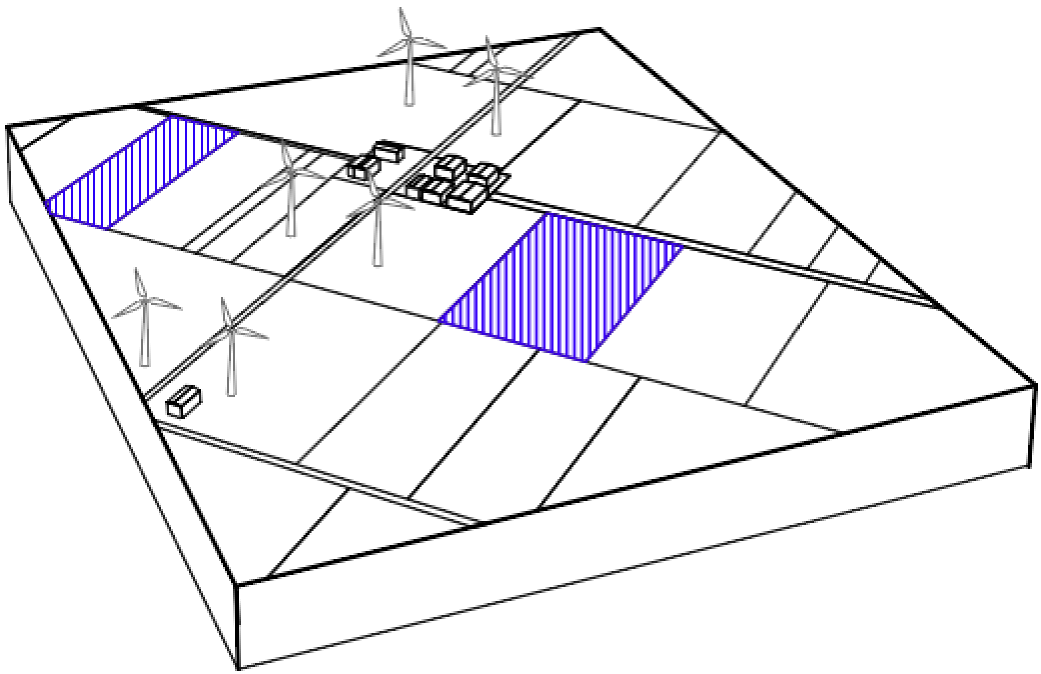


Fig. 30 Spatial Context flax cultivation

Cultivation

The agricultural sector plays an important role in the flax supply chain, influencing the quantity and quality of the flax fibers produced. Actions in this phase of the supply chain encompass strategically selecting suitable land for cultivation, preparing the land, sowing the seeds, cultivation, harvesting, rippling, and retting.

This phase starts with strategically selecting suitable land. Flax cultivation requires good moisture-retaining soil with an undisturbed profile structure. Flax thrives best on heavy clay soil, but all soil types are suitable for flax cultivation. However, on plots with a high soil stock of nitrogen and soils with strong nitrogen mineralization, the risk of lodging is too great. These plots are therefore less suitable. Sandy and valley soils can be suitable, provided the pH is 4.5 or higher. Plots with structural problems and plots infected with northern root-knot nematode pose a problem for flax cultivation (Vreeke et al., 1991, p.14).

The best time to sow the flax seeds is between the end of March until mid-April. Sowing early

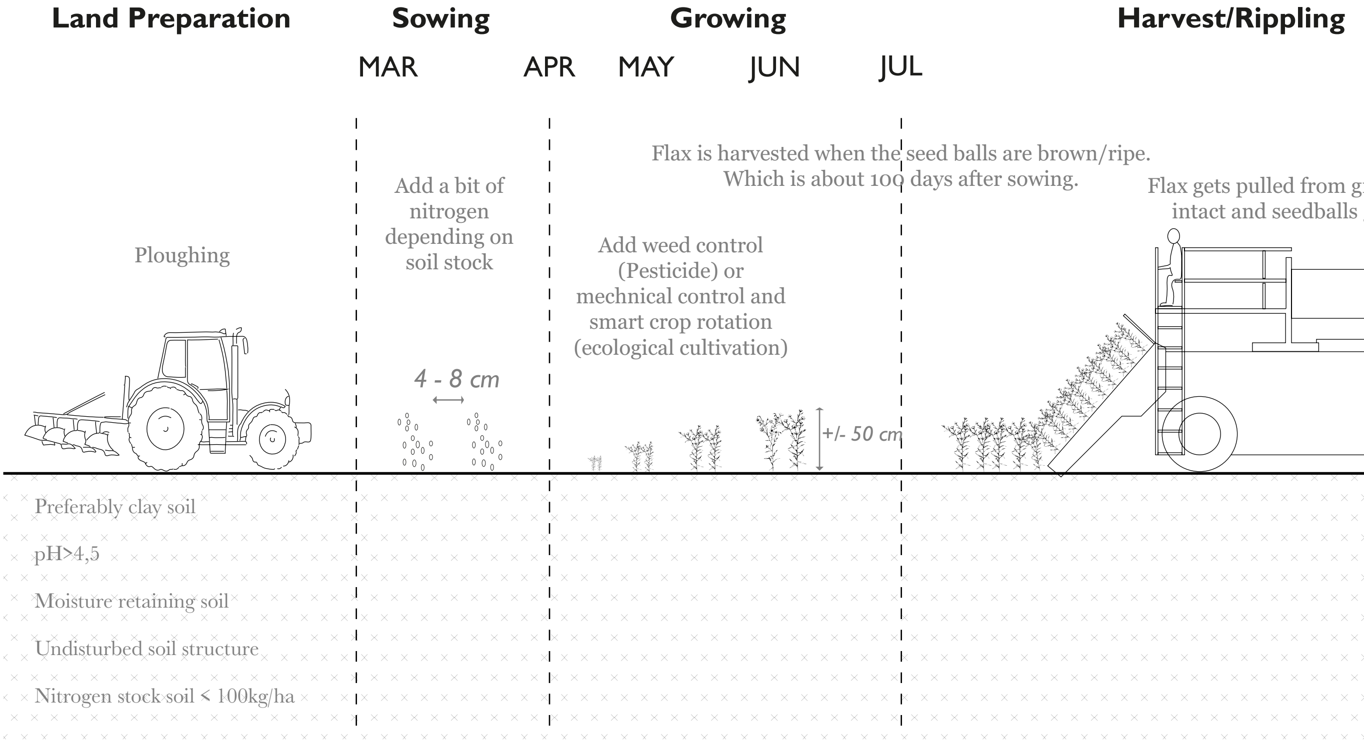
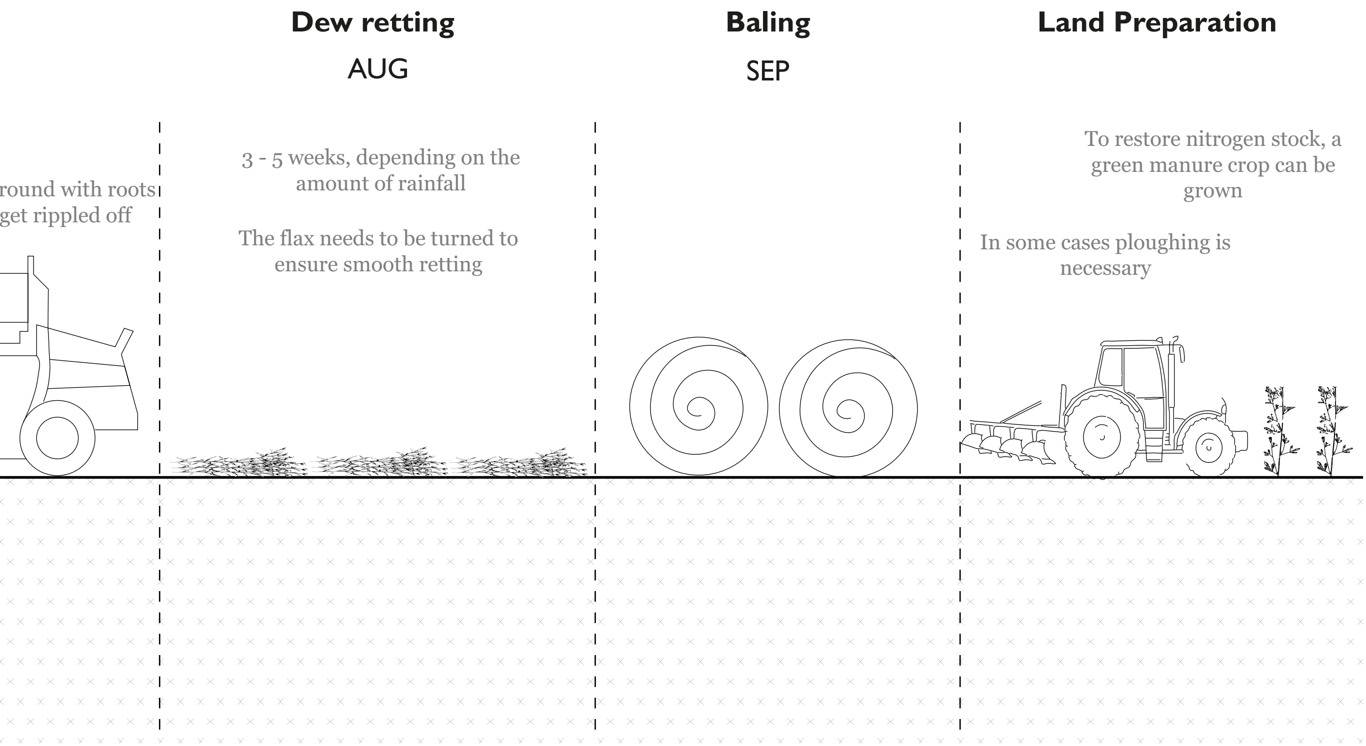


Fig. 31 Flax Cultivation Scheme

is favorable, because it generally ensures a higher yield. Flax seeds can already germinate at temperatures from 3 degrees up, but in the early stages, it is sensitive to frost. For the best result, the seeds should be sown with narrow row spacings between 4 and 8 cm. With row spacings larger than 12,5 cm the density within the row increases and this leads to a higher risk of lodging. Right after sowing a bit of nitrogen nutrients should be added. The amount depends on the nitrogen stock in the soil (Vreeke et al., 1991).

Flax can only be grown on the same plot once every 7 years to prevent the disease ‘Verticilium Dahliae’ and should therefore be included in a crop rotation scheme to keep the soil healthy. When choosing the preceding crop, it is important to check the nitrogen supply. Preceding crops with a green manure crop and grass seed, for example, are not suitable. Growing flax is beneficial for the soil structure and after growing flax, it’s possible to grow most other crops without risk. Because flax does take out most nitrogen from the soil, it can be necessary to grow a green manure crop afterwards to restore the nitrogen stock. Another possibility is leaving the land empty for a year for the soil to restore (Vreeke et al., 1991).



In June the flax flowers for one day. Around mid-July, the flax gets harvested. The flax is pulled from the ground with the roots still intact and they get laid on the ground in bundles to start a process of dew retting. During the harvesting process, the seeds get separated from the rest of the plant. The dew retting happens on the field over the course of three to five weeks, depending on the amount of rainfall (Brancheorganisatie Akkerbouw, 2005). The flax needs to be turned regularly to ensure smooth retting (van den Oever et al., 2023). Once the flax is sufficiently retted and dried, it gets rolled into large bales (Vreeke et al, 1991). These bales can then be transported to processing facilities.

Flax Industry - Site Visit Van de Bilt Zaden en Vlas

To get a better understanding of the industrial processing of flax, I visited ‘van de Bilt Zaden en Vlas’ in Sluiskil. ‘van de Bilt Zaden en Vlas’ is the largest flax processing company in the Netherlands and transforms flax that is cultivated in both France and in the Netherlands and they provide the service of guided cultivation. Their long and short fibers are transported over sea to China and India, the shives are used for animal bedding. The price of the fibers fluctuate and depend on the quality, but generally the price of the short fiber is approximately 1/10 of the price of the long fibers. There for the fibers are often mixed, which reduces the quality of a fabric, but makes it more affordable.

The site visit taught me that a large flax processing facility:

- requires approximately 2500 ha of flax cultivation for it to be viable
- takes up approximately 2 ha of space
- employs approximately 40-50 people
- levels fluctuations to maintain a constant flow, as this is more fair for the employees
- does not lead to air or noise pollution
- requires a lot of storage space
- needs a good connection to infrastructure to ensure efficient logistics
- requires properly baled roles of flax, as this influences the efficiency of the processing

Fig. 32 Flax shives

Fig. 33 Long Flax fibers ready for export

Fig. 34 Location van de Bilt Zaden en Vlas (reprinted from Google Earth)

Fig. 35 Entrance van de Bilt Zaden en Vlas

Fig. 36 Storage space retted flax van de Bilt Zaden en Vlas

Flax Industry

The industrial processing of flax is necessary to transform the raw materials into usable products for construction or other purposes. Actions in this phase include storing the bales, scutching and potentially hackling. These actions require space, special machinery and knowledge.

Currently, there are only a four companies that take care of the first processing of flax in the Netherlands, and they are all located in Zeeland, where most of the production of flax currently happens. And they are situated between the agricultural fields. These companies process 2/3 of the dutch cultivated flax, and additionally they also process flax from other countries, mainly from France. The remaining 1/3 of dutch cultivated flax gets processed in Belgium (Leendertse et al., 2020).

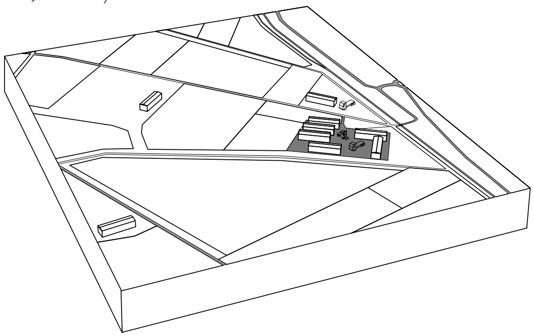


Fig. 37 Spatial Context flax industry

Fig. 38 van de Bilt Zaden en Vlas (Harold Koen, 2019)

Fig. 39 Flax industry dimension of flax value chain (Pictures from ‘a flax project’ by Christien Meindertsma)

Manufacturing of Building Materials

To the author’s knowledge there are only two companies that use flax to create building materials. One creates separation walls, one uses flax amongst other materials to create composites, and one creates insulation materials. All three are situated in industrial peri-urban areas.

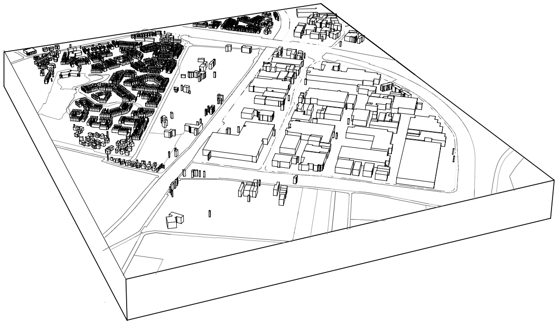


Fig. 40 Spatial Context Manufacturing Building Materials

Fig. 41 Pictures inside Faay (Faay Vianen, 2015)

Construction

There is a large demand for new housing, but also for renovation of existing housing. The demand for new housing is primarily found in ‘de randstad’, while the demand for renovation is more scattered through the country. The largest assignment for renovation is renewing the insulation.

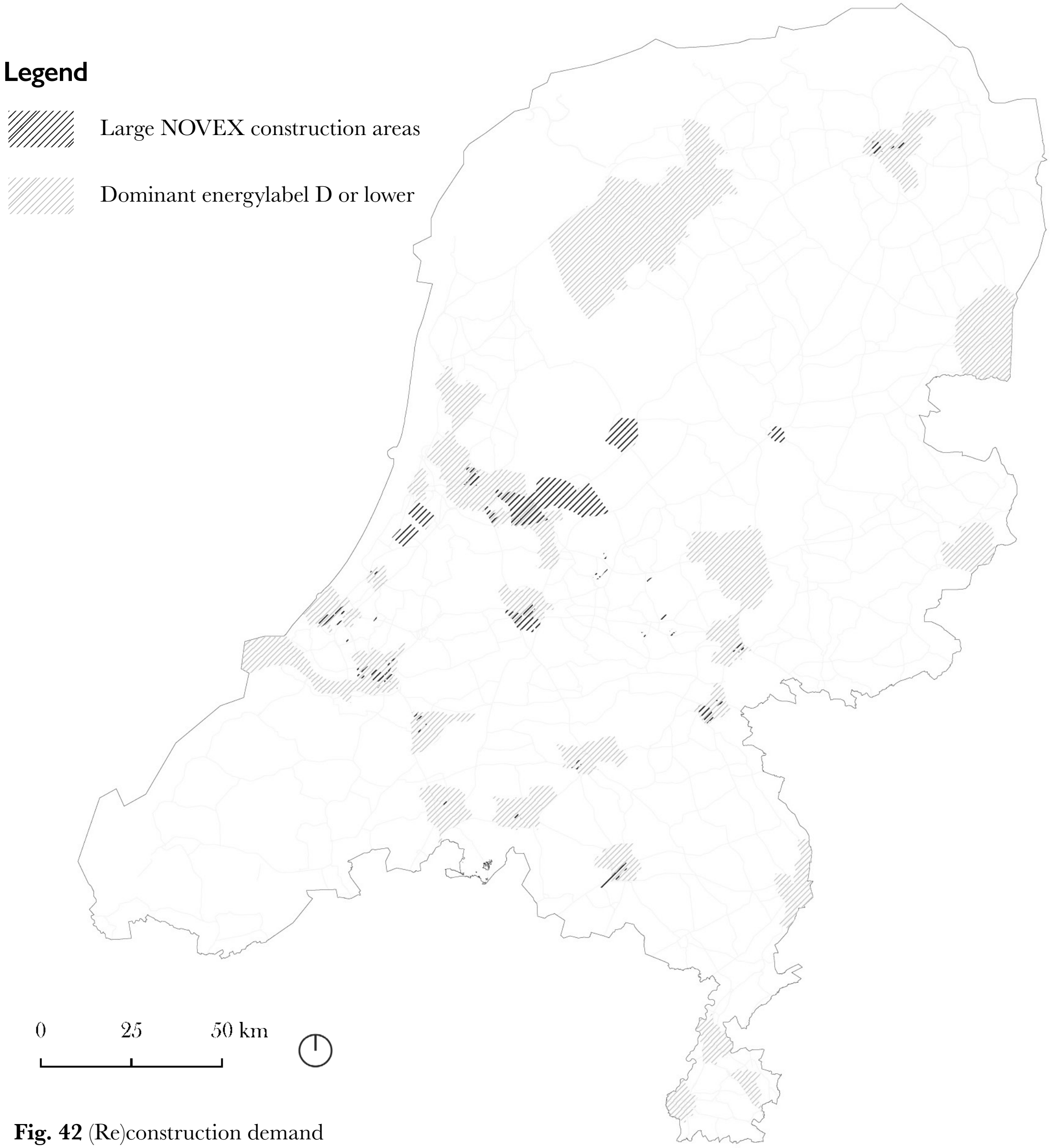


Fig. 42 (Re)construction demand

Adapted from (Rijksinstituut voor Volksgezondheid en Milieu, 2024) (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2023)

Historical Development

Flax has rich history. In this section, a diachronic analysis is performed for the flax value chain. A diachronic analysis helps in understanding the factors that have contributed to changes in the flax value chain. This includes shifts in market demands, technological advancements, policy interventions, or environmental considerations. It also helps to create an understanding of the socio-ecological dynamics involved in the flax value chain over time.

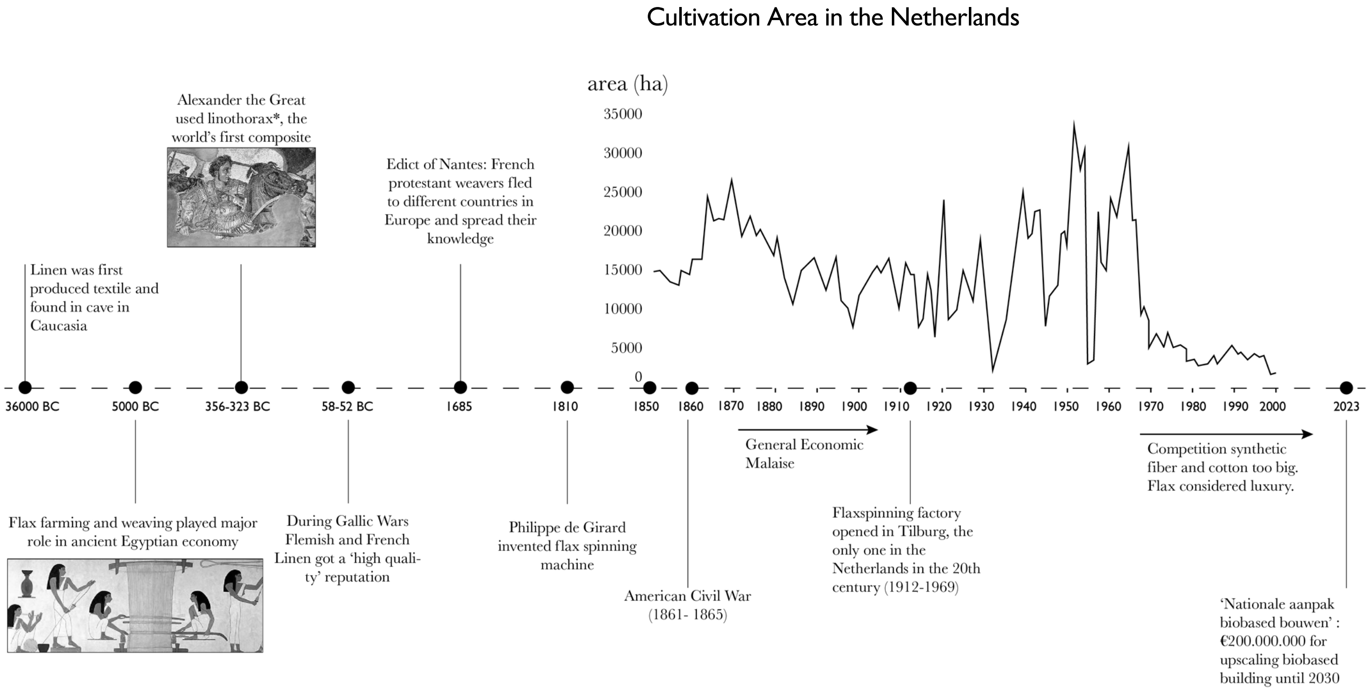


Fig. 43 Flax timeline (Alliance for European Flax-Linen& Hemp, n.d.)
Flax land use graph (Bieleman,2008, p.38)

Cultivation of flax requires certain soil and climate condtions and knowledge and expertise. The climate and soil conditions in the Netherlands are naturally suitable for flax cultivation. Flax grows best on clay soil, which explains the concentration of flax cultivation in regions with clay soil.

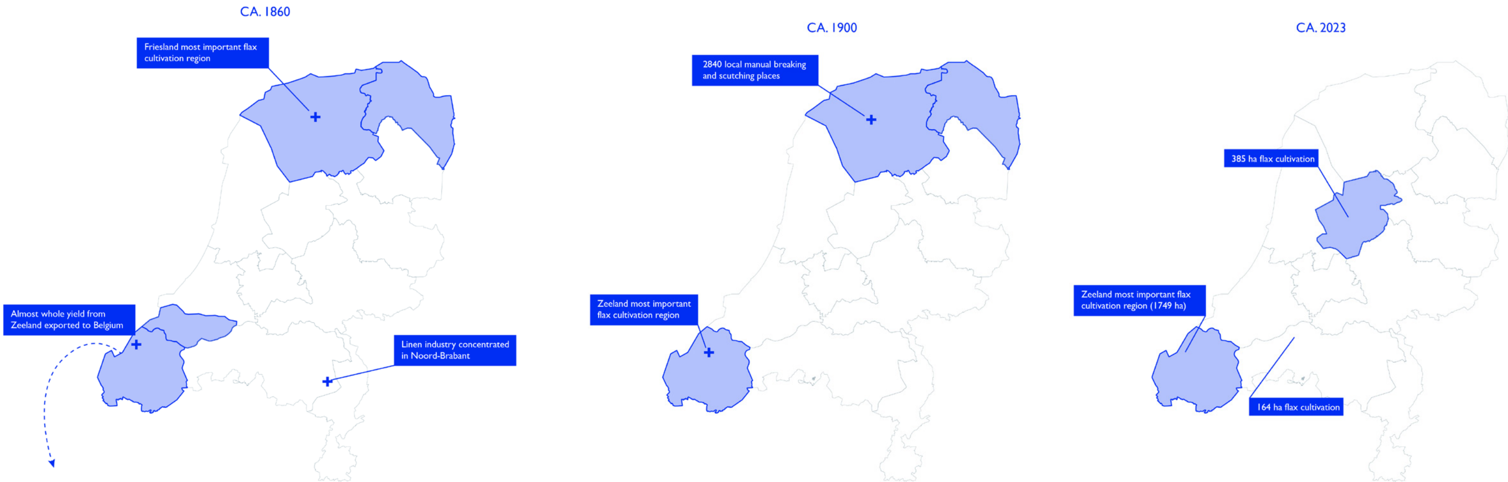


Fig. 44 Historical development flax regions (based on Baas, 1996)

Before 1850

For centuries, linen, made from flax, was the primary plant-based textile fiber in Europe, much like wool dominated among animal fibers. The exact timing of when flax was first cultivated and processed in the Netherlands is not known. However, there is soma data that indicates that in 1669, unhackled flax and tons of linseed were exported from Rotterdam (Kunst, 2003). By the early eighteenth century, flax cultivation was of significant importance in the Netherlands, taking the form of a household industry where flax was processed into rough linen, mainly to meet local clothing and linen needs.

Originally, flax cultivation and processing thrived as cottage industries in the sandy soils of East Netherlands. In the first half of the eighteenth century, flax cultivation and processing shifted to the fertile sea clay soils in the west and north of the Netherlands (Kunst, 2003).

Retting was done in water and all processing happened manually.

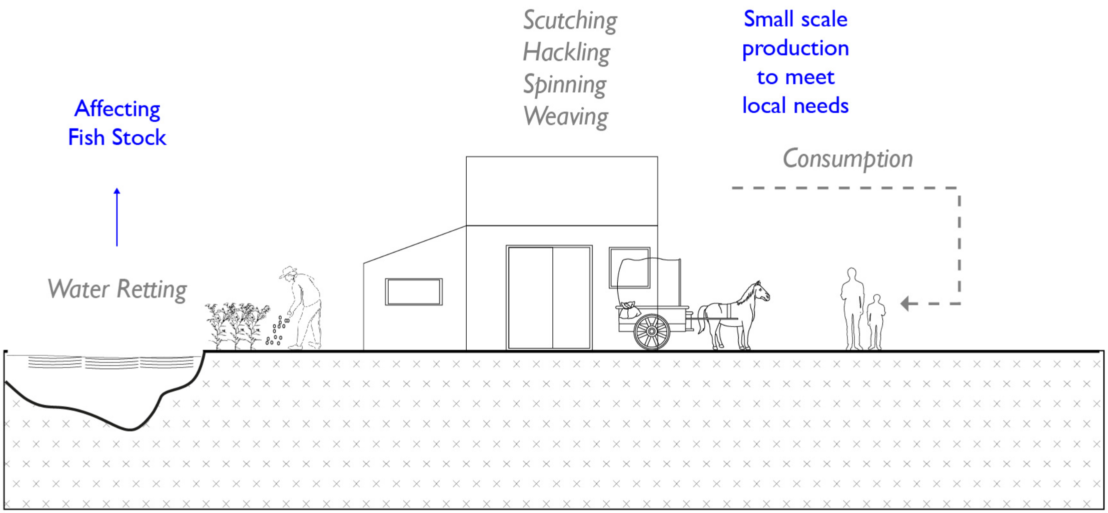


Fig. 45 Systemic section of flax value chain before 1850

Fig. 46 Working weaver , 1656, Frans Halsmuseum

Ca. 1850-1900

Around 1860, the flax industry flourished. In this period, flax was often retted in water. In some regions the location of cultivation and processing would be allocated on their proximity to closed waterbodies for the retting process (de Jong, 2022). However in other regions, Zeeland for instance, they did not use existing water bodies, but they would dig ditches for the retting alongside existing waterbodies. The reason for this was that retting in fresh water was prohibited, as it would affect the fish stock (Baas, 1996).

The flax industry in this period was very labour intensive and relatively slow with mechanization. At the end of the 19th century around 15.000 to 18.000 people worked in this branche. Contrary to Belgium, that had a flourishing spinning sector, the Netherlands has never had a lot of spinning factories. Around this time there were only a few factories, but it is very likely that a lot of people, especially on the countryside, had spinning machines at home (Baas, 1996).

However, the working conditions were often very bad. The water from the ditches in which the flax was retted often got mixed with drinking water. And after retting, the flax was removed from the ditches and released bad smells and potentially harmful gases. Additionally, the processing was often executed in small, poorly-ventilated spaces close or attached to houses, and was accomponied with significant dust development, resulting in diseases and quite a high death rate (Baas, 1996).

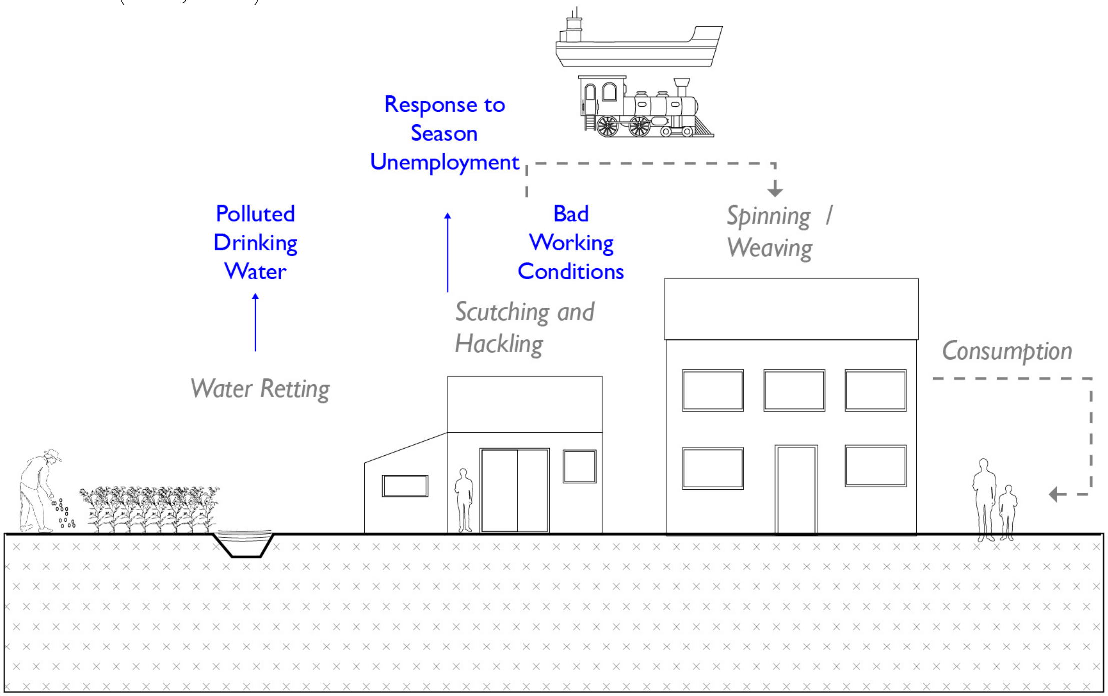
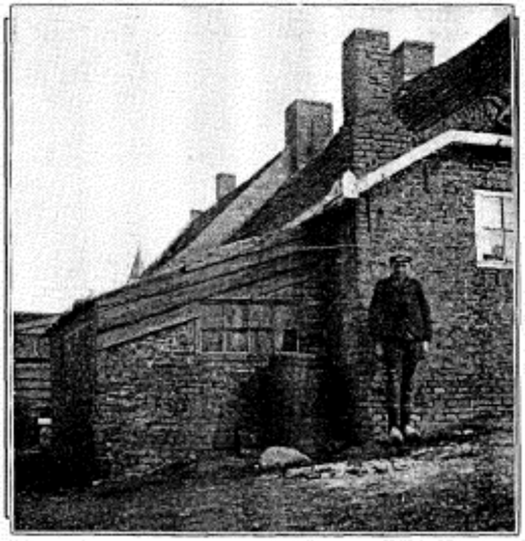


Fig. 47 Systemic section of flax value chain 1850-1900

Afbeelding 2.7: Zij-aanzicht van braakhok/ zwingelkeet (Bron: Baart, De vlasnijverheid, 28)



2. aan het woonhuis aangebouwd braakhok

Dit type verschilde met bovenstaand type alleen hierin dat het hoogste gedeelte van het hok tegen de woning aan was gebouwd. Het nadeel hiervan was dat de afvoer van stof bemoeilijkt werd met als gevolg dat het stof de woning binnendrong.

Afbeelding 2.8 Braakhok/zwingelkeet aan woonhuis (Bron: Verslagen en mededelingen, 104)

Fig. 48 Scutching sheds (Baas, 1996, p.36)

Ca. 1900-1950: A period of mechanization

Flax no longer got retted in water. Methods used in this time were dew retting (retting on open field) and warm water retting in steam driven retting houses.

The historical evolution of flax processing, particularly the transition from manual to mechanized methods, is relevant to socio-ecological metabolism. Before the 20th century and at the very beginning of the 20th century, flax processing happened manually. The spatial distribution of these manual facilities, concentrated in specific provinces, reflects the socio-eco-

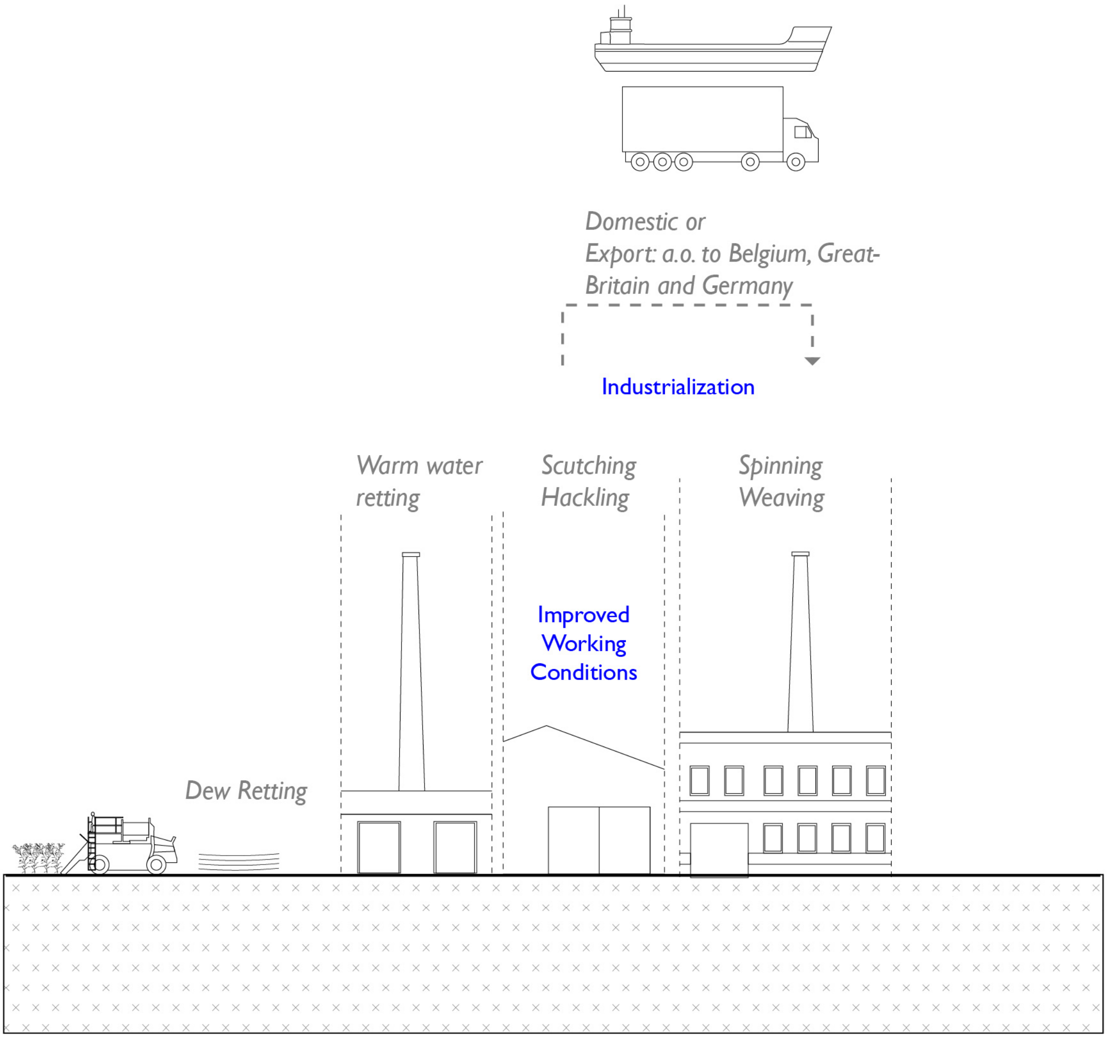


Fig. 49 Systemic section of flax value chain before 1900-1950

logical interactions within regional contexts. A large part of the local population worked in agriculture, seasonal unemployment was a consequence. The abundance of manual facilities can be seen as a socio-economic response to the seasonal unemployment, engaging the local population in the appropriation of natural resources during spring and summer (flax cultivation) and transforming them through various processes like retting and scutching in winter. However, more and more steam driven flax factories were established, and with this the working circumstances improved.

A lot of the processed flax got exported through the Rotterdam trade cemter to be spun. It would get imported again to be woven (Baas,1996).

Fig. 50 Scutching department flax factory Dinteloord, Steenbergen (TextielMuseum)

1950-2023

In the second half of the 20th century, the tide definitively turned against flax. The competition from synthetic fibers grew stronger, and the quality and price of cotton became increasingly attractive to consumers, making linnen an old-fashioned and luxury item. Additionally, the appearance of high-quality flax from the Soviet Union greatly reduced market opportunities for Dutch flax and flax is only cultivated and processed on a small scale in Zeeland (Baas, 1996). However, now that we need to transition to a biobased economy, demand for flax is increasing again (Leendertse et al., 2020).

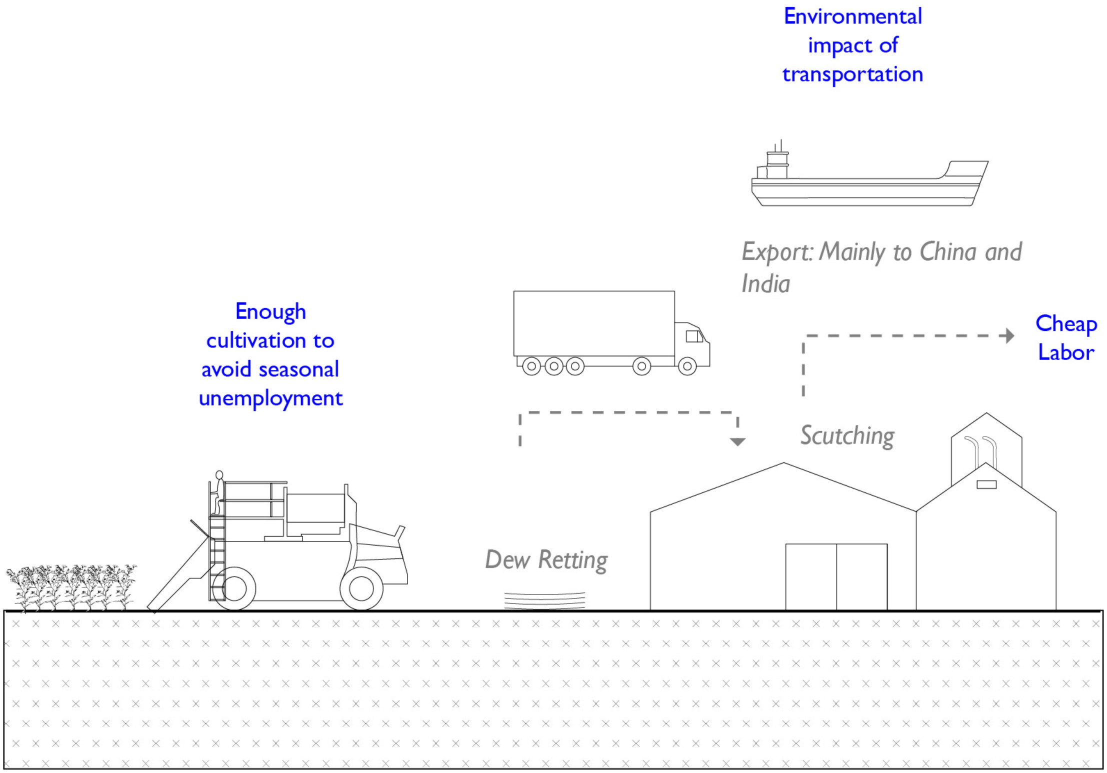


Fig. 51 Systemic section of flax value chain 1950-2023

Environmental Impacts

Biomaterials offer environmental advantages compared to conventional materials by contributing to carbon sequestration, saving energy, reducing greenhouse gases and reducing use of non-renewable resources (Fernando et al., 2014). However, flax being a biomaterial, does not automatically ensure that the value chain is environmentally friendly (Jacobsson, 2018).
To get an idea of the environmental impacts of flax in a biobased building sector, the environmental impact should be assessed throughout the whole value chain.

Cultivation

The environmental impact of the cultivation process can be measured by the amount of greenhouse gasses that are emitted and captured, the pollution of natural resources due to the adding of nutrients and pesticides, the water use, the influence on the soil (structure) and the influence on biodiversity. Sources of CO2 emittance are the production of fertilizers and fuel use for the vehicles used. Sources of (indirect) N2O emissions are the soil and fertilizers.

Flax requires water right after sowing, so it depends on rainfall if this can happen naturally or if extra water is needed.
Currently, pesticides are often used during the cultivation of flax, which is not good for the biodiversity. However, it is possible to cultivate flax ecologically without using pesticides by replacing it with mechanical weed control and smart crop rotation to keep insects away. Ecological cultivation may result in a lower yield, but it also reduces costs.

When flax is compared to glass or polyester on environmental impacts for reinforcement of composites, flax scores better on energy requirement, global warming potential and acidification potential, but worse on eutrophication potential, due to the use and production of fertilizers (Fernando et al., 2014).

To minimize environmental impacts during the cultivation phase, adequacy between crop and location is very important.

Processing

The processing of flax requires energy, but generally this is less than is needed for the production of conventional building materials. In the production of building materials from flax, the environmental impact also depends on the choice of the binder. Which influences the amount of raw materials needed for the production, as well as the end-of-life options. Spinning and weaving affect the environment the most in the processing phase, as these steps often happen in China and a large part of the energy there comes from burning coal (Fernando et al., 2014).

Transportation

The Flax market is a global market, including a lot of trade. The Netherlands has no spinning facilities, and therefore, after the first processing (breaking, scutching and potentially hackling), the fibers get exported to a.o. Belgium, France and China for spinning and weaving. This transportation affects the environmental impact. However partial production in China is more attractive from an economic perspective, because of their technical capacities and low labour prices (Gomez-Campos et al., 2020).

Application

During the cultivation of flax, it sequestrates carbondioxide. When flax is made into textile or building materials, the carbiondioxide gets stored for a longer period of time, which is important to reach the climate goals. This gives fiber crops an advantage compared to food crops for which the carbon sequestration has a much shorter cycle (Jacobsson, 2018). It is also recognized that greater use of flax in the textile industry could contribute to the sustainability of the textile industry by replacing the conventional unsustainable synthethic fibers (Fernando et al., 2014) (Leendertse et al., 2020).

Circularity

The end-of life options influence the environmental impacts. Reusing has the lowest environmental impact, recycling and composting follow, then incineration, and lastly landfilling performs the worst because some of the flax degrades anaero-bically to methane instead of CO2 (Fernando et al., 2014). In a study by Wageningen University & Research (van den Oever et al., 2023) also mentions how linen 'waste' from the textile industry can be used for insulation material or composites in the building sector. However, according to the author's findings, there is limited data available on the current end-of-life management of flax based building material. This can probably be explained by the fact that application of flax based building materials does not happen too often yet. A research from 2021 states that 95% of flax insulation panels get incinerated at the end of their life (Velzing et al., 2021).

Land Use

Currently, land use dedicated to cultivating fiber crops is only marginal. When increasing land use for the cultivaton of fiber crops, it will compete with food agriculture, urbanization and nature protection. Therefore, there should be aimed for positive effects, or at least minimal negative effects from the land use change. Regarding this, flax could fit in crop rotations with food crops, improving soil health and reducing ethical concerns on land use (Fernando et al., 2014).

Environmental Impacts

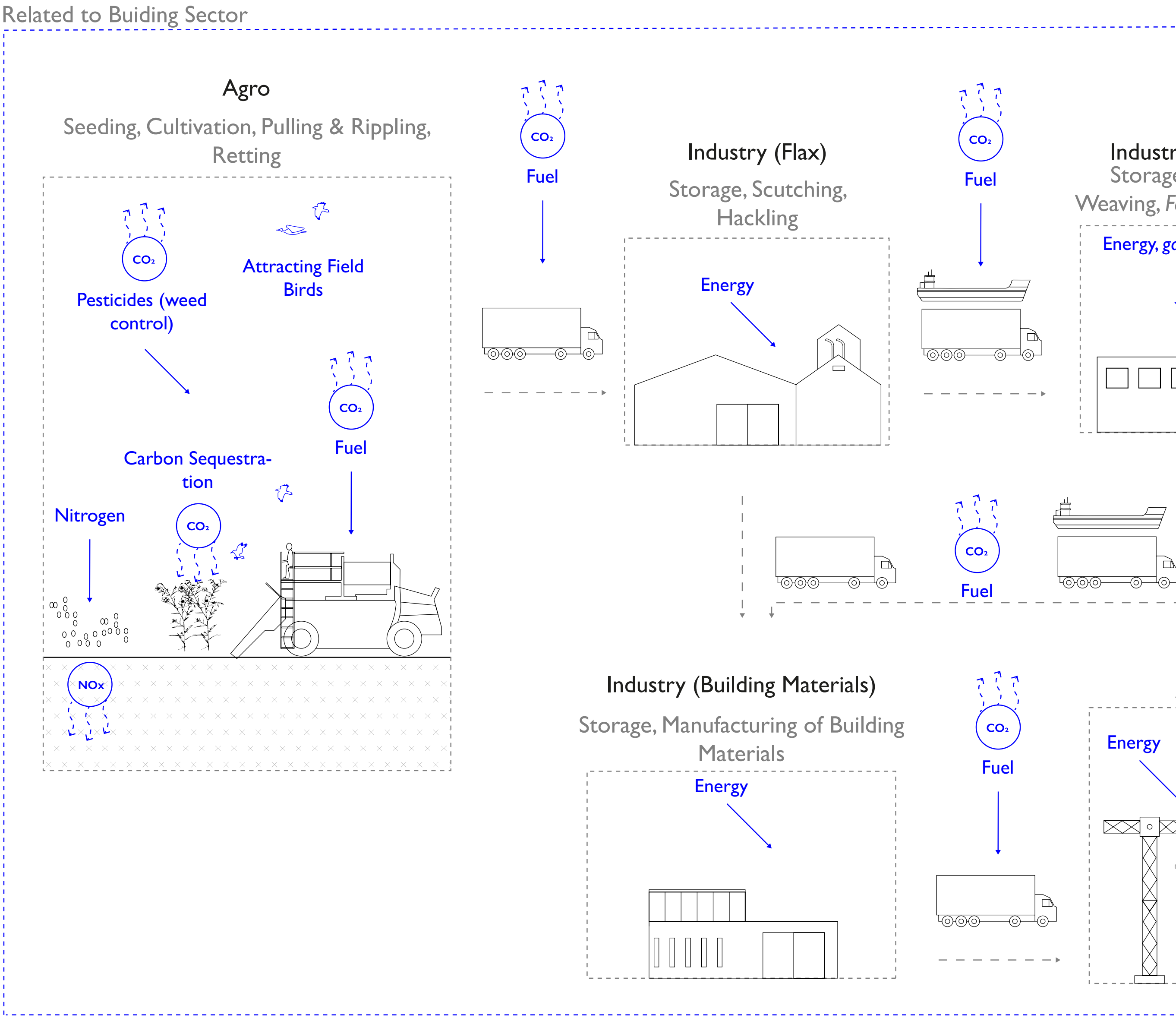
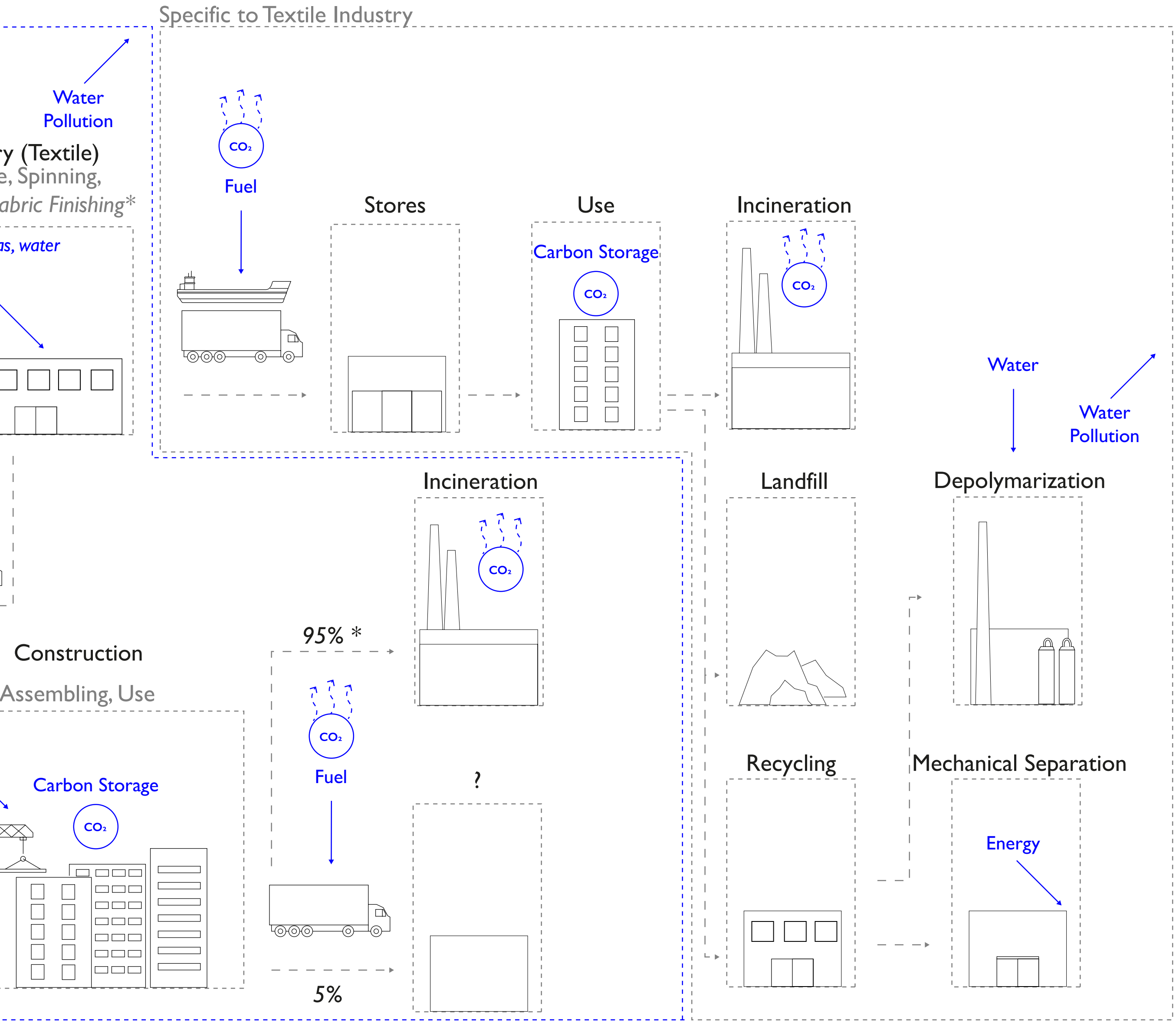


Fig. 52 Scheme of environmental Impacts flax value chain


Specific to Textile Industry
Water
Pollution
ry (Textile)
e, Spinning,
abric Finishing*
as, water
CO₂
Fuel
Stores
Use
Carbon Storage
CO₂
Incineration
CO₂
Water
Water
Pollution
Incineration
CO₂
Landfill
Depolymarization
95% *
Construction
Assembling, Use
CO₂
Fuel
Carbon Storage
CO₂
?
Recycling
Mechanical Separation
Energy
5%

Socio-economic aspects

Fiber flax is mostly produced in Europe, but spinning and weaving is often done outside of Europe. France is the biggest export of scutched flax and China is the biggest importer. In China the long fibers are processed into yarns and fabrics. The reason for this to happen in China is because of the low wages.
The Western European coastal region (from Normandy to the Netherlands) is known to produce high quality flax fibers. However, compared to France and Belgium, the flax cultivation and processing industry in the Netherlands is very small. Demand for flax fibers, and therefore the price of the fibers, fluctuates with fashion trends. In times of low demand, the fibers can be stored until the demand goes up again. In times of high demand, France and Belgium significantly increased their cultivation area, while in the Netherlands it stayed more constant, limited due to high land prices (van den Oever, 2023).

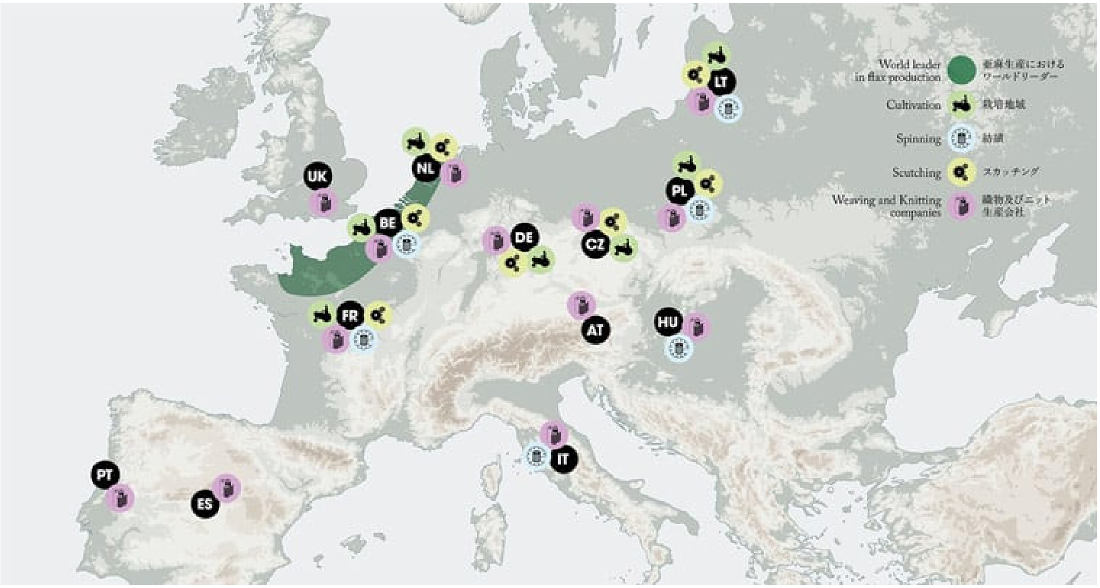


Fig. 53 Textile Industry Europe (Mugmagazine, 2017)

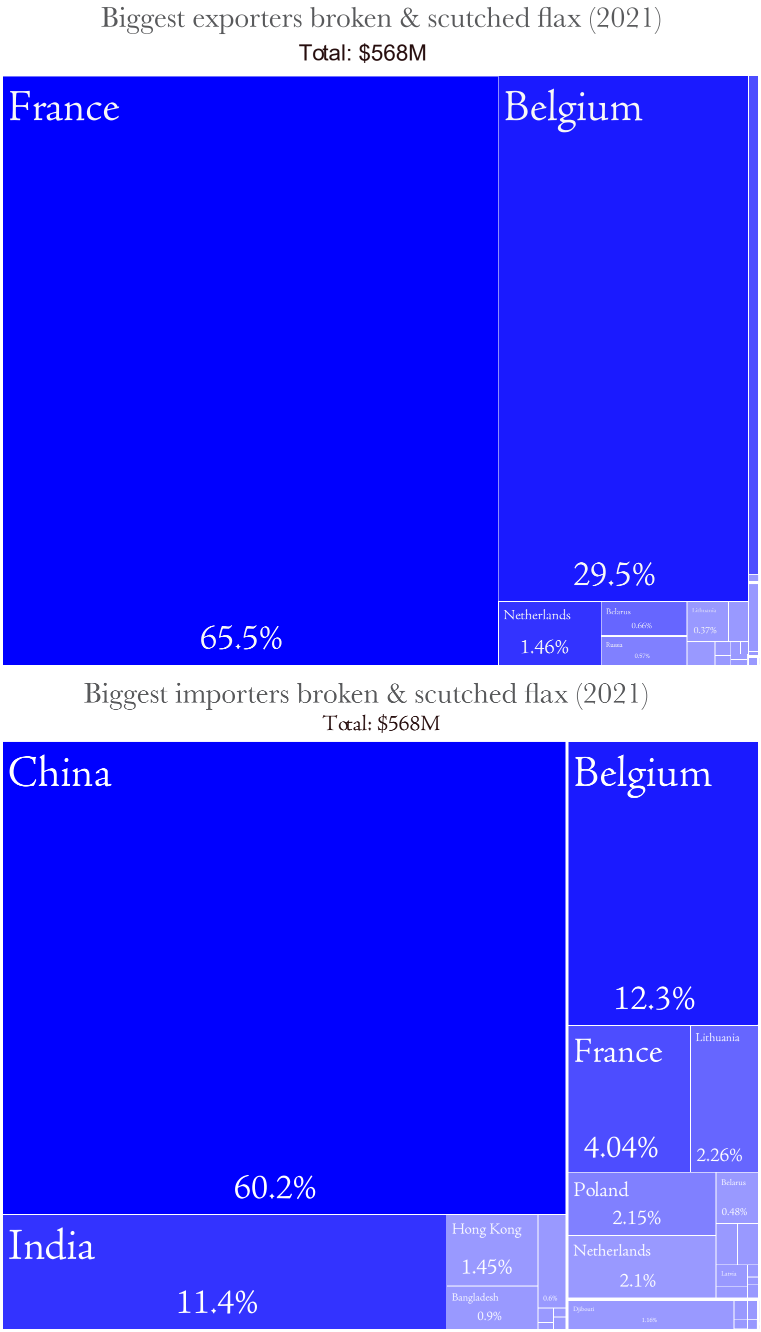
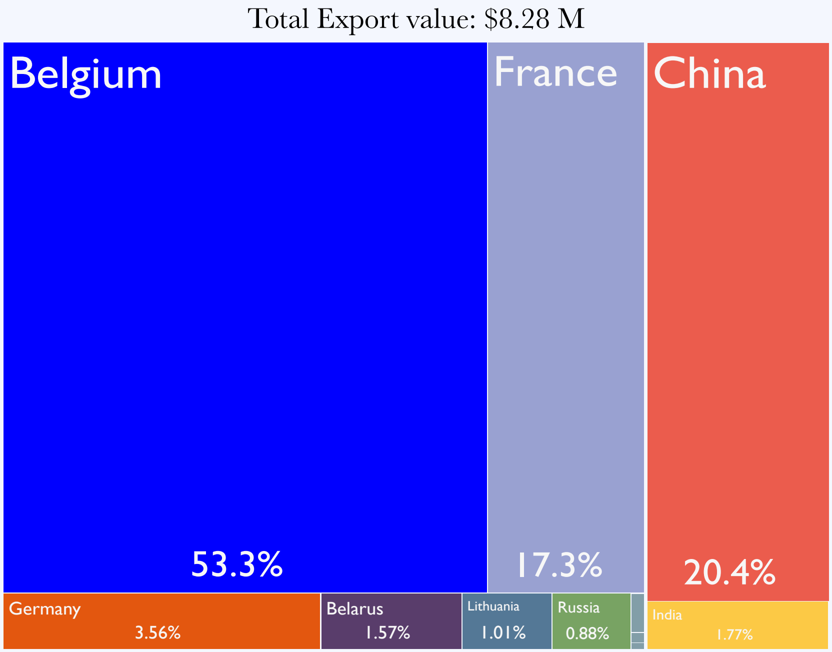


Fig. 54 Biggest importers and exporters of broken & scutched flax in 2021 (Adapted from The Observatory of Economic Complexity,2021)

Export of Broken and Scutched Flax from the Netherlands

Europe has a few spinning mills, but the Netherlands does not have one, partly due to high labour costs, therefore almost all the scutched long flax fibers from the Netherlands gets exported (van den Oever, 2023).



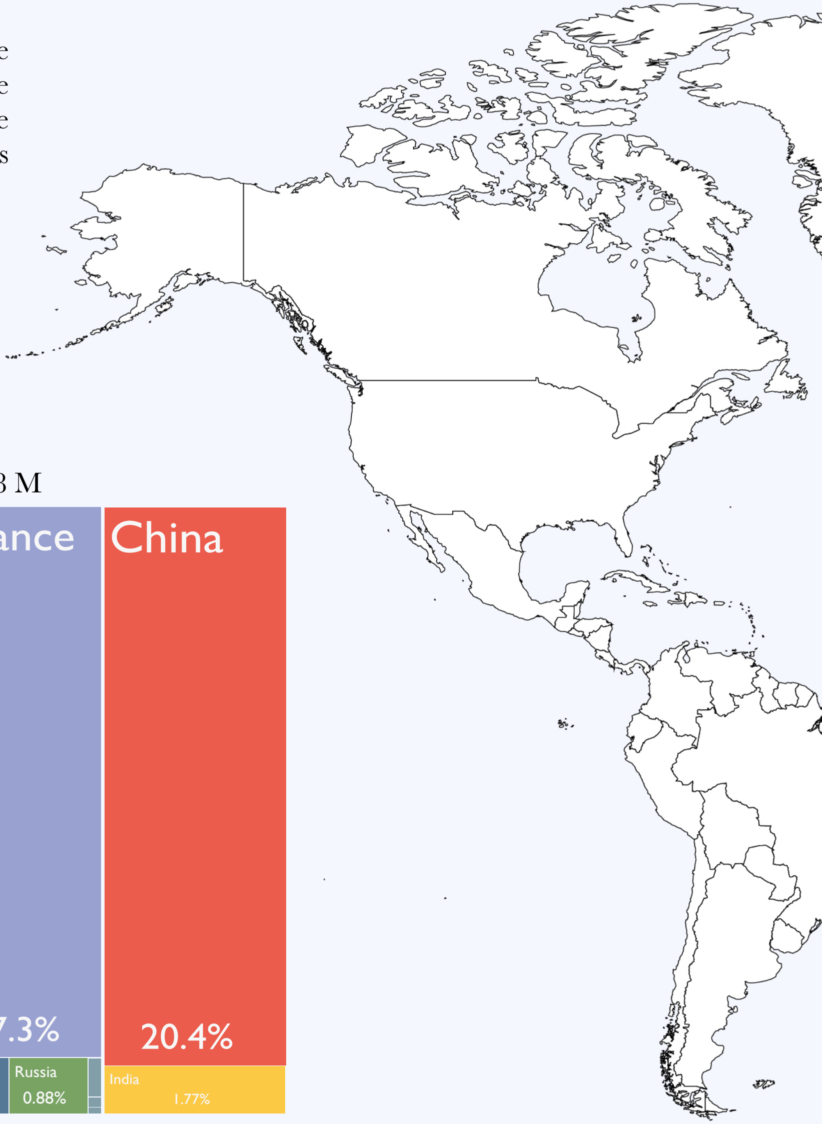
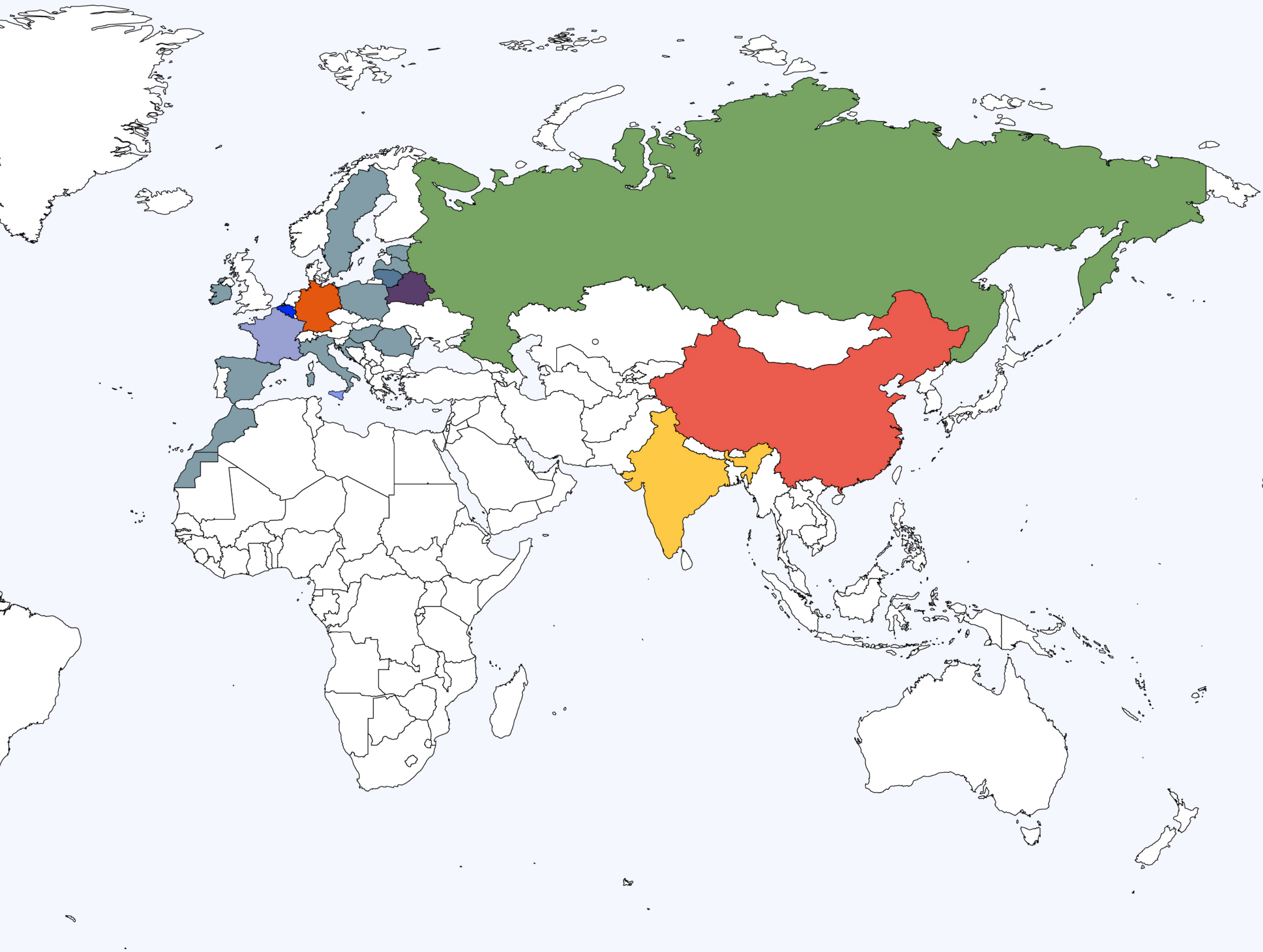
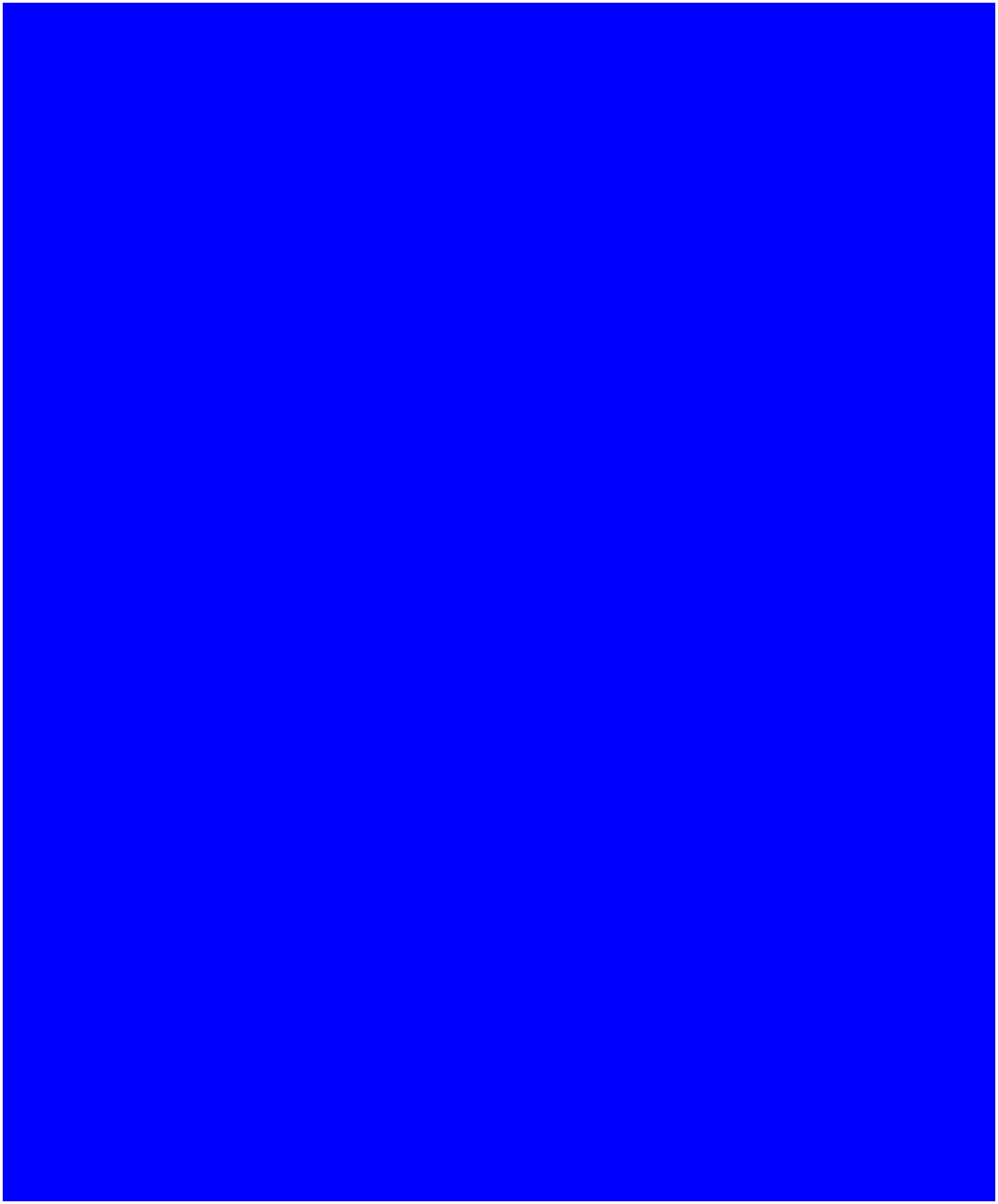


Fig. 55 Diagram: Biggest importers of broken & scutched flax from the Netherlands in 2021 (Adapted from The Observatory of Economic Complexity,2021)

Fig. 56 Map: Biggest importers of broken & scutched flax from the Netherlands in 2021 (Adapted from The Observatory of Economic Complexity,2021)





Chapter 7:

A Flax Future for the Netherlands?

What are spatial principles, and environmental and socio-economic requirements for a sustainable circular flax supply chain?

Backcasting Scenarios

Backcasting can be defined as looking backwards from a generated desired future and creating a strategy on how this future can be achieved. It involves analysing and experimenting with different ways to achieve this future (Abou Jaoude et al., 2022). This method is chosen because in November 2023, the Dutch Government published the program 'Nationale Aanpak Biobased Bouwen' (National Approach to Biobased Building) (Ministry of the Interior and Kingdom Relations et al., 2023), in which concrete intended results for 2030 are given.

Alongside the National Approach to Biobased Building, the government has allocated €200 million to establish independent chains for biobased construction materials, with €25 million designated for market development from 2023-2025 (phase 1) and €175 million reserved for market expansion from 2025-2030 (phase 2). The main objective of the National Approach to Biobased Building is to "bijdragen aan nationale doelstellingen op het gebied van CO_2-reductie, stikstofreductie, circulaire economie, natuur- en biodiversiteit en ruimtelijke kwaliteit' (contribute to national goals of CO2 reduction, nitrogen reduction, circular economy, nature and biodiversity, and spatial quality)" (Ministry of the Interior and Kingdom Relations et al., 2023, p.16).

This program mentions the following intended results for 2030:

- At least 25 producing chains of farm-processing-construction
- At least 50.000 ha of fiber cultivation for construction annually
- Processing capacity of at least 400.000 ton fibers annually

These represent tangible outcomes, however, a spatial strategy, or an idea detailing the ratio of specific crops, and their respective cultivation and processing locations is missing. To come to a more complete vision of the desired future and the expected role of flax in this, information from a report by Wageningen University & Research, 'Regional supply of herbaceous biomass for local circular bio-based industries in the Netherlands' (van den Oever et al., 2023), was used.

The report by Wageningen University & Research (van den Oever et al., 2023) analyses and explores the potential of production and valorization of herbaceous feedstock (like flax, hemp, miscanthus, cereal straw, reed, and verge grass) in the Netherlands with applications in various sectors. These sectors encompass construction, textile, paper, automotive, horticulture, and livestock farming.

In this report, estimations are made of the potential demand for crops in different applications at given replacement shares and the related required cultivation area.
The first scenario derives from the goals set out in the 'National Approach to Biobased Building' and the estimated required cultivation area from the study by WUR. In the second scenario, additionally the required cultivation area is given for a replacement share of 25% of textiles with flax and hemp, as the author recognizes the potential synergy between the building and textile sector.

Scenario 1 2030: Flax for composites

- For insulation application only residual streams of flax are used
- 30 - 50% of facades made of flax annually, resulting in **+ 1125 -1875 ha/a flax** additional to current production -->2250 - 3750 ton/a to process additionally
- 30% of other composites made of flax, resulting in **+ 466 ha/a flax** additional to current production -->922 ton/a to process additionally
- Establishing circular flax value chain
- Used textile for insulation and composites
- Investigate local spinning possibilites* (*typical conversion 1000 ton/ha)
- Total flax cultivation/a: 2300 ha/a (current production) + 1591-2341 ha/a (additional) = **3891-4357 ha/a**

Scenario 2 2030: Flax for Composites and Textiles

- For insulation application only residual streams of flax are used
- 30 - 50% of facades made of flax/hemp annually, resulting in **+1125 -1875 ha/a flax** additional to current production --> 2250 - 3750 ton/a to process
- 30% of other composites made of flax/hemp, resulting in **+466 ha/a flax** additional to current production -->2250 - 3750 ton/a to process
- 25% textiles replaced with flax/hemp, resulting in ca. **+42.875 ha/a flax and hemp** additional to current production
- Establishing circular chain
- Used textile for insulation and composites
- Investigate local spinning possibilites* (*typical conversion scale 1000 ton/a)
- Total flax/hemp cultivation/a: 2300 ha/a (current production) + 44.466 - 44.750 ha/a (additional) = **46.766-47.050 ha flax and hemp/a**

Systemic Section

Envisioning the future flax value chain, the systemic section helps to understand the relation between the physical built environment, flows, and socio-ecological factors (Wandl, 2023). In order to cultivate flax on a large scale, it should be grown on agricultural land in the rural hinterland, since it requires specific sowing and harvesting machinery. The first processing of flax, extracting the different components of the plant, should happen close to the raw material, and therefore, should be placed in more rural areas. The same allocation can be seen in current practice.

To make composites, or potentially even bearing structures, the long fibers should sometimes be spun, and in some cases also woven, depending on the desired outcome. Considering the spatial footprint of spinning and the possibility of making use of the existing infrastructure, spinning facilities should happen in industrial areas. To then turn it into composites or another technical requires knowledge and skilled labor, therefore it would make sense to locate the

Scenario 1 2030: Flax for composites

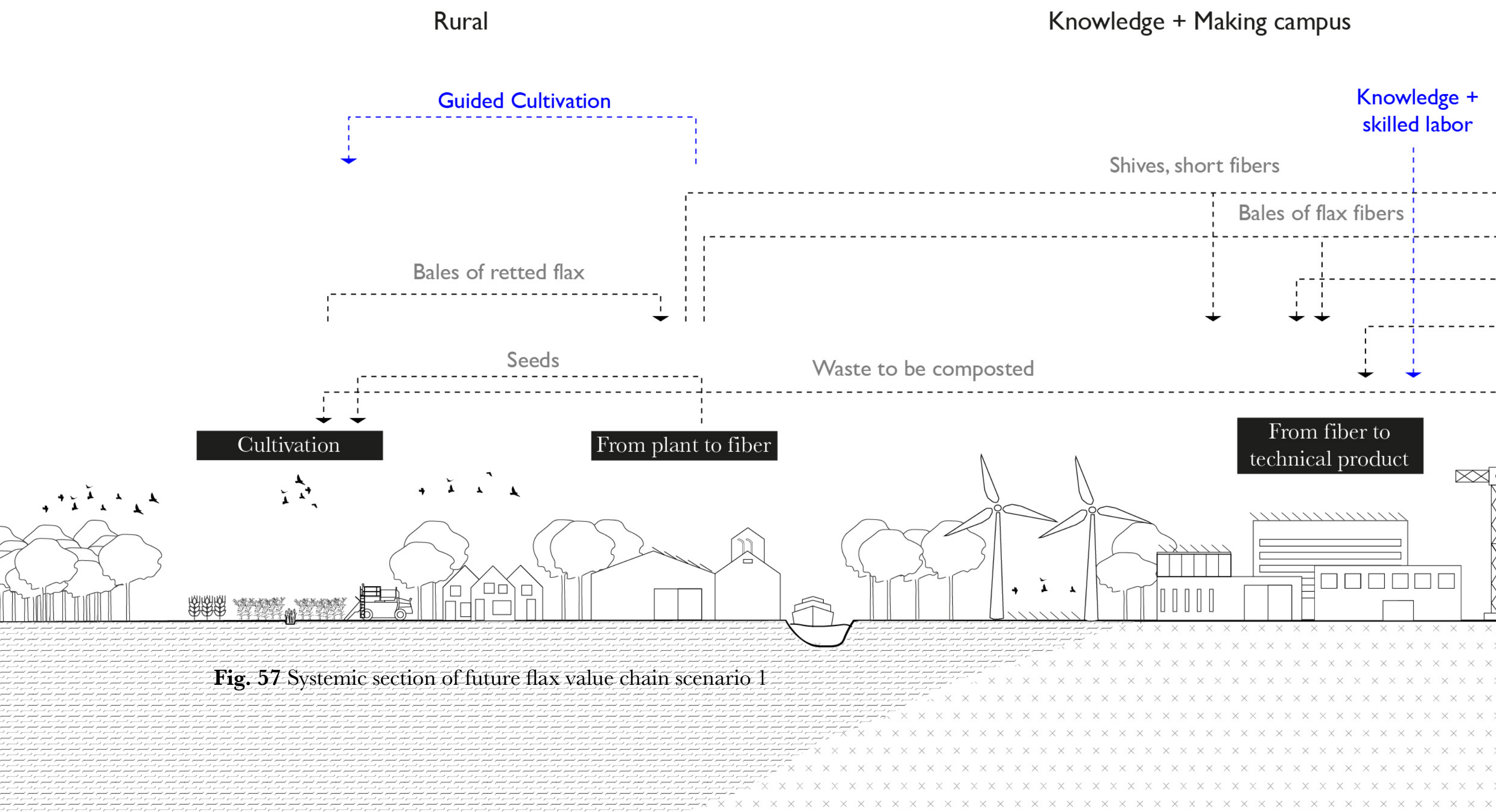
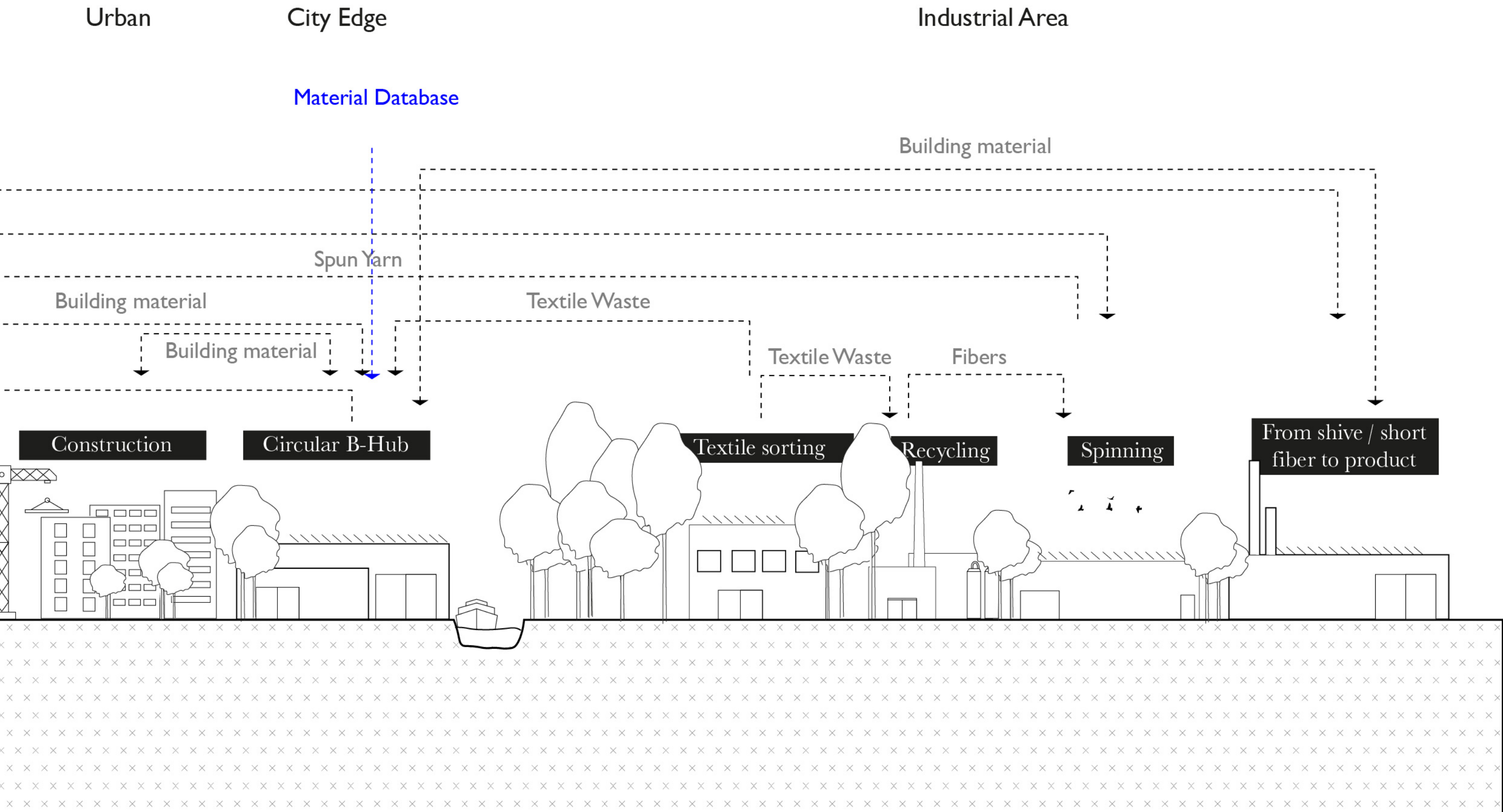


Fig. 57 Systemic section of future flax value chain scenario 1

companies near knowledge hubs.
Shives and short fibers, which are seen as residual products, can be used to create insulation material. Current insulation-producing companies can make a shift to biobased insulation materials. Another possibility is to blow-in insulation, requiring no transformation or processing of the material, and thus, no extra space. The raw material could be stored at a circular building hub, and be brought to construction sites from there. At the end of use, it can be shredded and used again. For both composites and insulation materials, using textile 'waste' could be explored more, creating a synergy between the construction and textile sectors.

The circular building hub is located at the city edge and has good connection to the larger infrastructure in the Netherlands and to the inner city infrastructure. It stores and manages material flows to and from construction sites. The aim of installing these circular building hubs is to reduce transportation and enhance circularity.



In the second scenario, in addition to using flax for composites, flax is used for making textiles. This requires a larger cultivation area and additional processing locations. In this scenario more residual materials from the textile industry become available for the building industry. Considering the scale of conversion, two large spinning facilities could be opened, preferably in regions which are already active in the textile industry, so there is somewhat of an infrastructure and knowledge base that could be relevant for the reopening of spinning mills and weaving mills. In this scenario, the synergy between the textile and building sectors is emphasized and the importance of exploring the potential use of textile 'waste' for composites and insulation should be underscored.

Scenario 2 2030: Flax for composites and Textiles

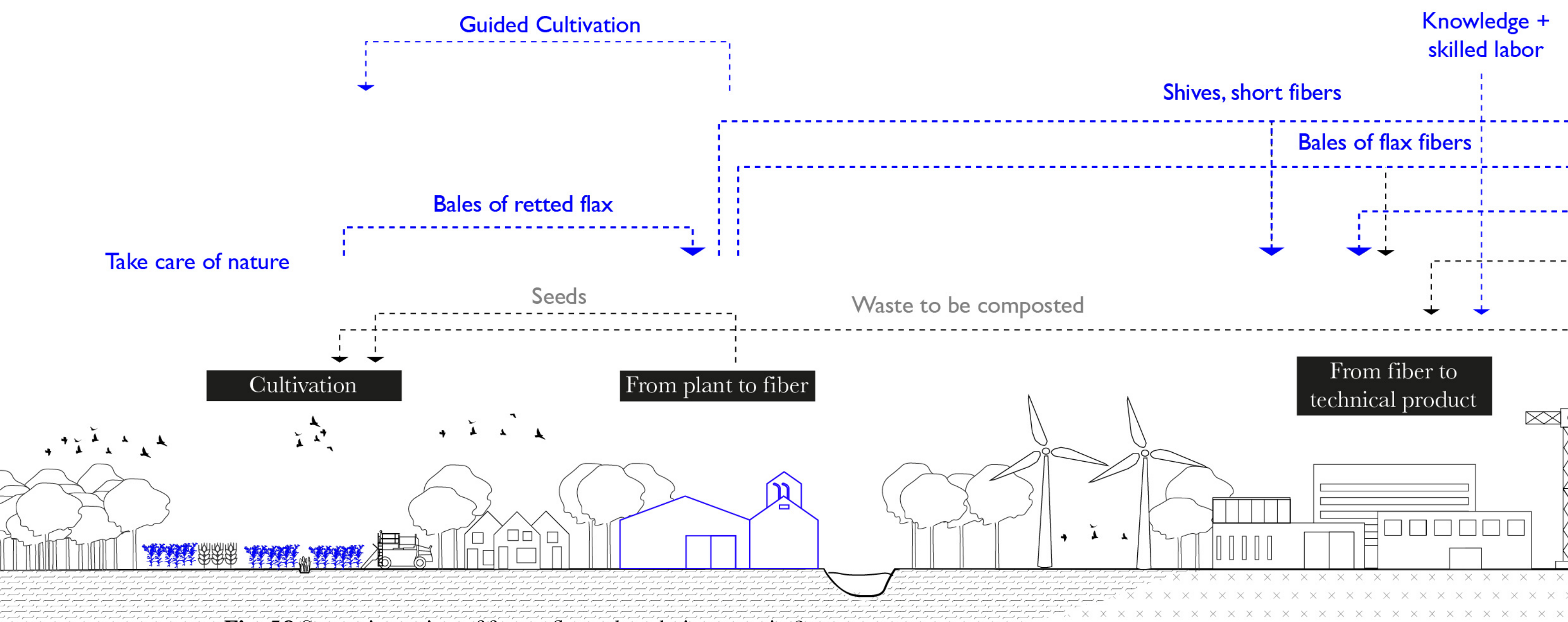
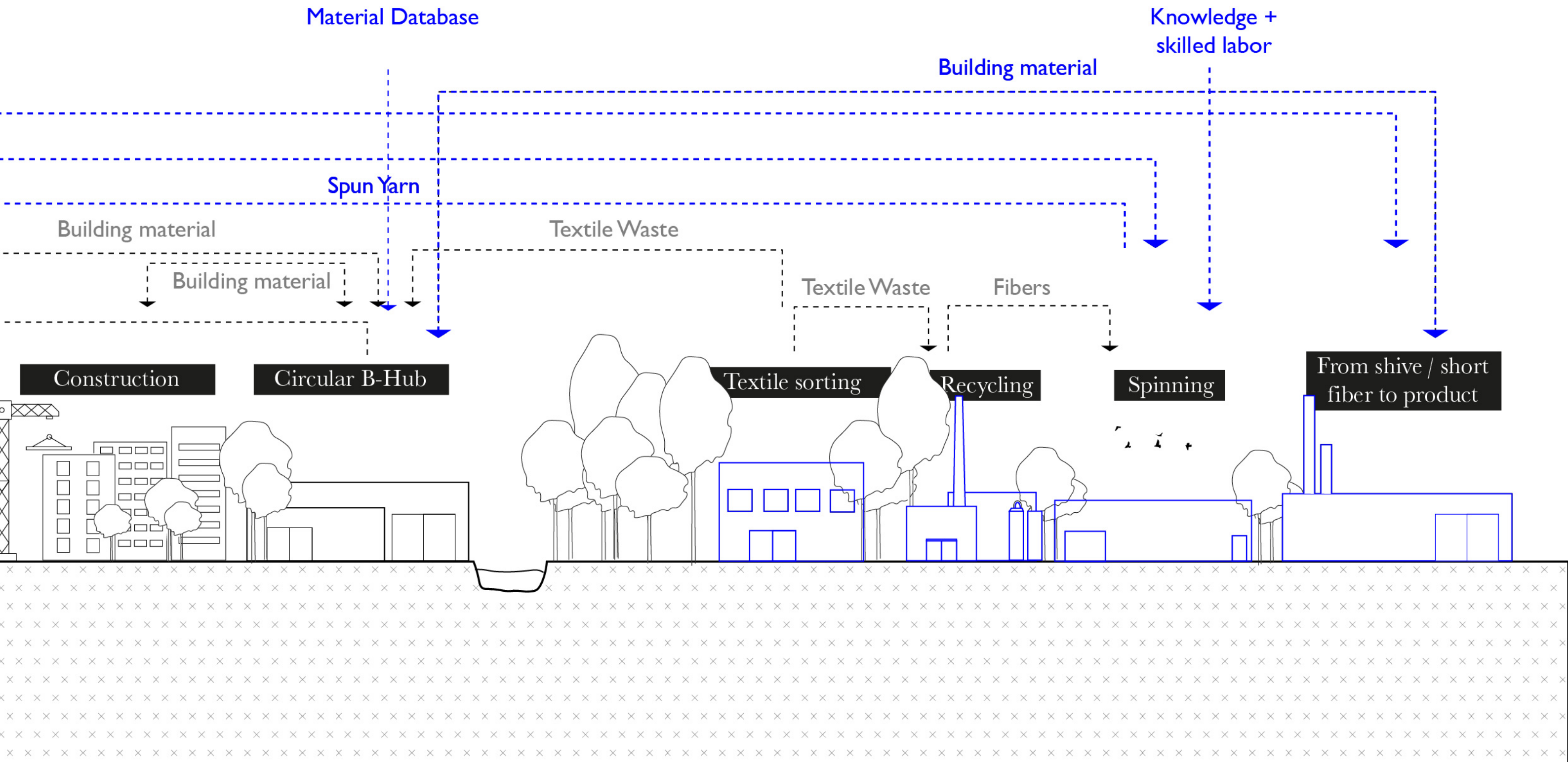


Fig. 58 Systemic section of future flax value chain scenario 2



Material Database
Knowledge +
skilled labor
Building material
Spun Yarn
Building material
Textile Waste
Building material
Textile Waste
Fibers
Construction
Circular B-Hub
Textile sorting
Recycling
Spinning
From shive / short
fiber to product

Suitability Analysis

Establishing a new value chain involves significant long-term commitments. Therefore, selecting the right location is a crucial factor that can ultimately determine the success or failure of the value chain (Rikalovic et al., 2014). To determine to most suitable locations for the different components of the flax value chain in the Netherlands, a suitability analysis is performed in this section. This is a process of narrowing down options, illustrated in figure 59x.
Of the total number of available sites, I am most likely only aware of a number of them. For all the industrial functions in the flax value chain, the input layer used is a selection of 'IBIS bedrijventerreinen' (2022) that still has issuable land. To Analyse the land use suitability, firstly decision criteria should be formulated for each stage of value chain. By giving weight to the layers, overlaying them and ranking the suitability of the industrial sites for a certain land use, the options are narrowed down to locations that are being considered. As the value chain should function as a network, and the suitability of sites also depends on the proximity of other stages in the value chain, the final selection of sites can only happen after the suitability analysis is performed for all stages of the value chain. Based on the criteria, considering the whole network and closer site evaluation, I finally choose the most suitable locations manually.

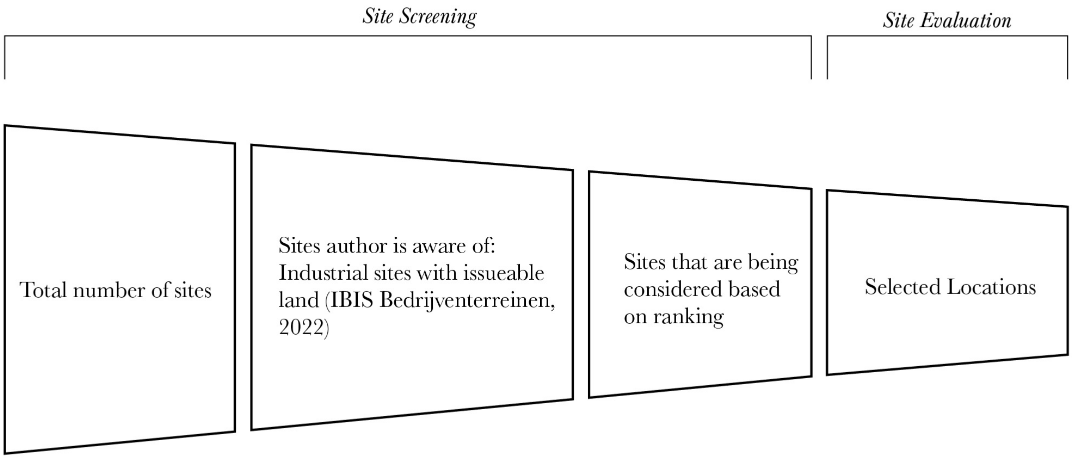


Fig. 59 Selection of Industrial Sites. Based on (Rikalovic et al., 2014, p.3)

Suitable Cultivation Parcels

The selection of suitable parcels for cultivation of flax requires a slightly different approach. The input layer is a dataset of the agricultural parcels in the Netherlands (Basisregistratie Gewaspercelen (BRP), 2024) and the selection of parcels is narrowed down without using a point system. It should also be noted that the outcome of the suitability analysis for the cultivation of flax changes yearly, as the input layers include dynamic factors. As flax can only be grown on the same plot once every 7 years, the total amount of suitable cultivation parcels should be divided by 7 if you want to ensure a steady flow of flax yearly. Resulting in a maximum of 10.000 ha of flax yearly (Figure 65).

Clay Soil

Total arable land on clay: +/- 850.000 ha

Fig. 60 Clay Soil. Based on BOFEK 2020 (Wageningen Environmental Research, 2021)

No risk of Soil Subsidence and Salinization

- 270.000 ha

Fig. 61 Agricultural land on clay with no risk of soil subsidence and salinization

Suitable Precop

+/- 75.000 ha suitable land left

Fig. 62 Agricultural parcels on clay with suitable precrop for flax cultivation (BRP, 2024)

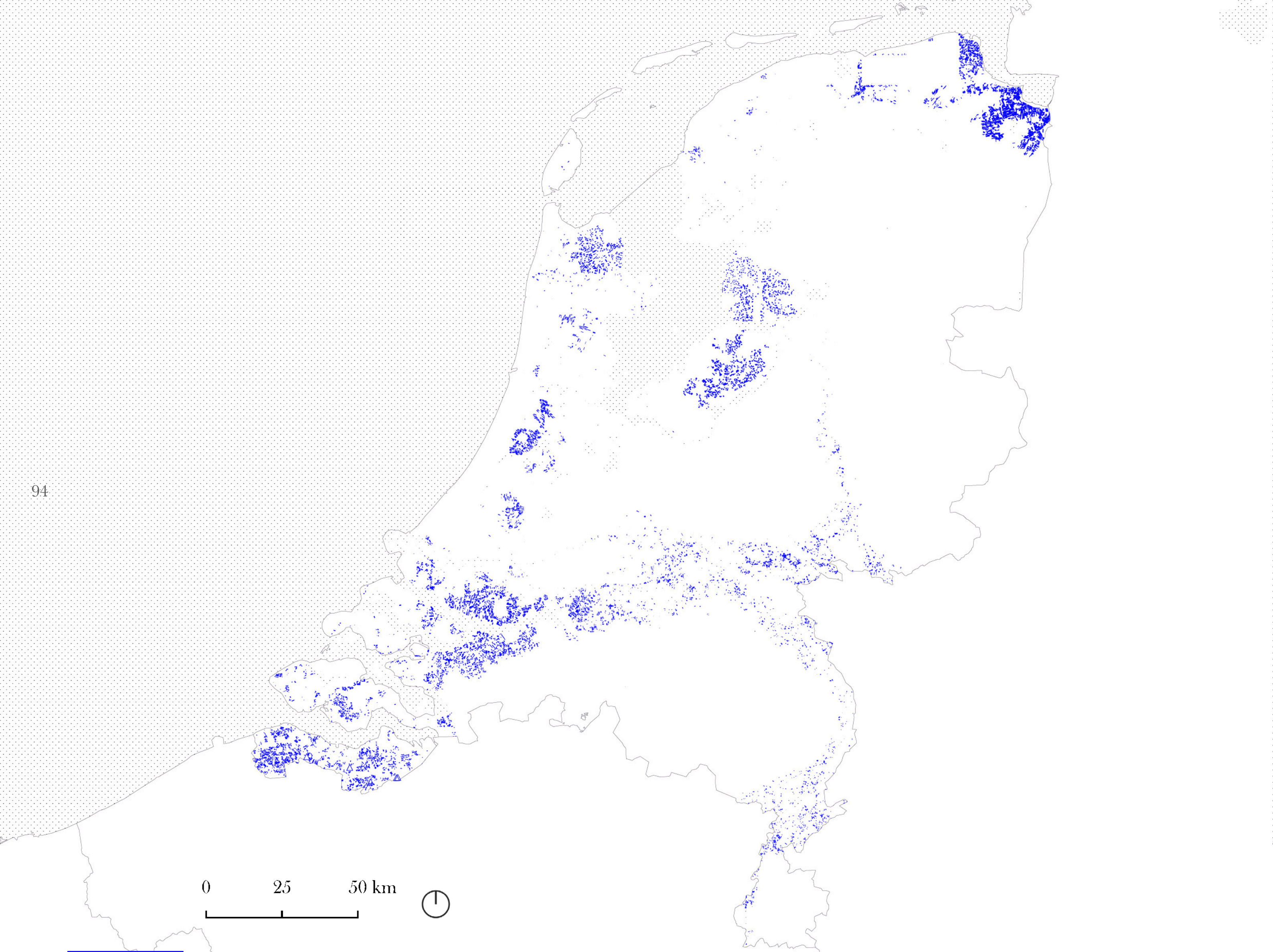
7 years of flax

14.000 ha the last 7 years.

Fig. 63 Agricultural parcels on which flax was cultivated the last 7 years (BRP, 2024)

Suitable Cultivation Parcels

+/- 70.000 (changes yearly)



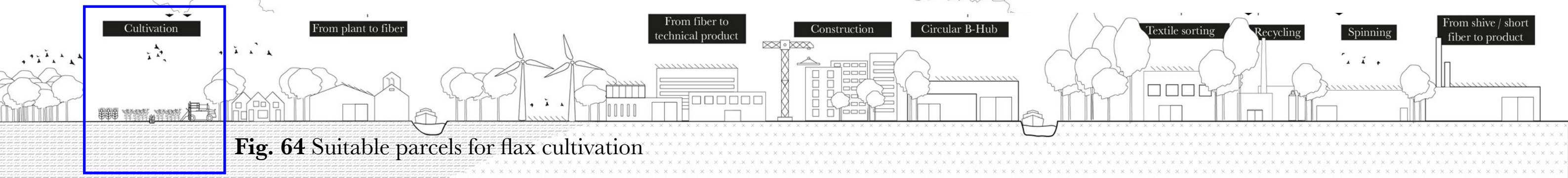


Fig. 64 Suitable parcels for flax cultivation

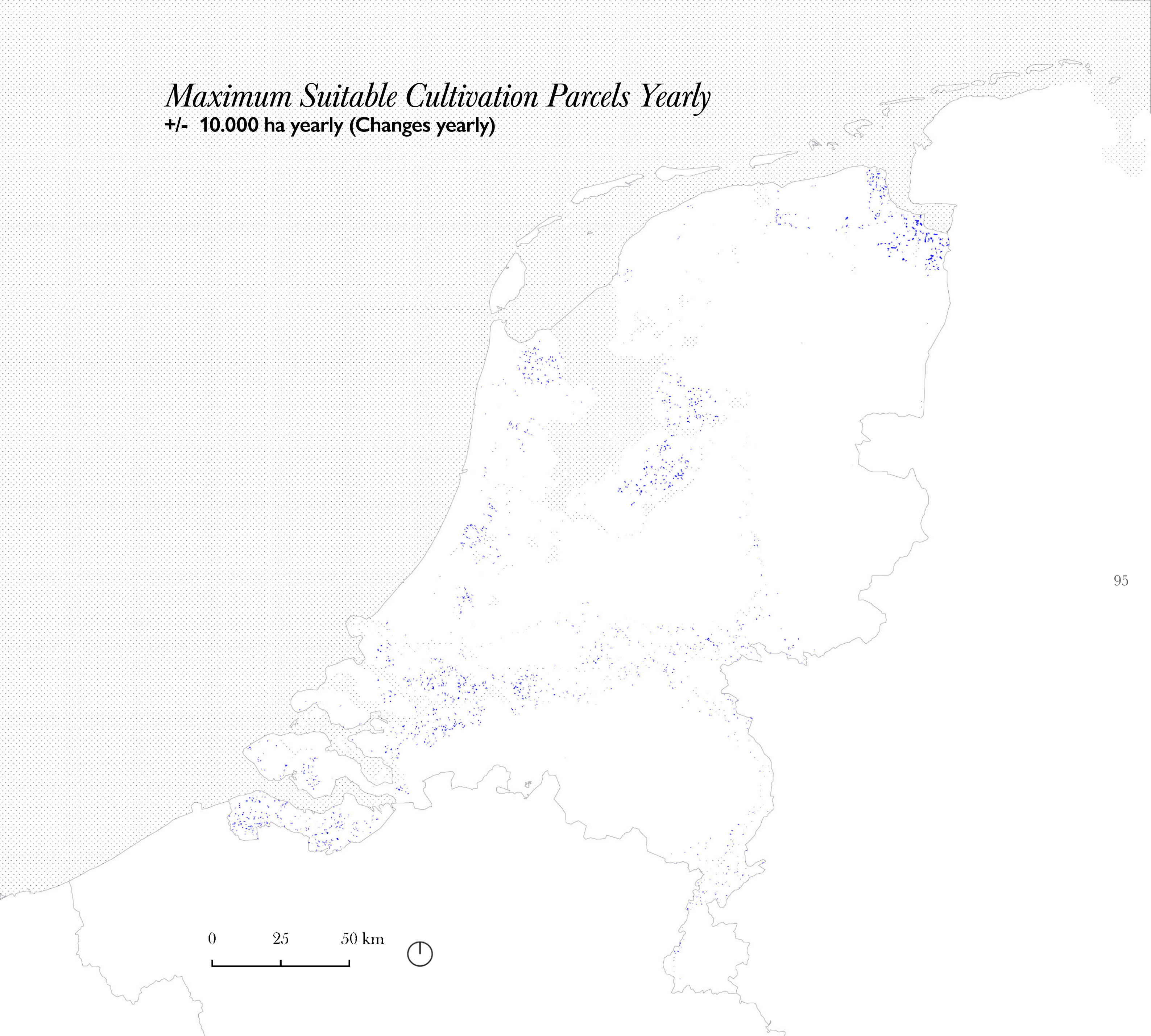
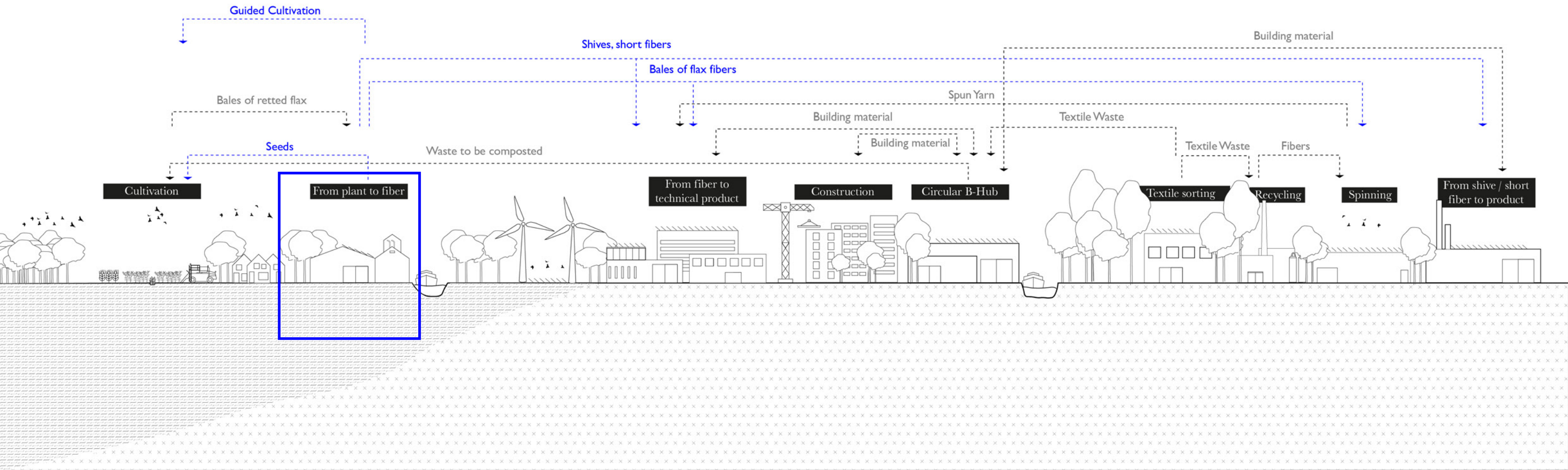


Fig. 65 Maximum suitable parcels for flax cultivation yearly

Suitability Factors - From Plant to Fiber

The decision criteria for the location of flax processing (from plant to fibers) include:

- Proximity to multimodal transport: Proximity and having access to relevant transport infrastructure results in greater operational efficiency, reduced transaction costs, and enhanced collaboration.
- Proximity to Flax Cultivation: Establishing processing facilities in proximity to flax fields will lead to reduced transportation costs, lower environmental impact, and improved supply chain resilience.



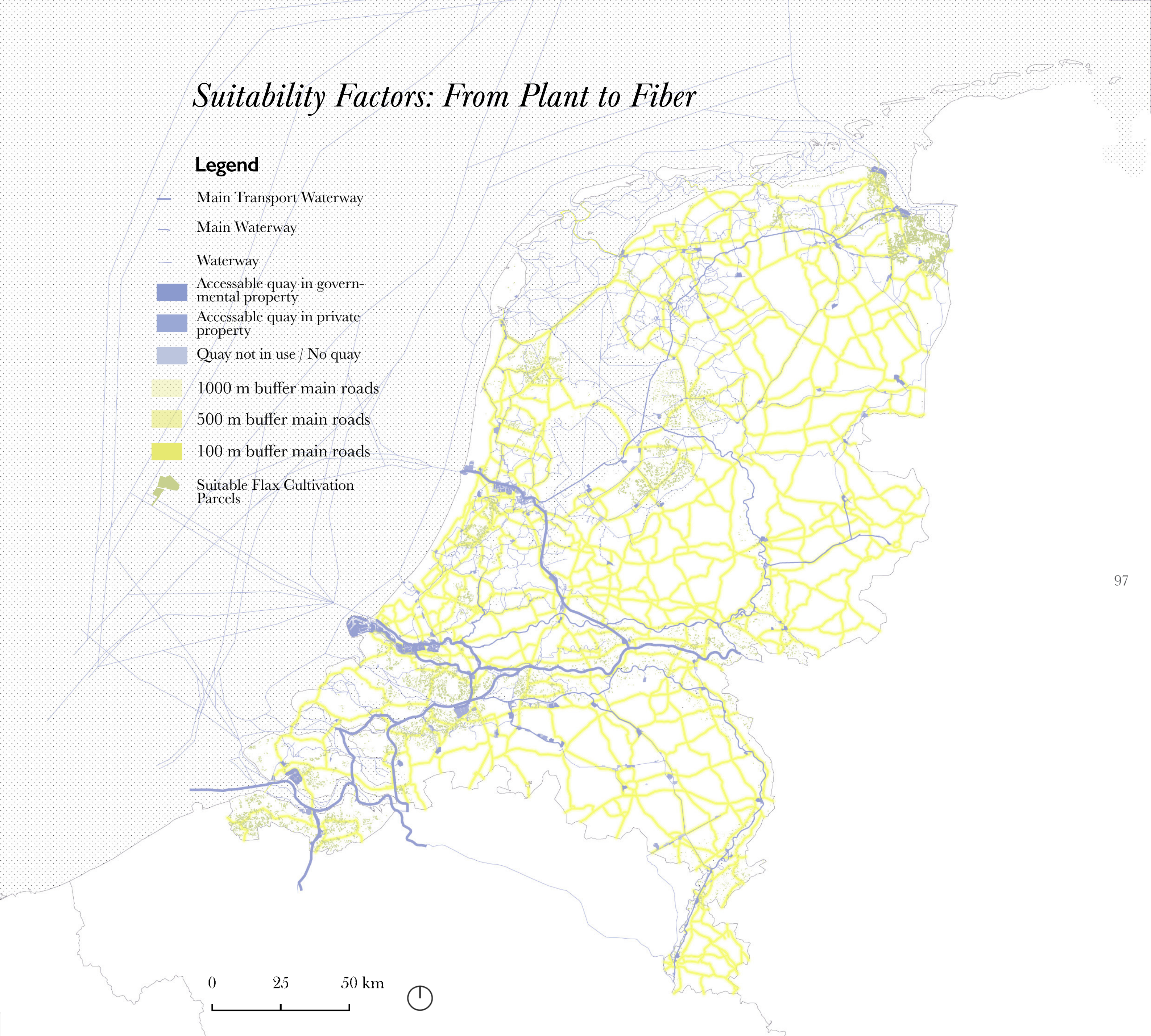


Fig. 66 Suitability factor: from plant to fiber

Assessing Suitability Factors - From Plant to Fiber

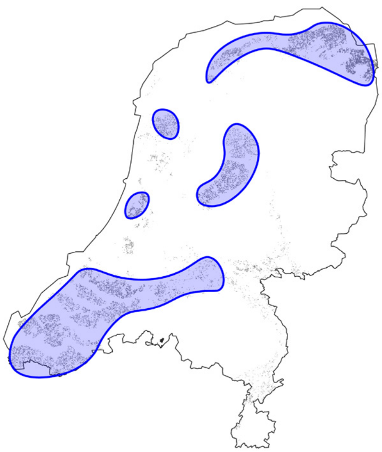
Proximity to Main Roads

1 pt. 1000 m buffer main roads
2 pt. 500 m buffer main roads
3 pt. 100 m buffer main roads

Possibility Water Transport

3 pt. Accessable quay in governmental property
2 pt. Accessable quay in private property
1 pt. Quay not in use / No quay

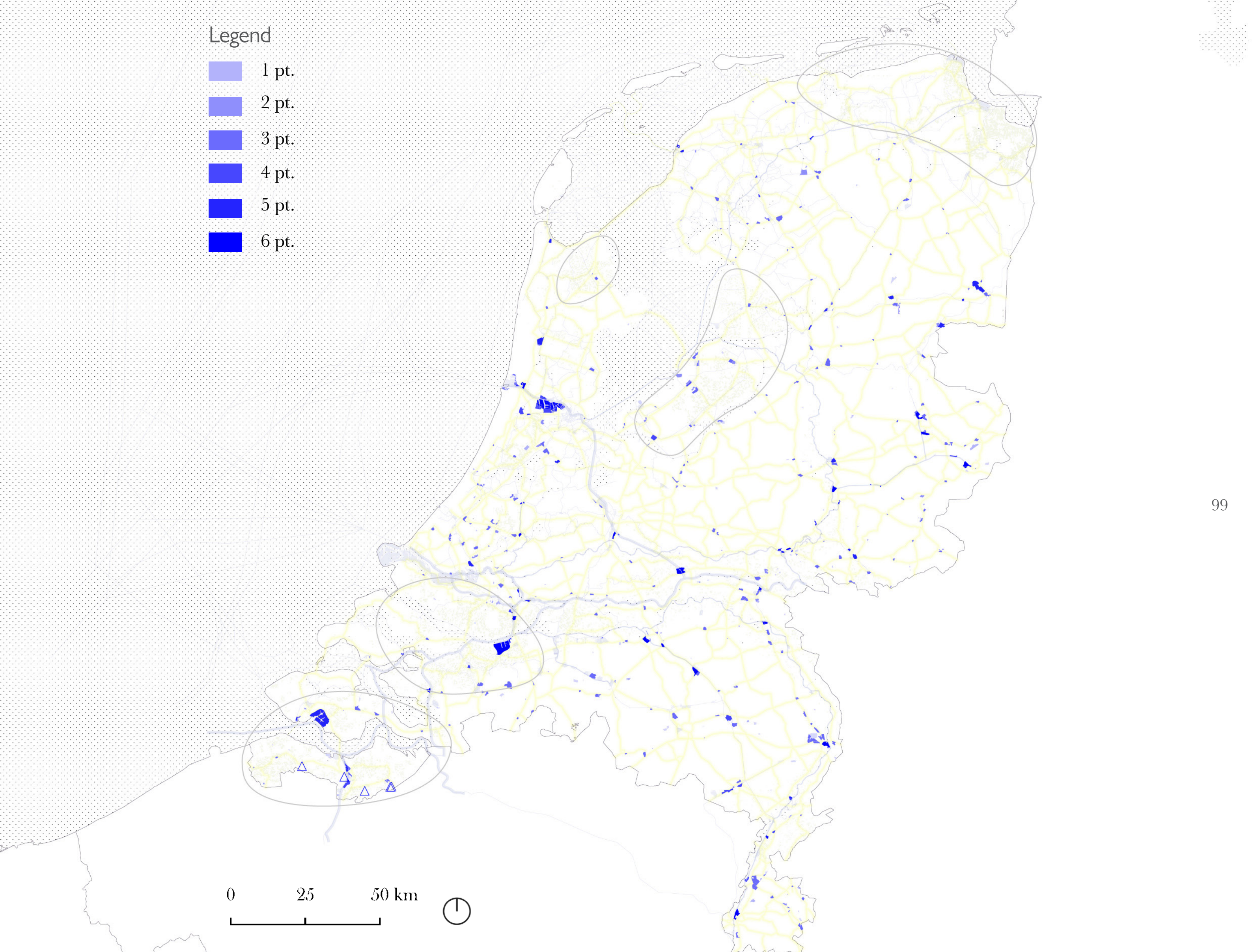
Proximity to Cultivation



Cluster of flax cultivation

Fig. 67 Ranking suitability factors: from plant to fiber

Assessing Suitability: From Plant to Fiber



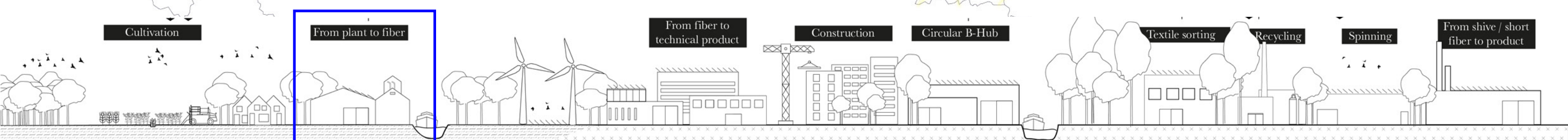
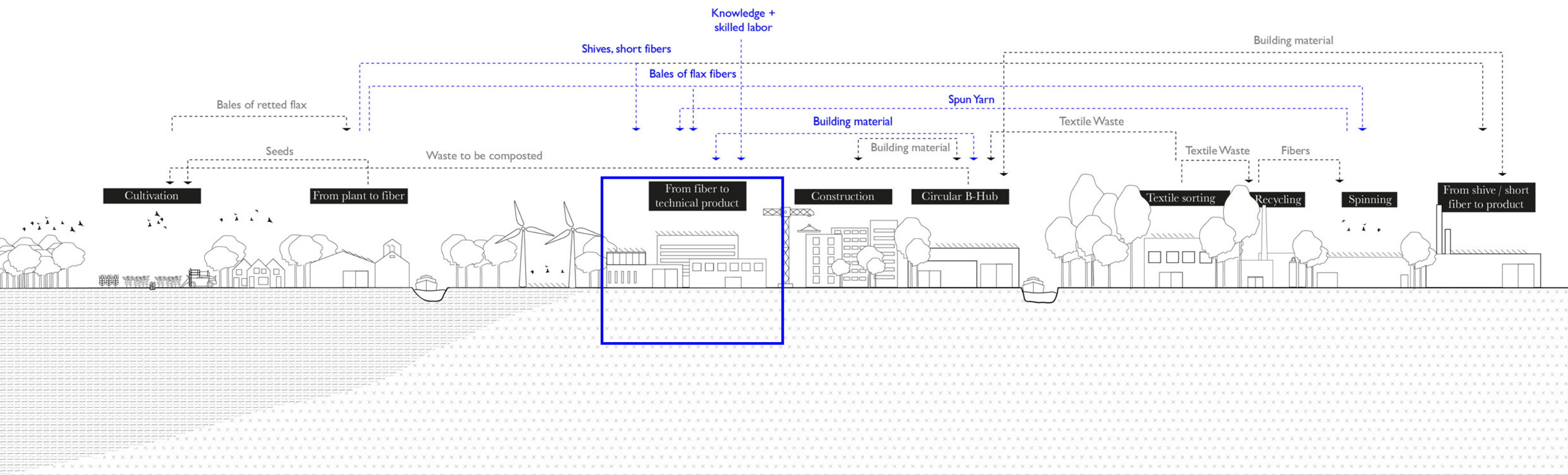


Fig. 68 Ranking suitable parcels: from plant to fiber

Suitability Factors:From Fiber to Technical Product

The decision criteria for the location of companies that make technical products from flax include:

- Proximity to multimodal transport: Proximity and having access to relevant transport infrastructure results in greater operational efficiency, reduced transaction costs, and enhanced collaboration.
- Proximity to knowledge: As the development of technical products (like composites) from flax requires knowledge, proximity to universities and scientific institutions can foster collaboration that will eventually lead to innovation.
- Proximity to public transport: When the access to knowledge is required, people become important. Therefore the accessability of the location with public transport is very important.



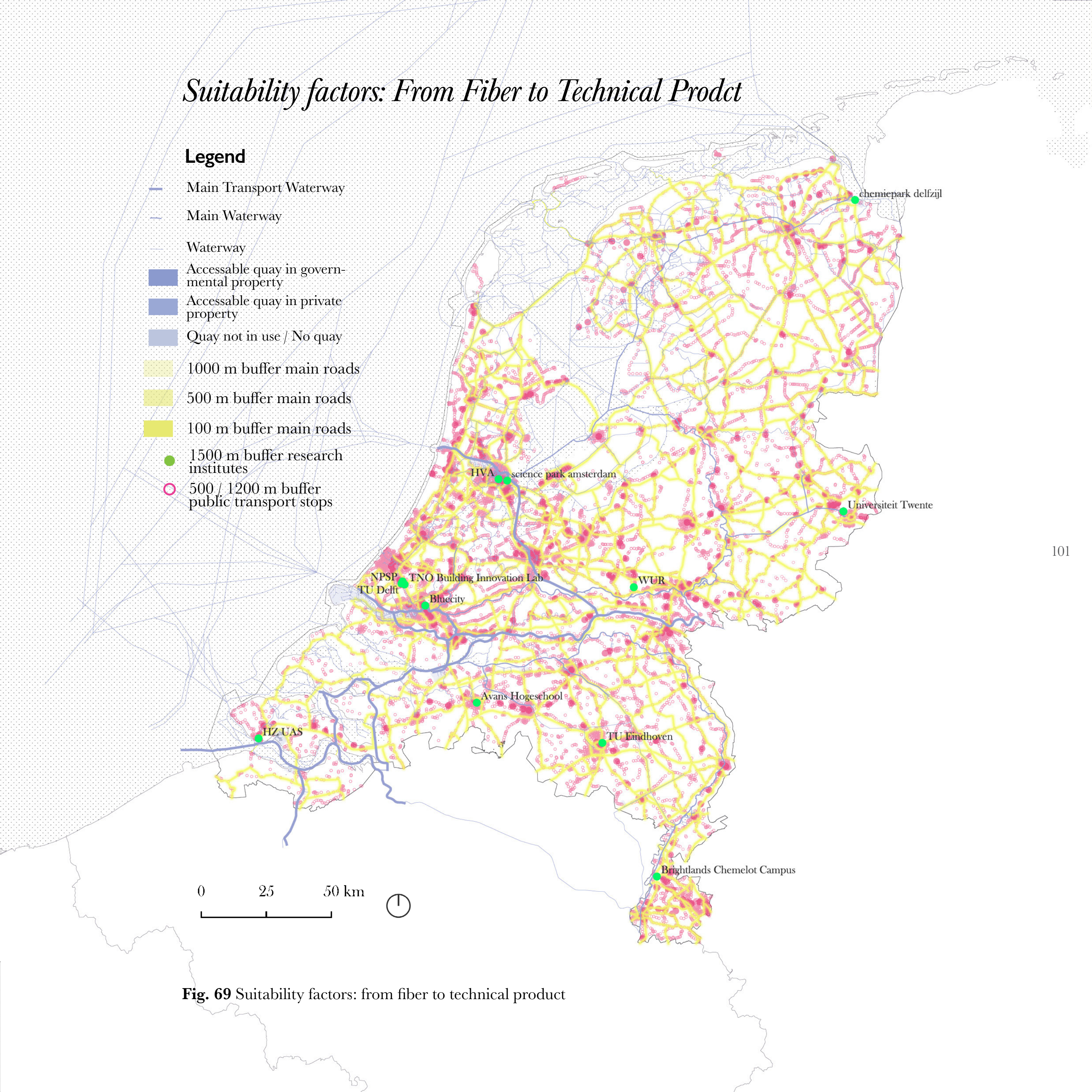


Fig. 69 Suitability factors: from fiber to technical product

Assessing Suitability Factors - From Fiber to Technical Product

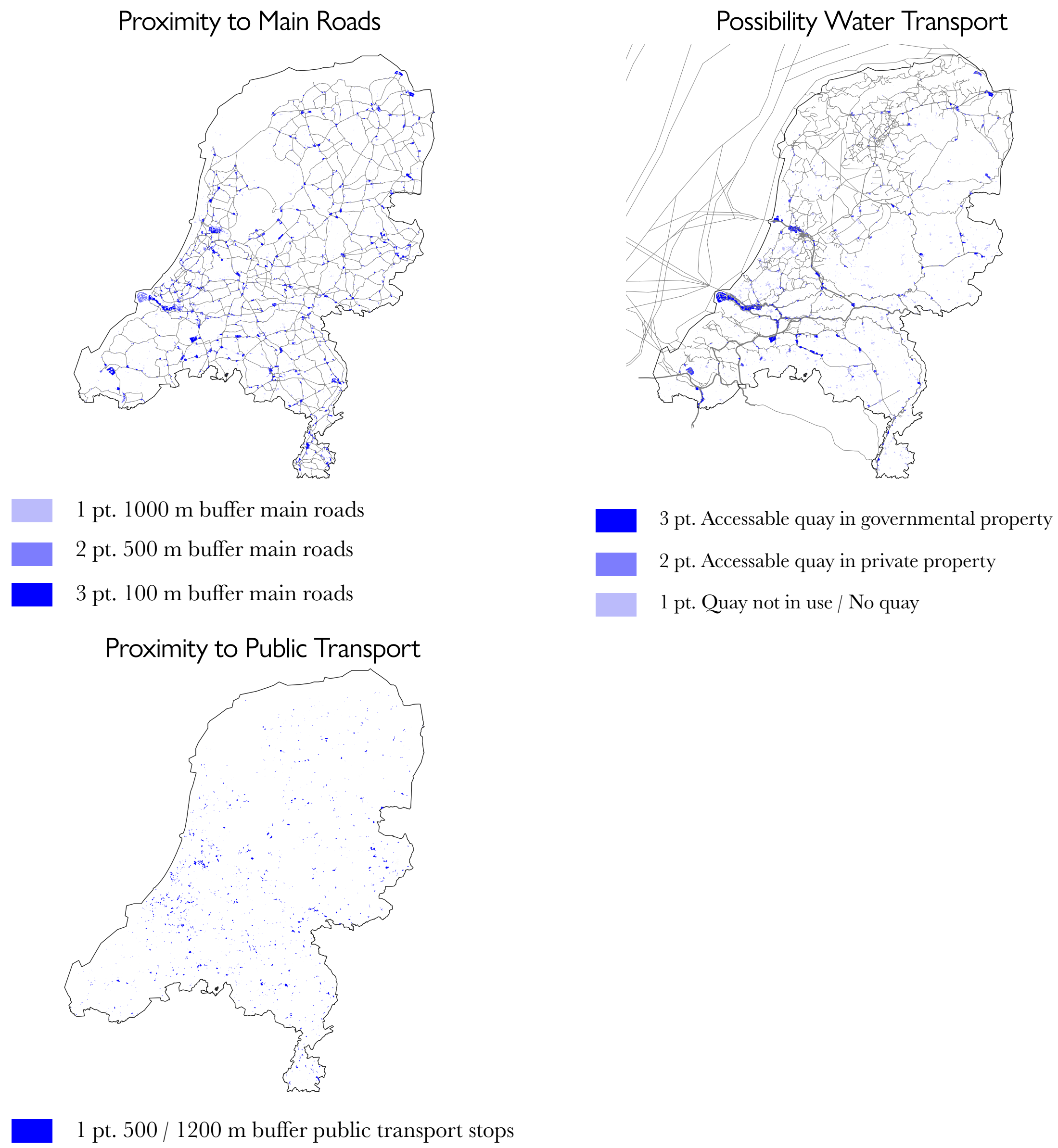
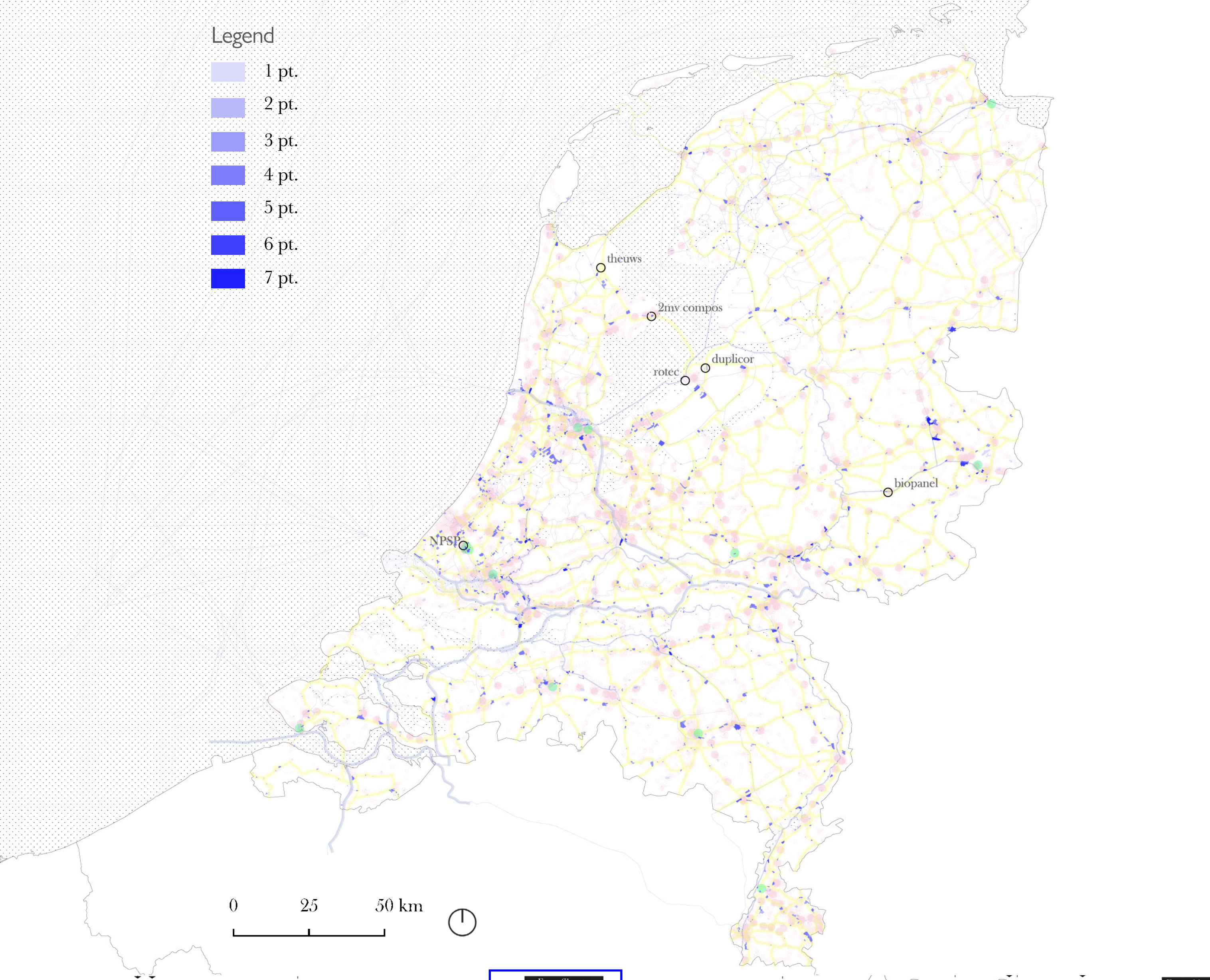


Fig. 70 Ranking suitability factors: From Fiber to Technical Product

Assessing Suitability: From Fiber to Technical Product



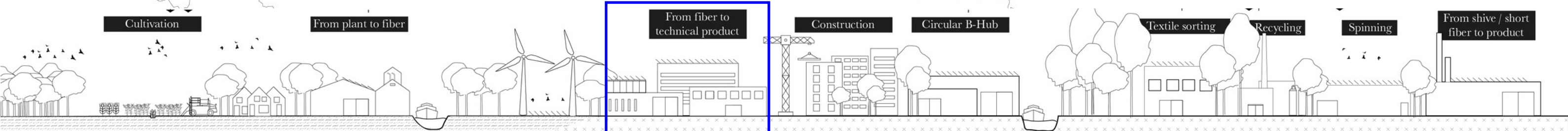
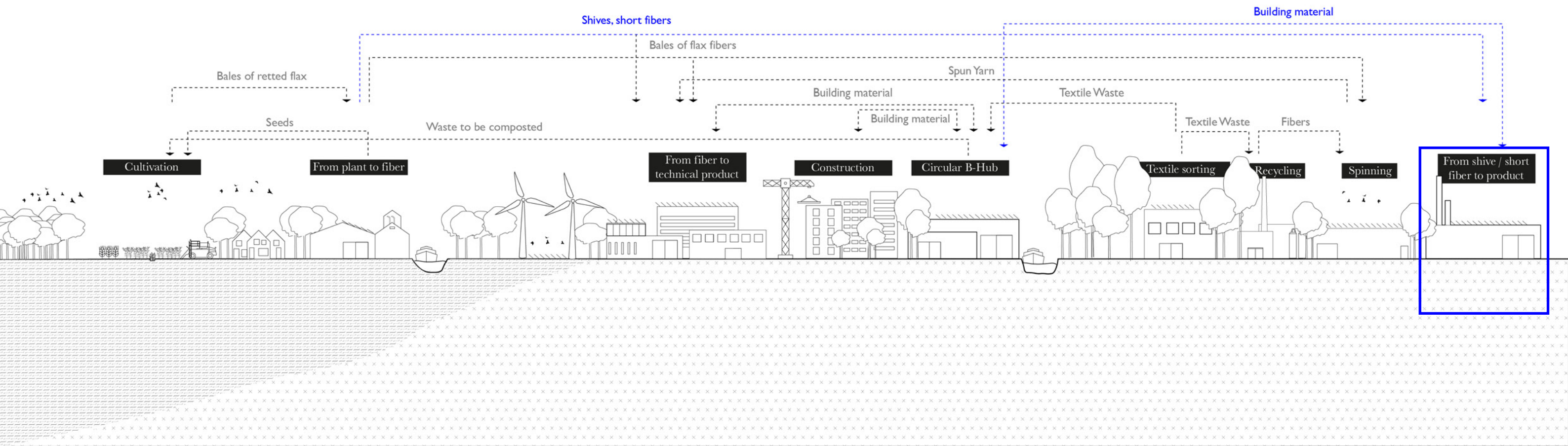


Fig. 71 Ranking suitable parcels: from fiber to technical product

Suitability Factors: Insulation Product

As the manufacturing of insulation material from flax requires less knowledge or specific labor skills, and adopting blow-in insulation techniques using flax shives requires no further processing, this step of the value chain will make use of the existing infrastructure. For existing companies it should not be too complicated to adopt flax based insulation material into their assortment.

The shives could go directly from the flax processing to the circular building hubs, and from there to the construction site, requiring no extra processing location. For (non-)woven insulation materials, the value chain can make use of the existing companies and their transport infrastructure.



Suitability Factors: Insulation Production

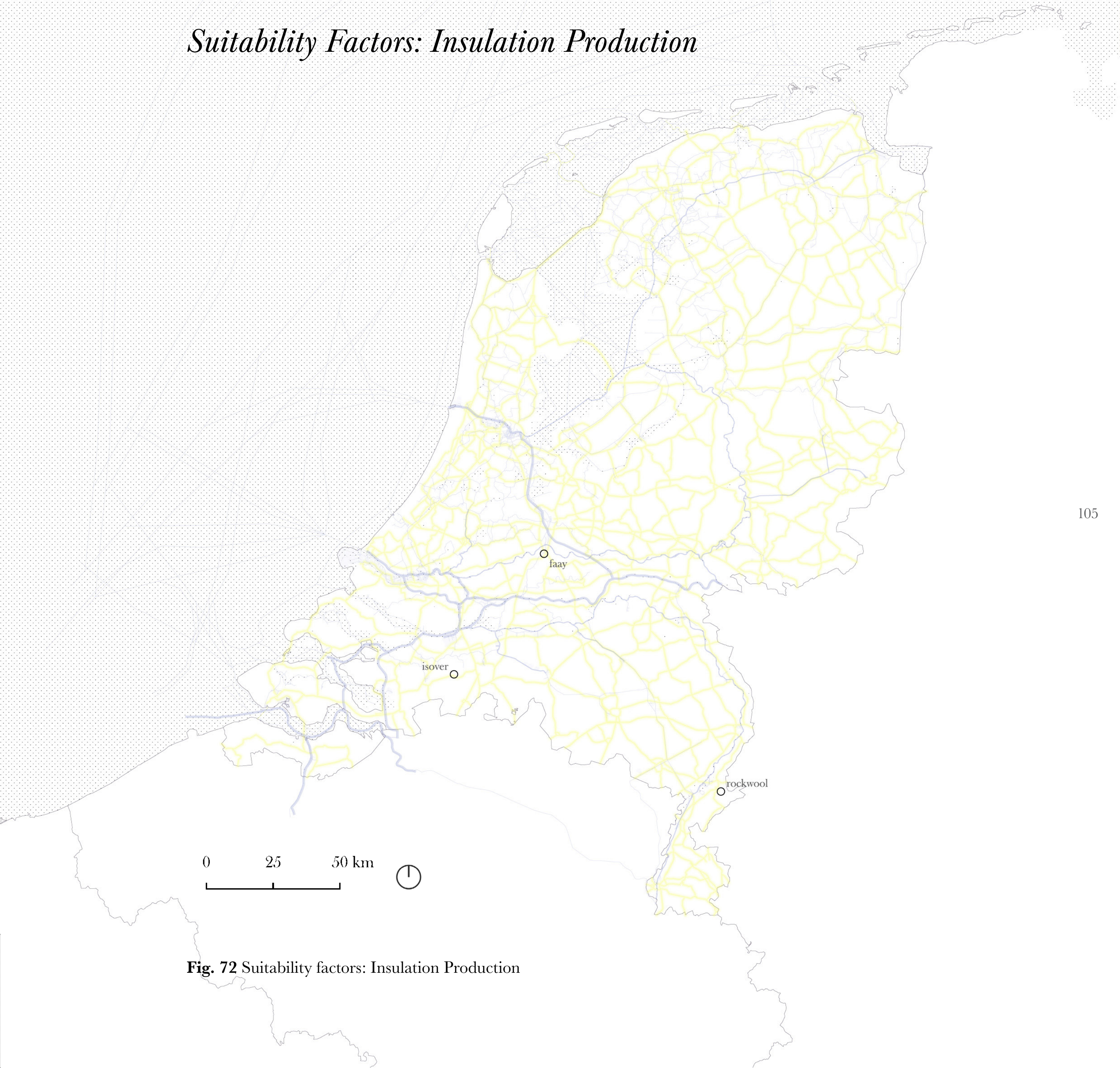
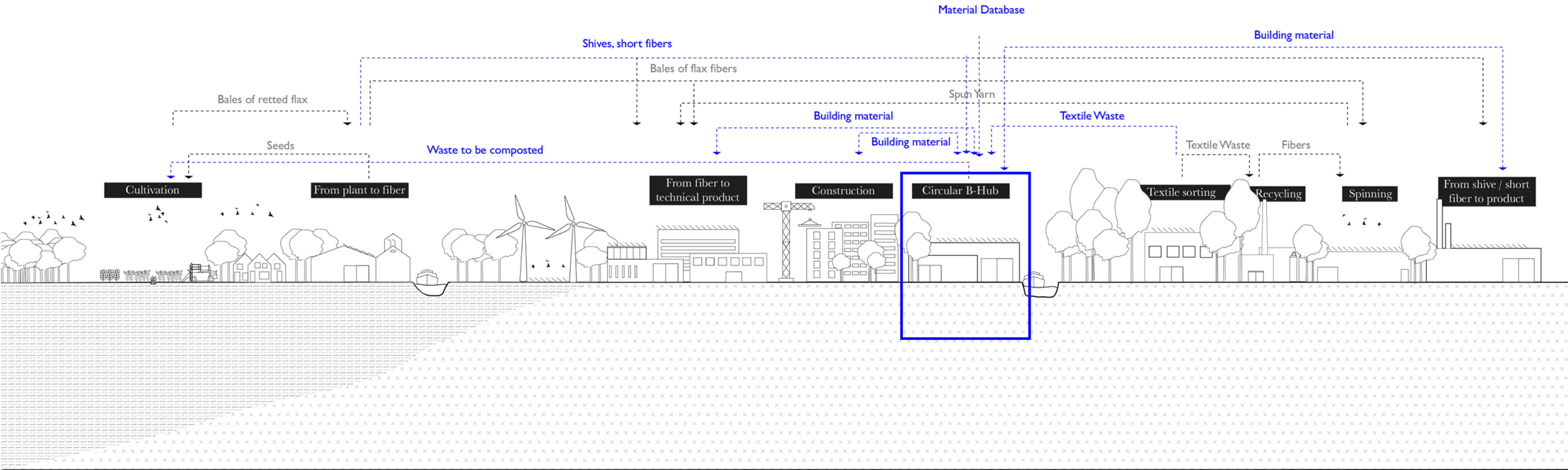


Fig. 72 Suitability factors: Insulation Production

Suitability Factors: Circular Building Hub

The decision criteria for the location of circular building hubs that manage and store the material flows from and to construction sites and material suppliers, and therby reduce transport , include:

- Proximity to multimodal transport: Proximity and having access to relevant transport infrastructure results in greater operational efficiency, reduced transaction costs, and enhanced collaboration.
- Located on the edge of large (re)construction areas: Circular building hubs are located on the edge of a city so they are in close proximity to constructions sites and are easily accessable for material suppliers outside the city



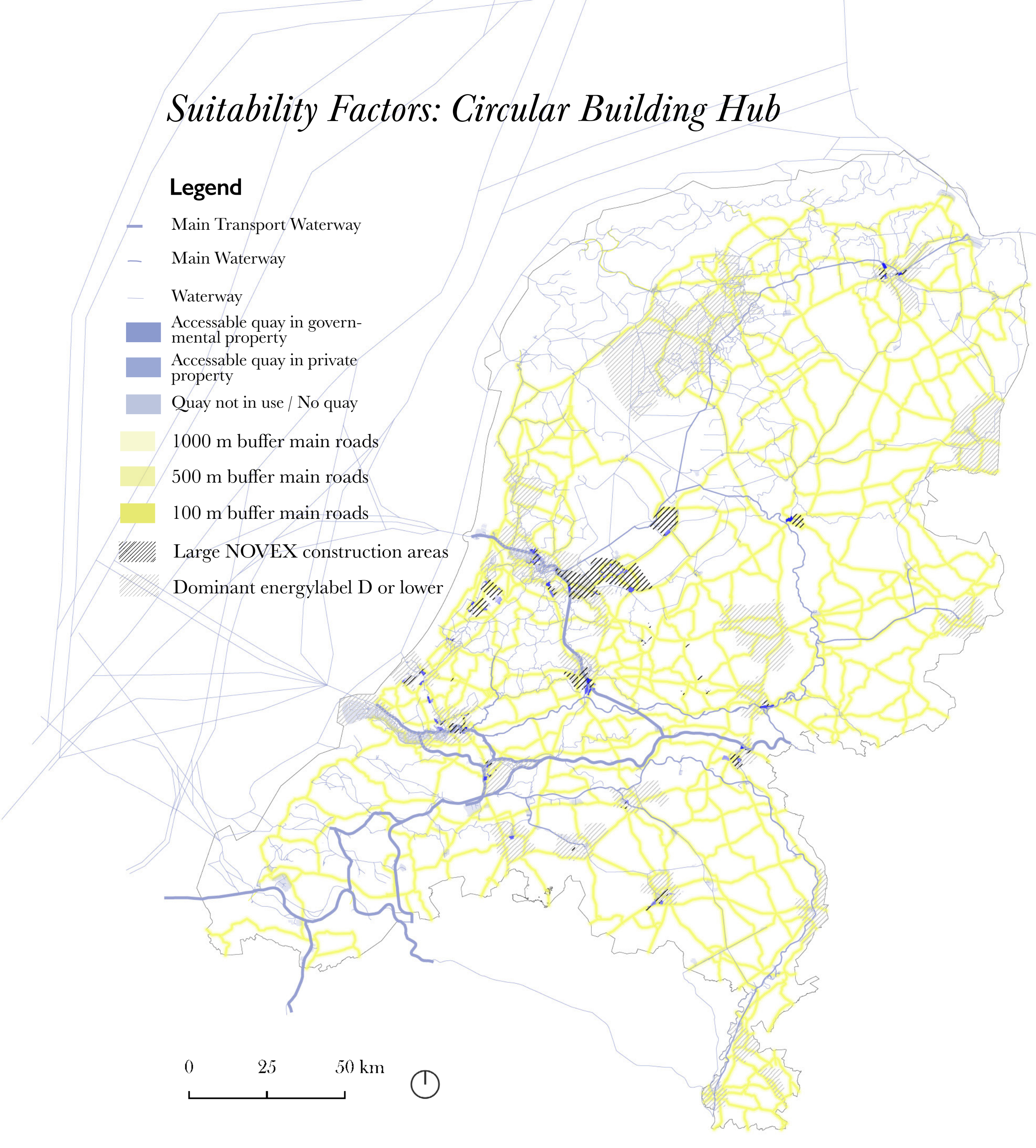


Fig. 73 Suitability factors: Circular Building Hub

Assessing Suitability Factors: Circular Building Hub

Proximity to Main Roads

1 pt. 1000 m buffer main roads
2 pt. 500 m buffer main roads
3 pt. 100 m buffer main roads

Possibility Water Transport

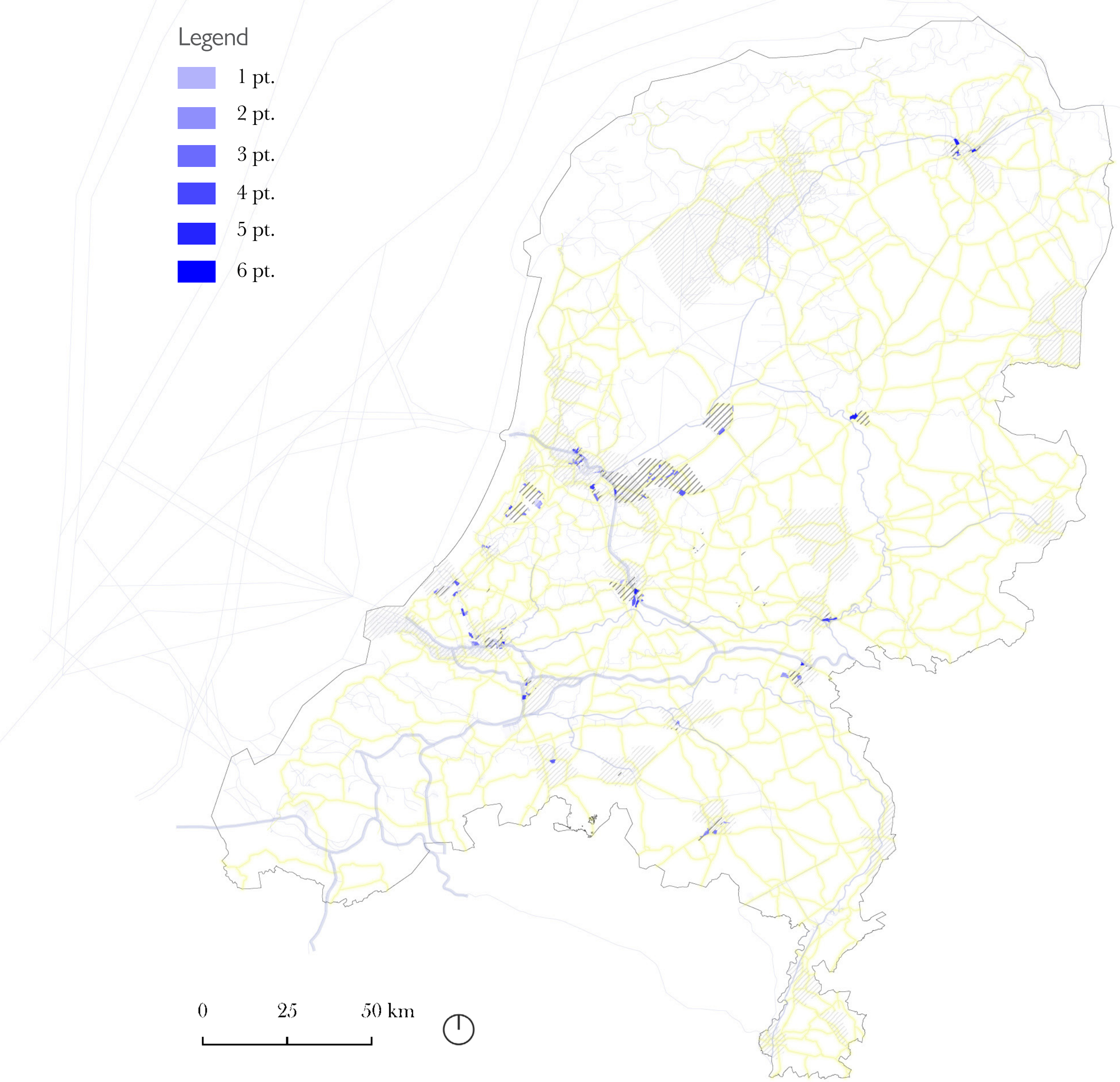
3 pt. Accessable quay in governmental property
2 pt. Accessable quay in private property
1 pt. Quay not in use / No quay

Edge of (re)construction locations

Requirement

Fig. 74 Ranking suitability factors: Circular Building Hub

Assessing Suitability: Circular Building Hub



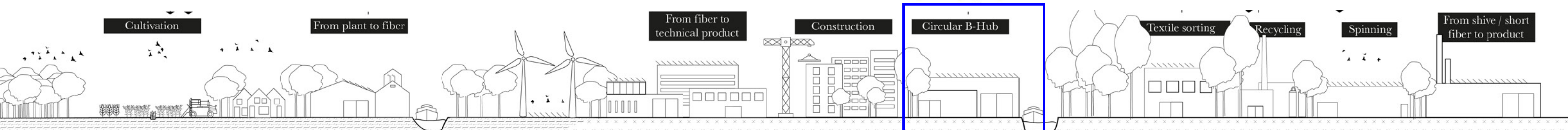
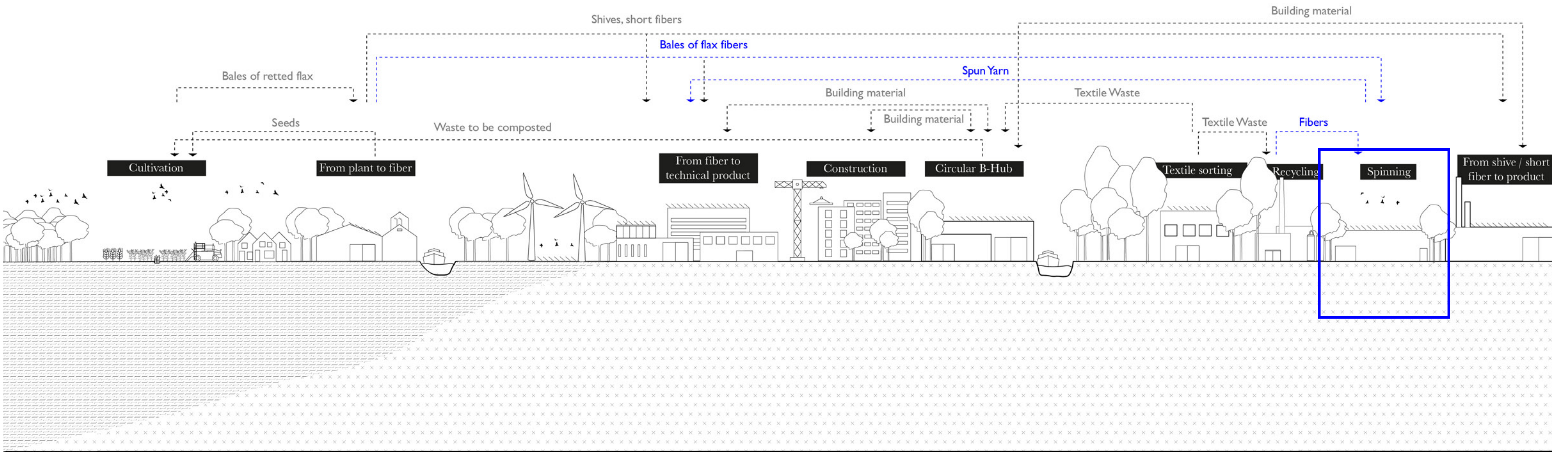


Fig. 75 Ranking suitability : Circular Building Hub

Suitability Factors: Spinning and Weaving

The decision criteria for the location of companies that spin and weave flax fibers into fabric:

- Proximity to multimodal transport: Proximity and having access to relevant transport infrastructure results in greater operational efficiency, reduced transaction costs, and enhanced collaboration.
- Textile Regions: As bringing back spinning and weaving to the Netherland requires knowledge and labor, locating them in regions in which there is or was somewhat of an infrastructure and knowledge base could be relevant for the reopening of spinning mills and weaving mills.
- Proximity to public transport: When the access to knowledge is required, people become important. Therefore the accessability of the location with public transport is very important.



Suitability Factors: Spinning and Weaving

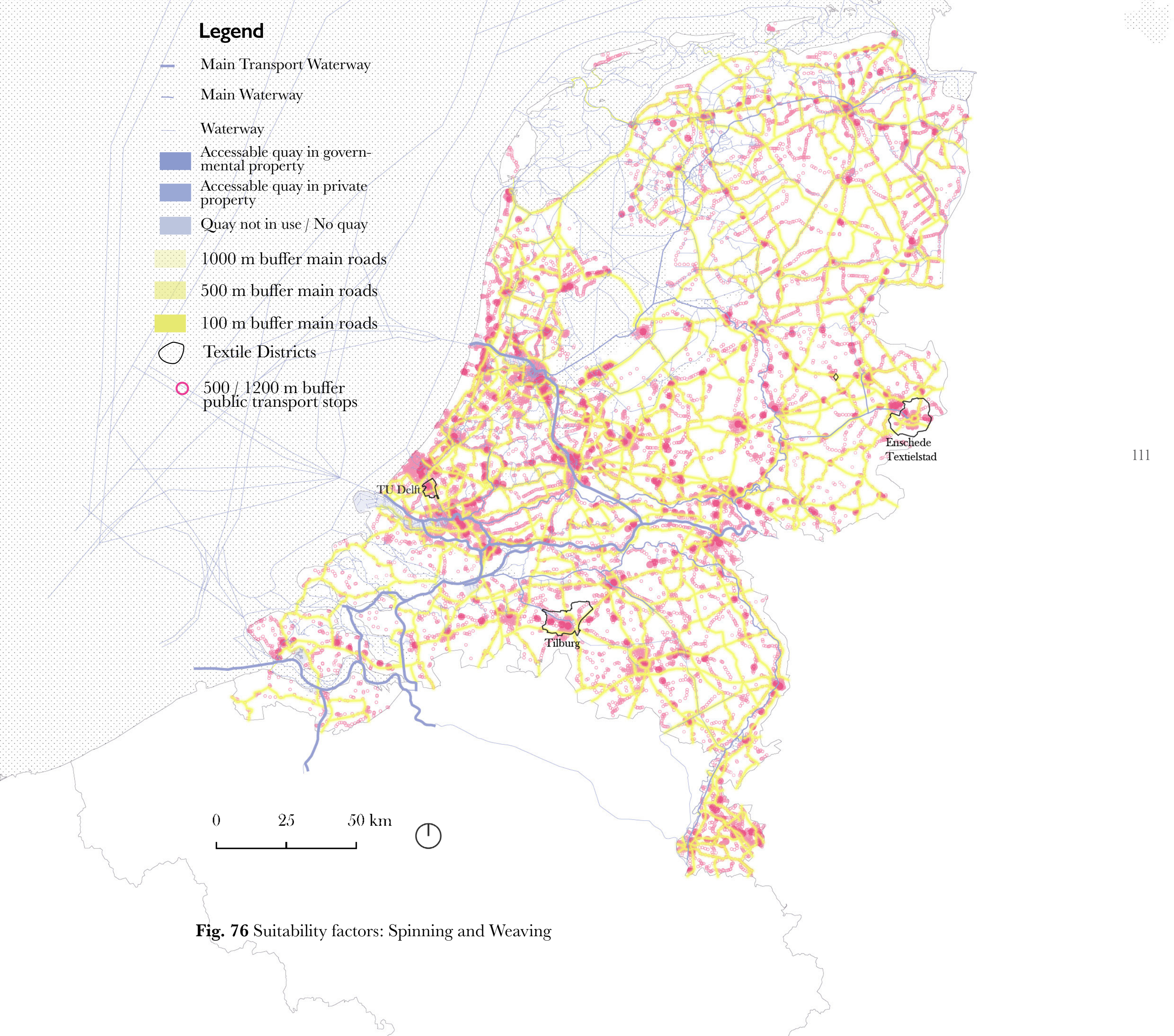
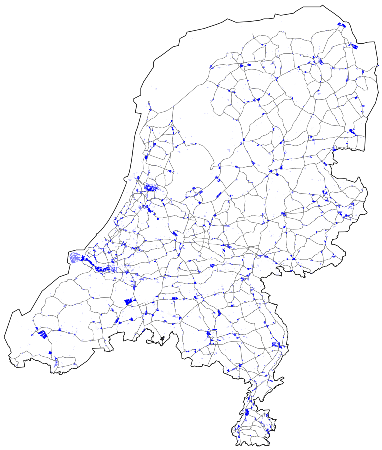


Fig. 76 Suitability factors: Spinning and Weaving

Assessing Suitability Factors: Spinning and Weaving

Proximity to Main Roads



1 pt. 1000 m buffer main roads

2 pt. 500 m buffer main roads

3 pt. 100 m buffer main roads

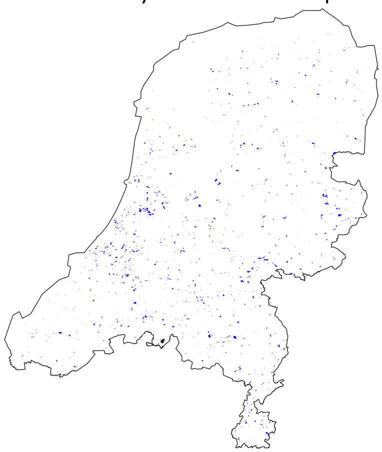
Possibility Water Transport

3 pt. Accessable quay in governmental property

2 pt. Accessable quay in private property

1 pt. Quay not in use / No quay

Proximity to Public Transport



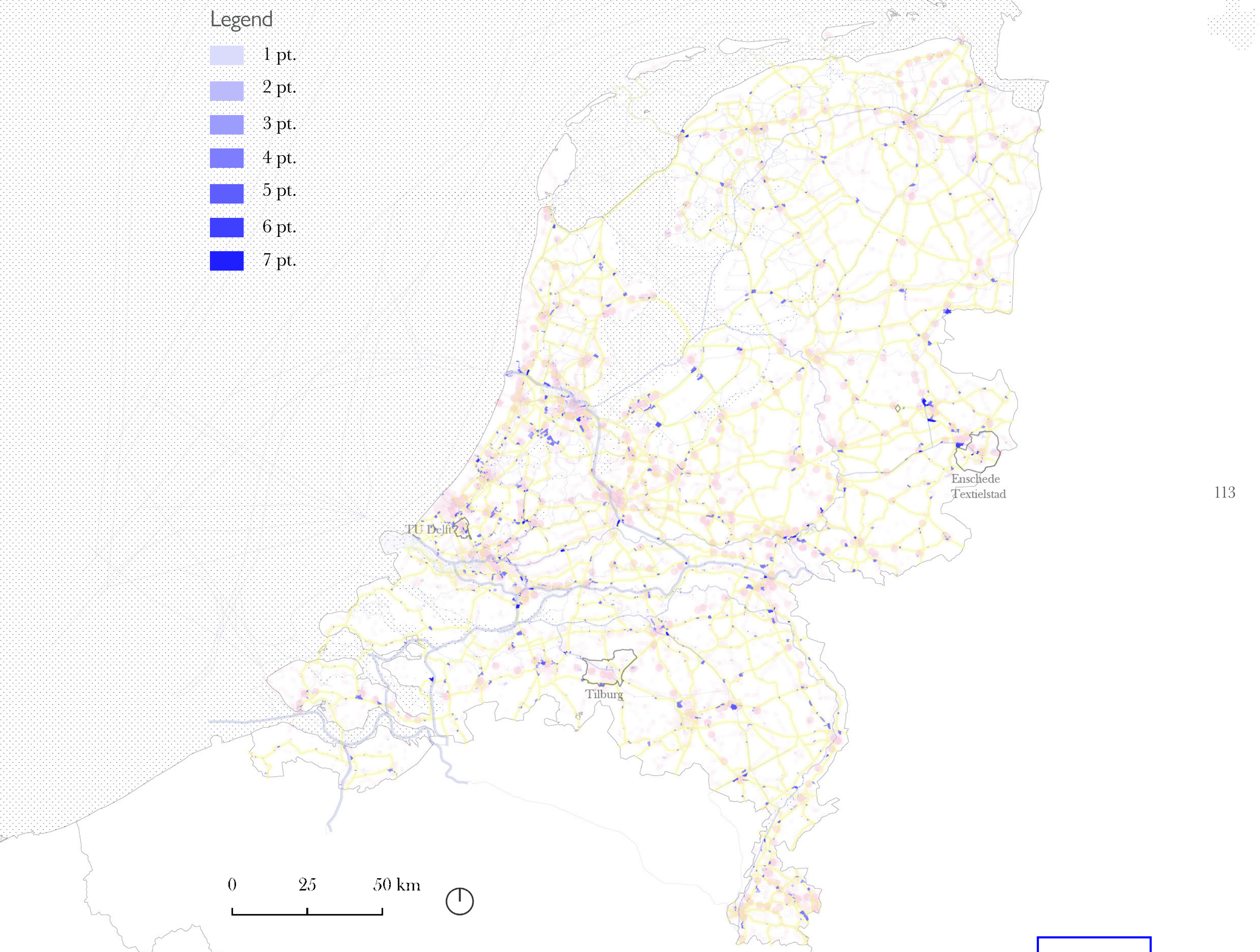
1 pt. 500 / 1200 m buffer public transport stops

Textile Regions

Requirement

Fig. 77 Ranking suitability factors: Spinning and Weaving

Assessing Suitability: Spinning and Weaving



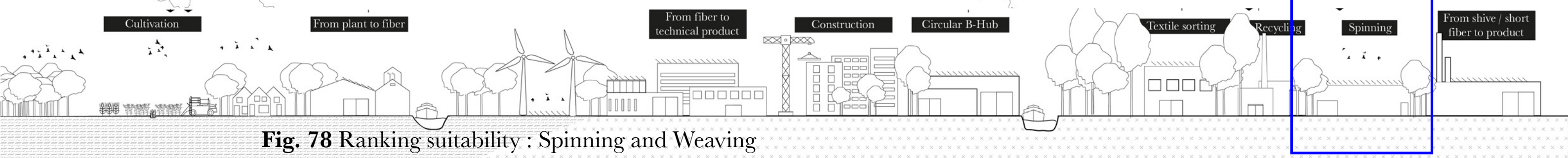


Fig. 78 Ranking suitability : Spinning and Weaving

Scenario 1: Flax for Composites

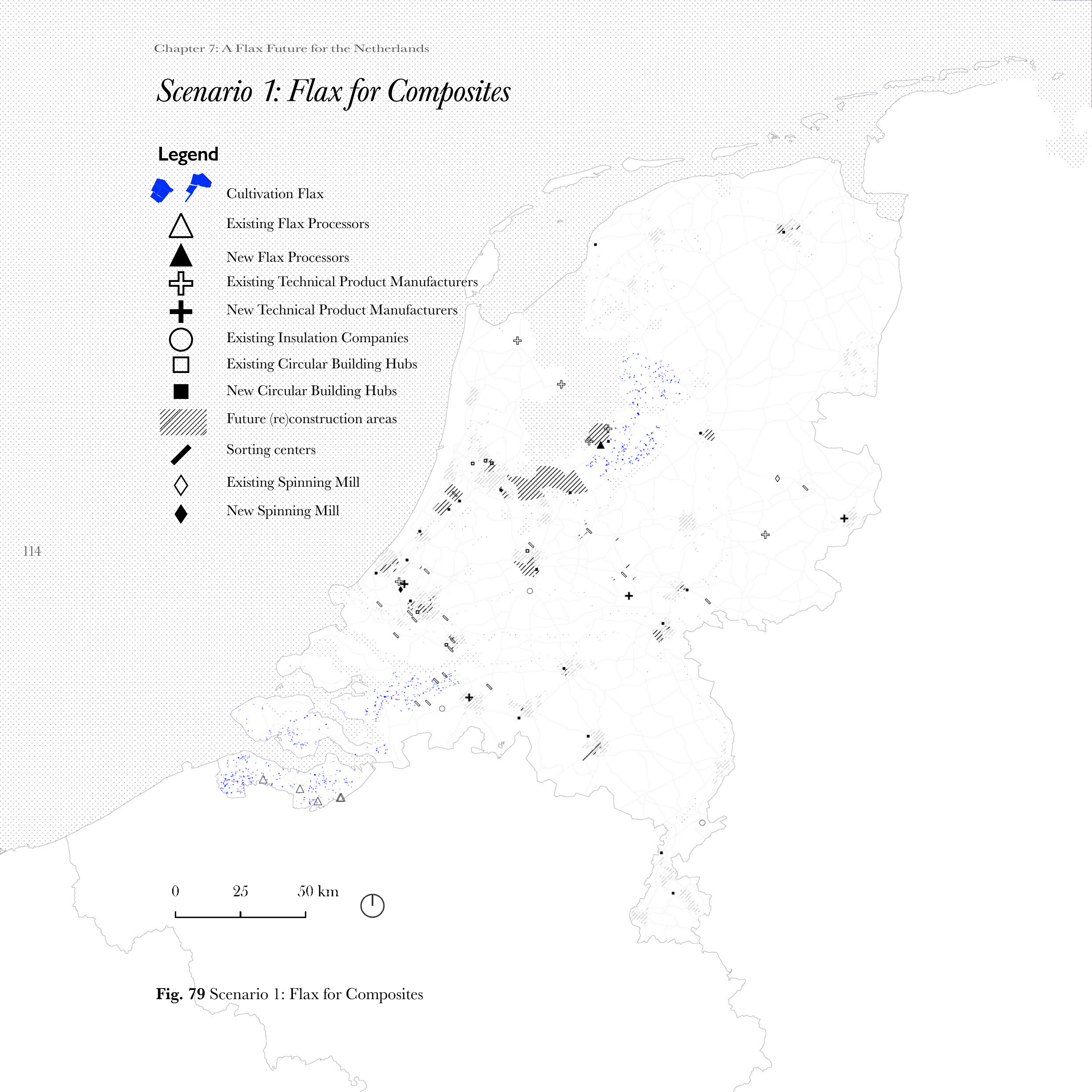


Fig. 79 Scenario 1: Flax for Composites

Now that the industrial sites are ranked on suitability for each stage of the value chain, the options are narrowed down to locations that are being considered. The next step is to select the most suitable sites and shape the network, resulting in a structure map for the Netherlands for both the scenarios.

Scenario 1 2030: Flax for Composites

In the first scenario, where flax is predominantly cultivated for making 30-50% of composite facades with flax and 30% of other composites, alongside current production, an estimated total of 4000 hectares of cultivation per year is needed. With approximately 2300 hectares currently cultivated in Zeeland, two additional potential clusters have been identified in Flevoland and Groningen. Opting for clustered cultivation offers logistical benefits and the potential for shared facilities. As the existing processing facilities and cultivation are currently clustered in Zeeland, it makes most sense to maintain this cluster. Despite the soil problems in this region, there is still enough suitable cultivation land. Moreover, due to its proximity to other potential facilities and the demand for housing, establishing an additional cluster in Flevoland is recommended.

Chapter 6 outlined that a single large processing facility typically requires around 2500 hectares of cultivation land annually to be viable. Using this estimate, it is determined that approximately 1000 hectares of flax cultivation correlate with approximately 1 hectare of processing facilities. Proximity to raw materials is of importance, narrowing down the selection to two sites in Flevoland with sufficient available land. One site, situated on the edge of Lelystad, is selected due to its proximity to existing composite companies, including one working with biobased composites.

For the manufacturing of technical products, suitable locations near academic institutions such as TU Delft, AVANS Hogeschool, Wageningen University & Research, and Twente University are chosen to facilitate research collaborations and technological innovation.

For insulation application, only residual streams of flax are used. Blow-in techniques using shives require no additional processing space, while existing insulation companies can integrate non-woven insulation mats into their product offerings. 4.000 ha of flax delivers around 1.200.000 kg of shives that currently is used for animal bedding, but could be used for insulation.
Several circular building hubs, managing material flows from and to constuction sites and building material manufacturers are established on suitable sites on the edges of cities with a large (re)construction assignment.

As flax based composites tend to be stronger when it uses woven fabric, local spinning and weaving facilities should also be developed. As the scale of conversion for small spinning mill starts at 1.000.000 ton of fibers (476 ha flax) and for a large spinning mill around 5.000.000 kg (2380 ha of flax) (Leendertse et al., 2020). A large-scale facility could be positioned near the TU Delft campus to leverage academic and research synergies. Additionally, existing textile sorting centers are identified on the map to explore the potential use of textile waste in insulation materials or composites, fostering synergy between the textile and building sectors.

Scenario 2 2030: Flax for Composites and Textiles

In the second scenario, in addition to using flax for composites, flax is used for making textiles if you would want to replace 25% of the current Dutch textile demand with flax and hemp, you would need 42,875 ha of cultivation land. As the suitability analysis showed that a maximum of +/- 10.000 ha of flax could be cultivated sustainably yearly, flax could replace 5% of the current Dutch Textile Demand. If larger replacement shares are desired, the potential of hemp should be further explored. The additional cultivation land requires three extra processing locations, which are placed on the sites that are ranked as most suitable and are in proximity or accessable to cultivation land. Figure 82 shows this relation between the cultivation land and processing locations. In this scenario, the quantity of shives that could be used for blow-in insulation largely increases, resulting in 30.000 ton shives. Considering the scale of conversion, two additional large spinning facilities could be opened. They are located on suitable sites in Twente and Enschede, considering these regions were and are active in the textile industry, there is somewhat of an infrastructure and knowledge base that could be relevant for the reopening of spinning mills and weaving mills. In this scenario, the synergy between the textile and building sectors is emphasized and the importance of exploring the potential use of textile 'waste' for composites and insulation should be underscored.

Fig. 80 Processing input areas

Scenario 2: Flax for Composites and Textiles

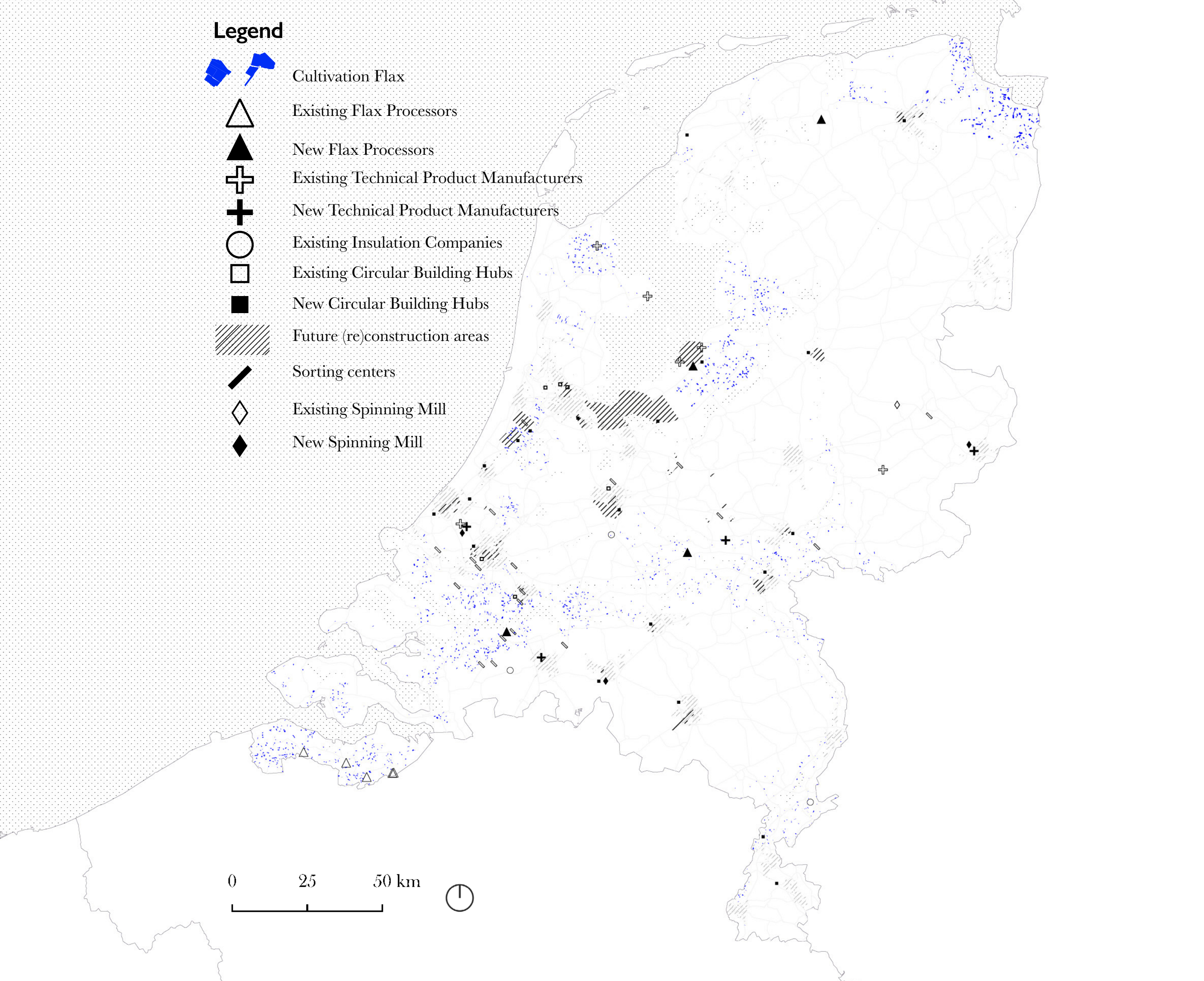
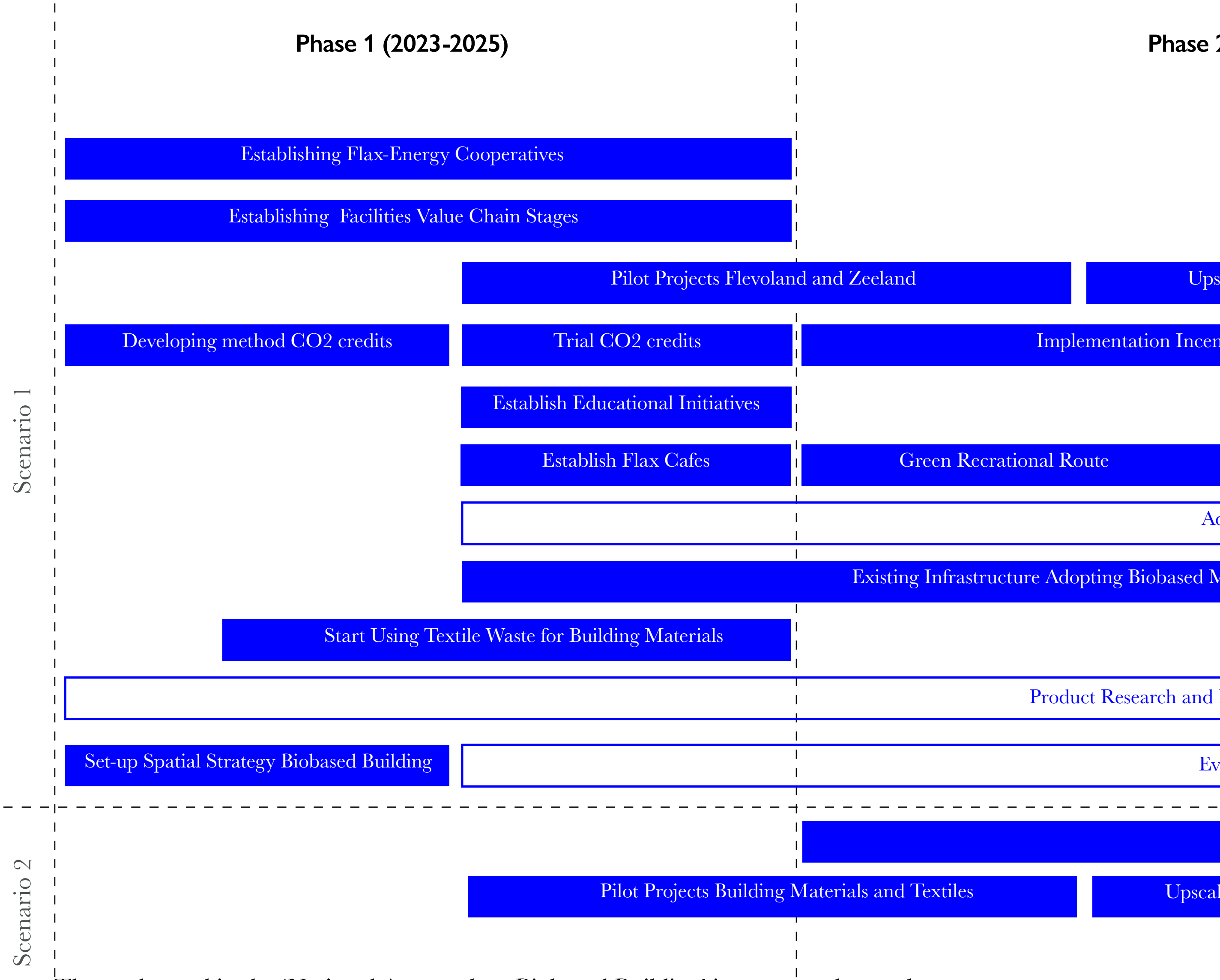


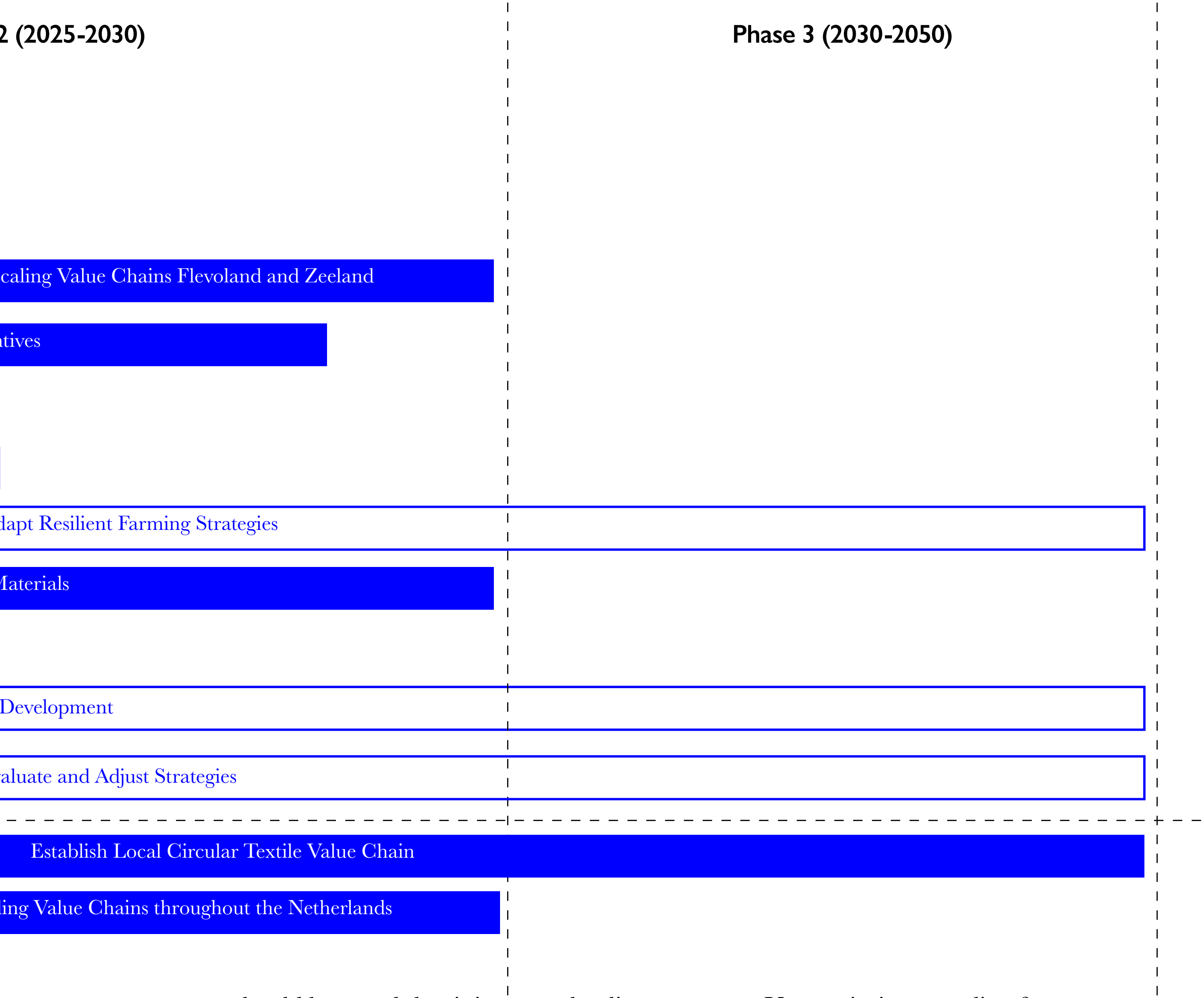
Fig. 81 Scenario 2: Flax for Composites and Textiles

Phasing



The goal stated in the 'National Approach to Biobased Building' is to create the market conditions for a biobased building sector by 2025 and to uspcale the chains until 2030. Although it appears from my strategy that in theory this should be feasible to realize, it

Fig. 82 Phasing



should be noted that it is not such a linear process. Uncertainties regarding future crop utilization and technological innovations necessitate adaptable design strategies and continuous re-evaluation to ensure resilience and sustainability in the evolving biobased economy.

Chapter 8:

A Pattern Language

What are spatial principles, and environmental and socio-economic requirements for a sustainable circular flax supply chain?

How could a circular flax supply chain be sustainably integrated in the territorial context of the Netherlands and how does it influence the landscape and built environment?

Introduction to the Method

This chapter presents the development and organization of a pattern language for a circular flax value chain. Urban environments are complex systems, and spatially facilitating a circular flax value chain is a complex task, requiring knowledge from different sectors and technologies and on different scales. To achieve circularity, a pattern language can be used as an instrument for interdisciplinary mediation (Hausleitner et al., 2020).

In 1977 Christopher Alexander developed this ‘archetypical language’, called ‘pattern language’. A method to understand and possibly control complex systems in spatial design, but also to function as a design tool that can build something functionally and structurally coherent (Salingaros, 2008). This method acknowledges complexity, but breaks it down in comprehendible blocks of knowledge or solutions, called patterns, translatable to a wide range of conditions.

Patterns are built up out of a hypothesis, theory supporting this hypothesis and a practical implication solution, clarified by a sketch or example (Rooij & van Dorst, 2020), thus functioning as a bridging tool between research and design. The patterns are either derived from theory, analysis or from the design process.

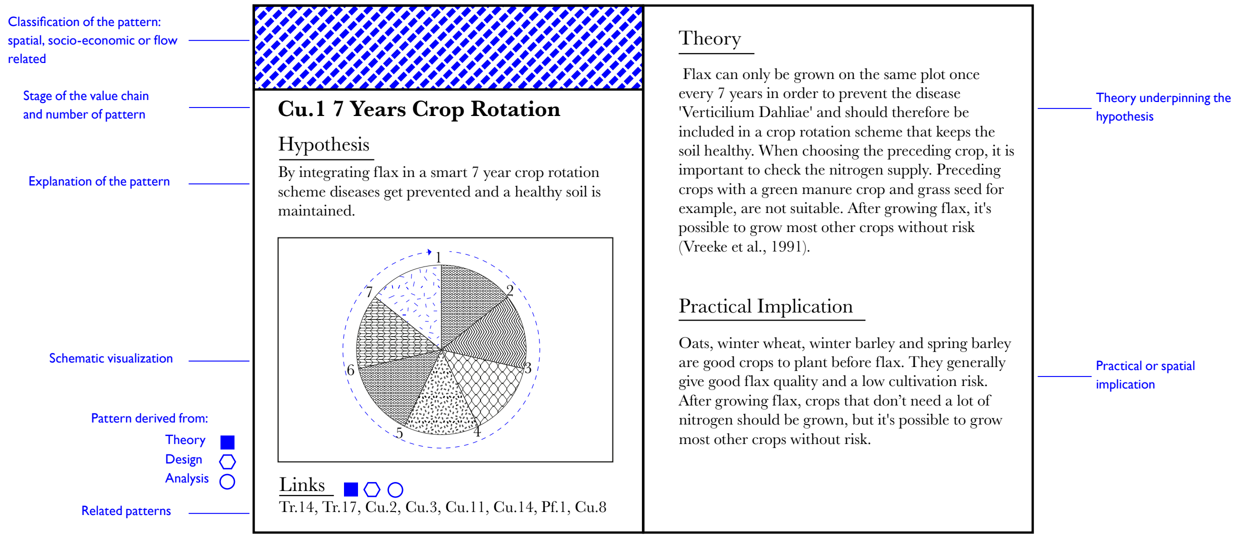


Fig. 83 Structure of Pattern

Each pattern is linked to one or more other patterns, through themes or level of scales. The 'pattern field' can be seen as a framework that describes the organization of the relations between the patterns. Through this organization, a hierarchy can be created. The pattern field helps you see relations between different design interventions. Two patterns may function independently, complement eachother or potentially even compete with eachother (Salingaros, 2018).

The patterns are classified as socio-economic, spatial or flow related, or potentially a combination. Socio-economic patterns primarily address the social and economic aspects of the flax value chain system. Flow-related patterns focus on the movement, exchange, and transformation of resources, materials, information, or energy within the flax value chain and limiting environmental impact. Spatial patterns focus on geographical allocation of functions, interventions in the physical built environment and what qualities they bring.

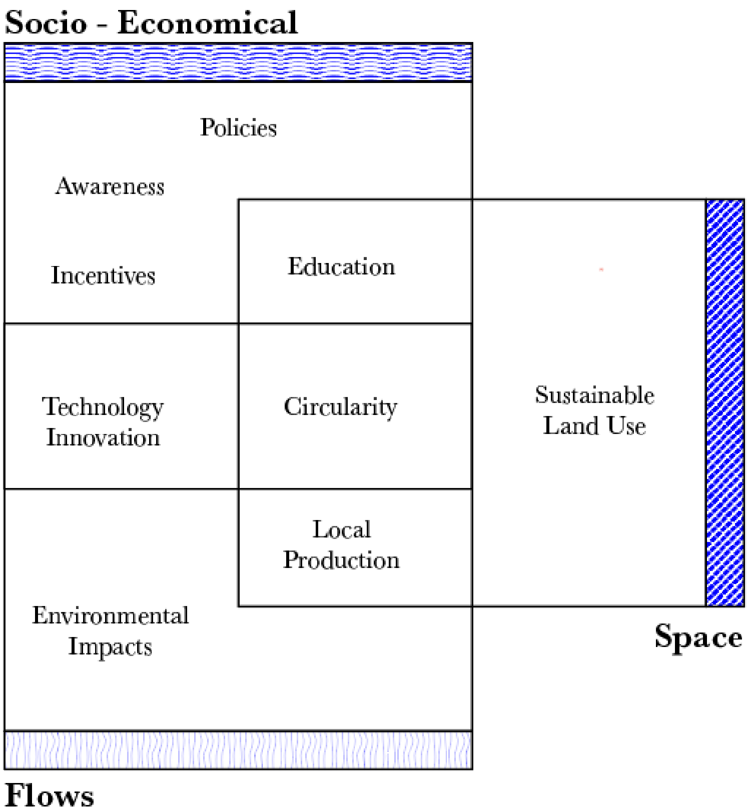
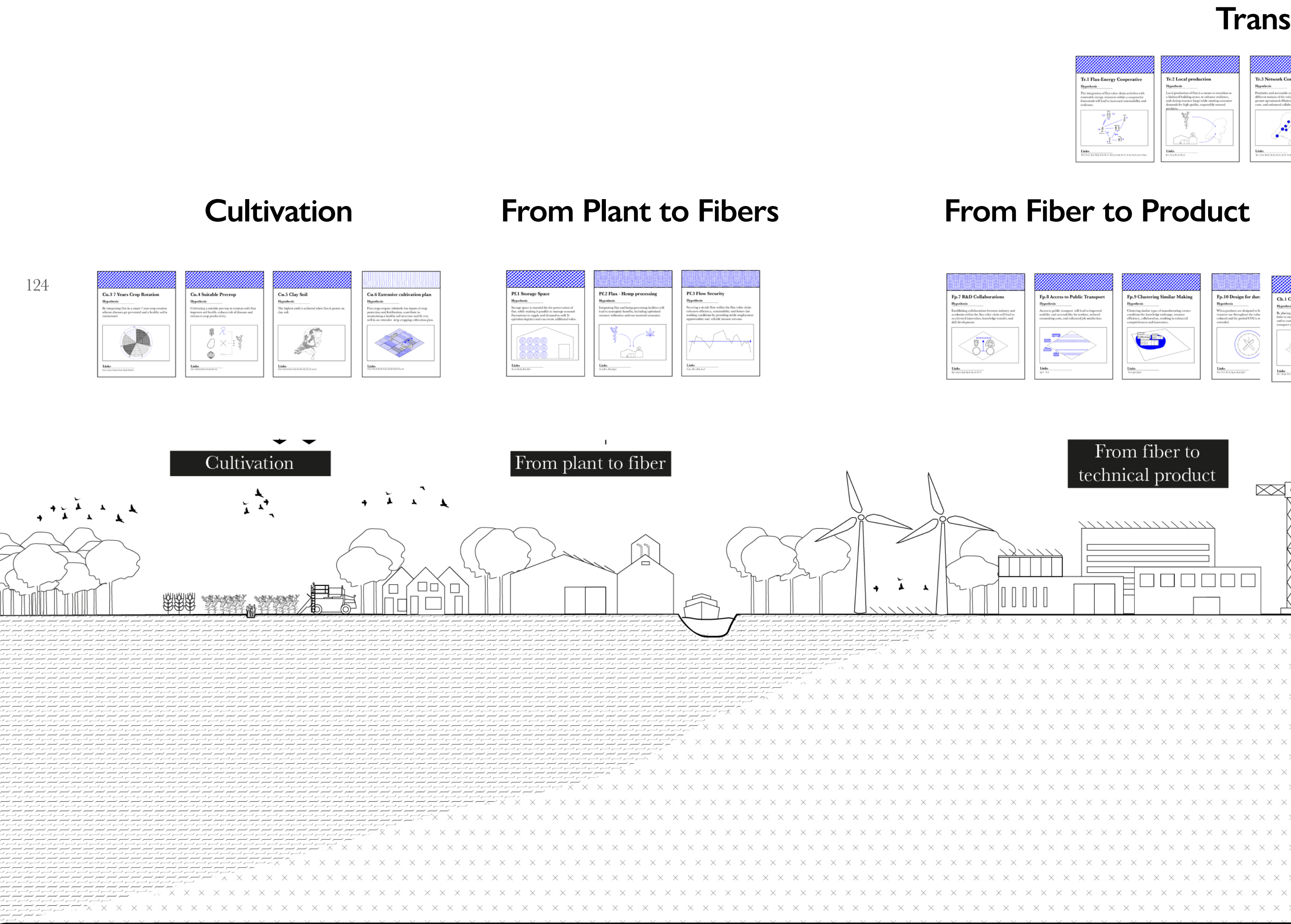


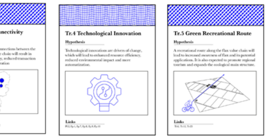
Fig. 84 Pattern Field

A Pattern Language to Make a Systemic Change

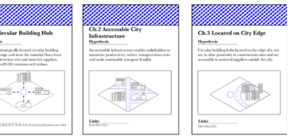
The Patterns are organized along the value chain. By aligning patterns with the stages of the flax value chain, it provides a structured and systematic approach to understanding and modifying the system. It also ensures that all critical stages of the value chain are adressed and that interdependencies and connections between the different stages are clear. Eventually, it will also help to translate systemic changes to land-use changes.
An overview of all the patterns can be found in the pattern booklet.



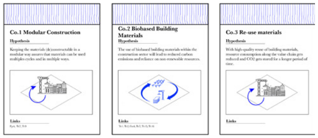
scalar



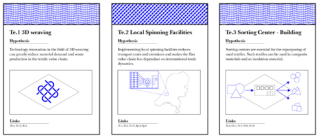
Construction

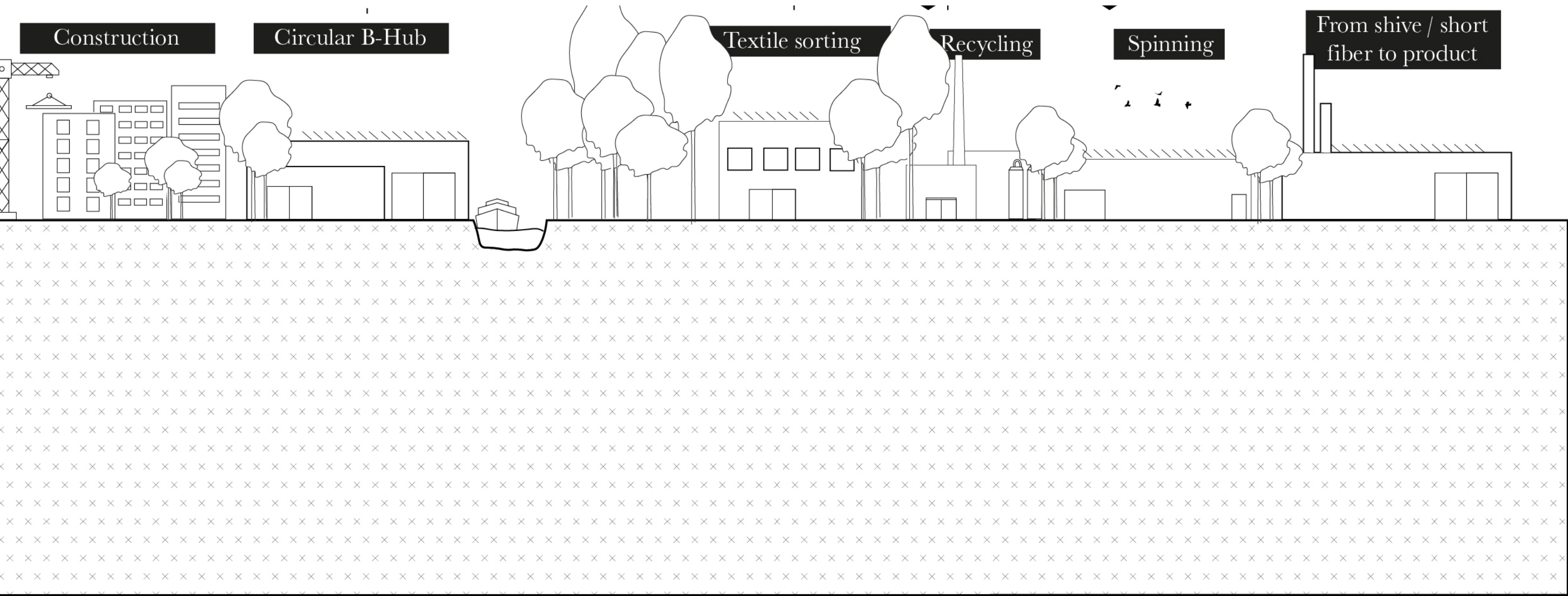


Circular Building Hub



Textile





Path Dependencies

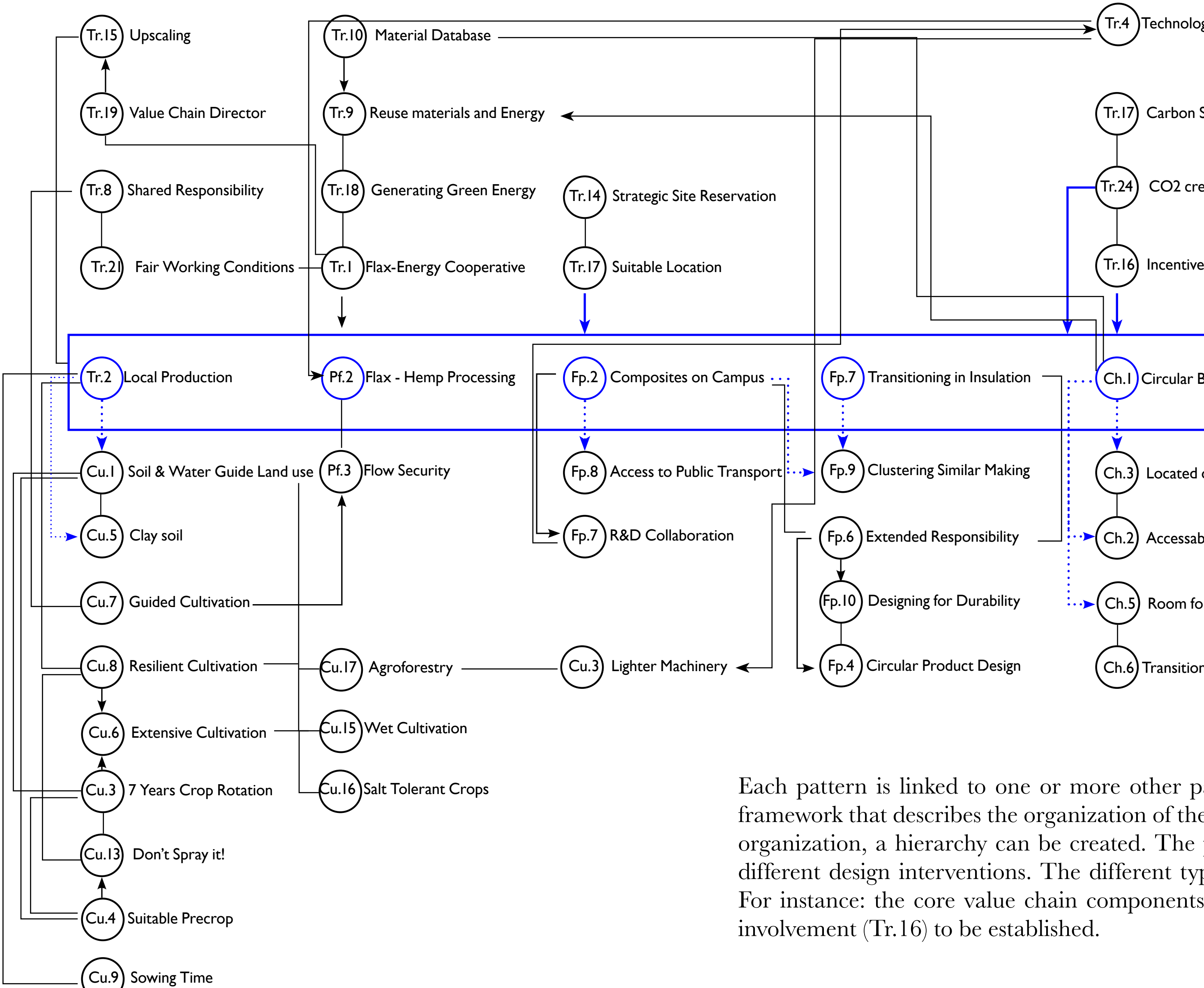
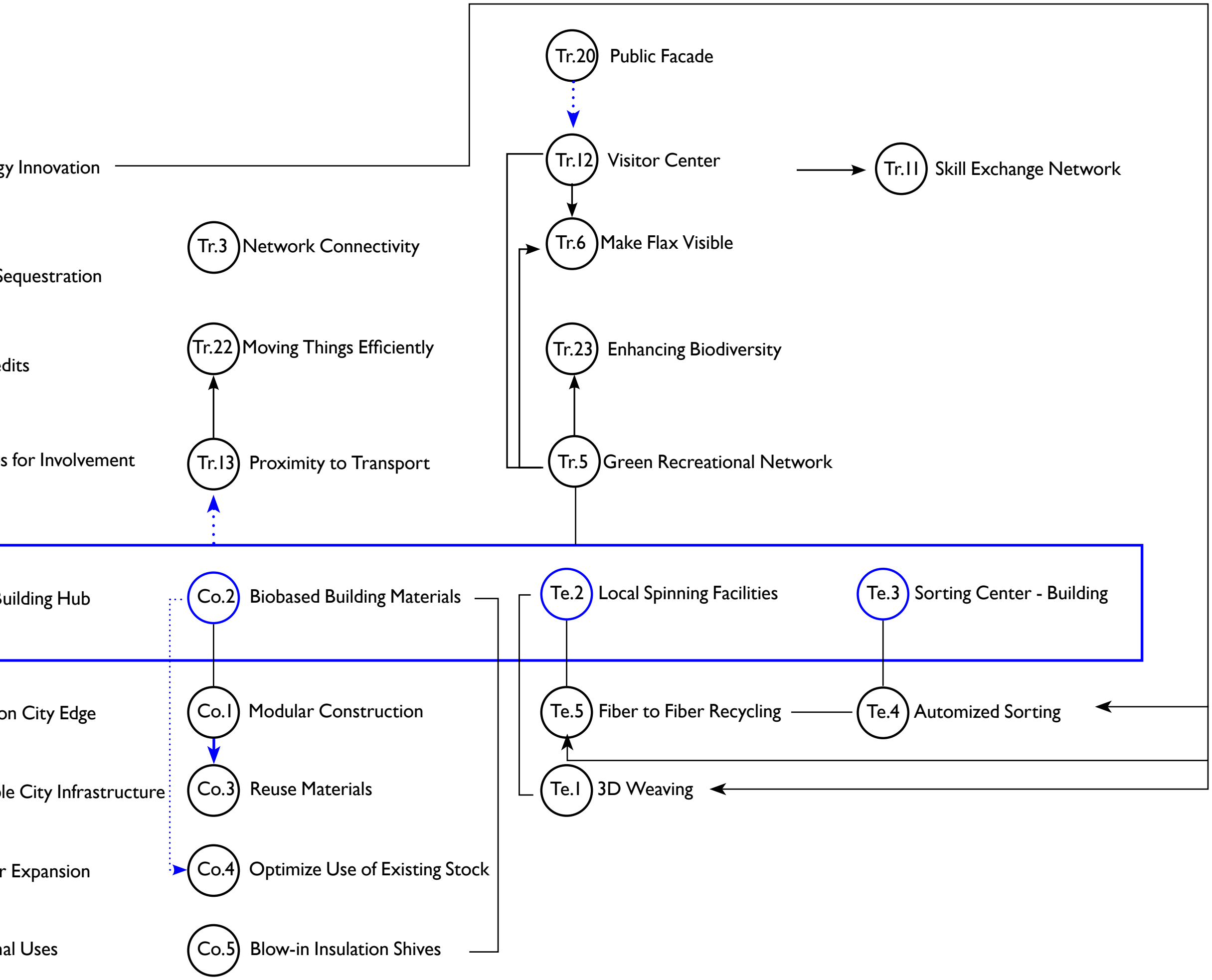
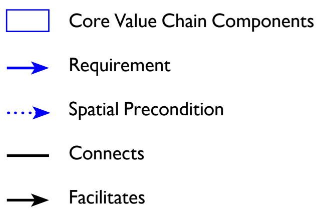


Fig. 85 Pattern Field

Each pattern is linked to one or more other p
framework that describes the organization of the
organization, a hierarchy can be created. The
different design interventions. The different typ
For instance: the core value chain components
involvement (Tr.16) to be established.



atterns. The 'pattern field' can be seen as a e relations between the patterns. Through this pattern field helps you see relations between pes of relations showcase path dependencies. depend on other actions like 'incentives for



Chapter 9:

Spatial Strategy: A Flax Flevoland

How could a circular flax supply chain be sustainably integrated in the territorial context of the Netherlands and how does it influence the landscape and built environment?

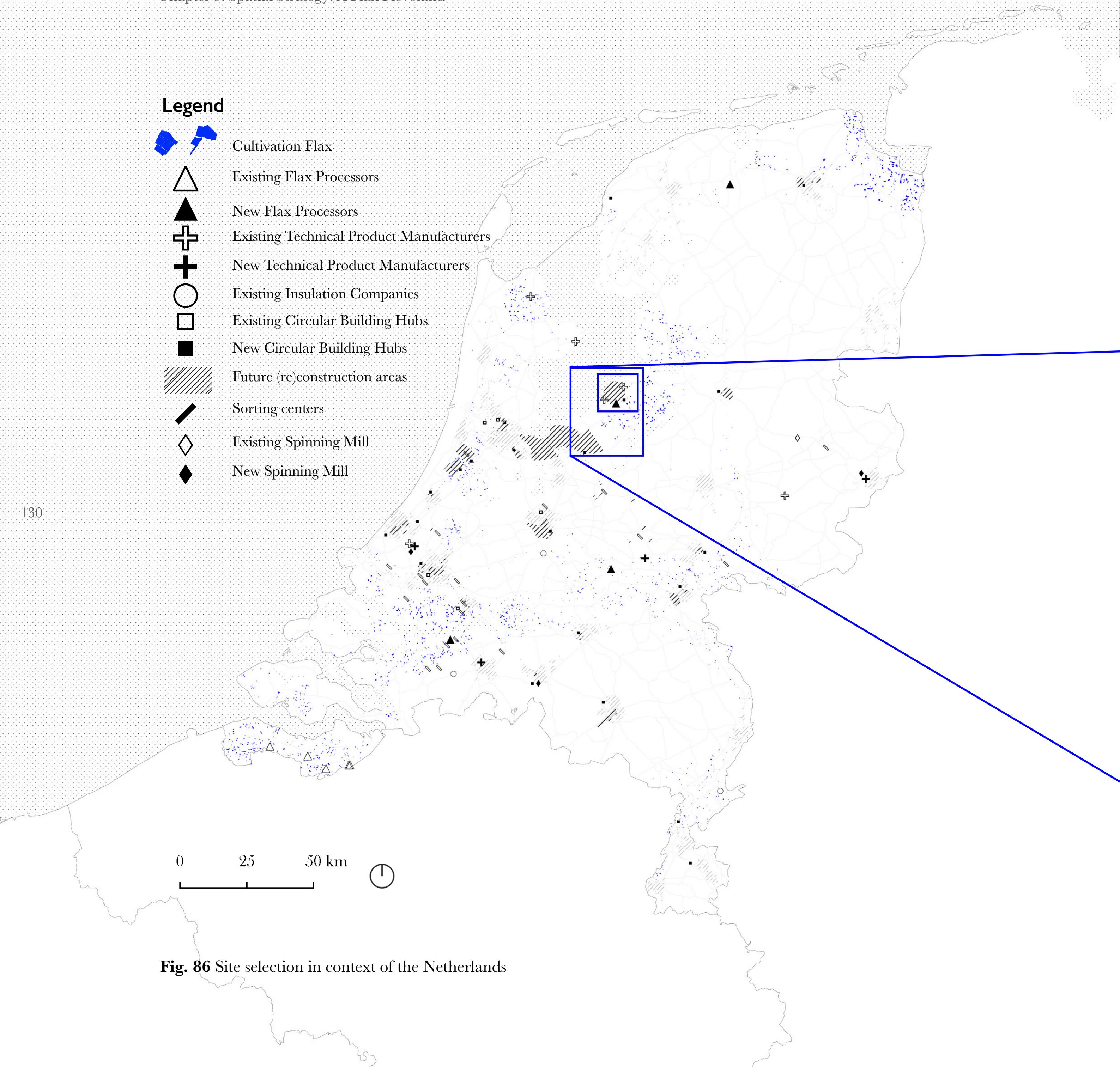


Fig. 86 Site selection in context of the Netherlands

Introduction: Zooming in on Flevoland

The formulated patterns will be implemented on the case of Lelystad, Flevoland, which serves an examplary project, to test and showcase how the systemic changes translate to land use changes, how it relates to the existing context and to see what spatial quality they can bring.

The case of Lelystad is chosen because in both scenarios flax cultivation takes place in Flevoland, a lot of new houses have to be built there, and because different components of the flax value chain are clustered around Lelystad. Therefore it serves as a good example to see how the different components of the flax value chain interact with eachother and with their environment. To understand the area, this chapter starts with a brief analysis of the characteristics of Flevoland.

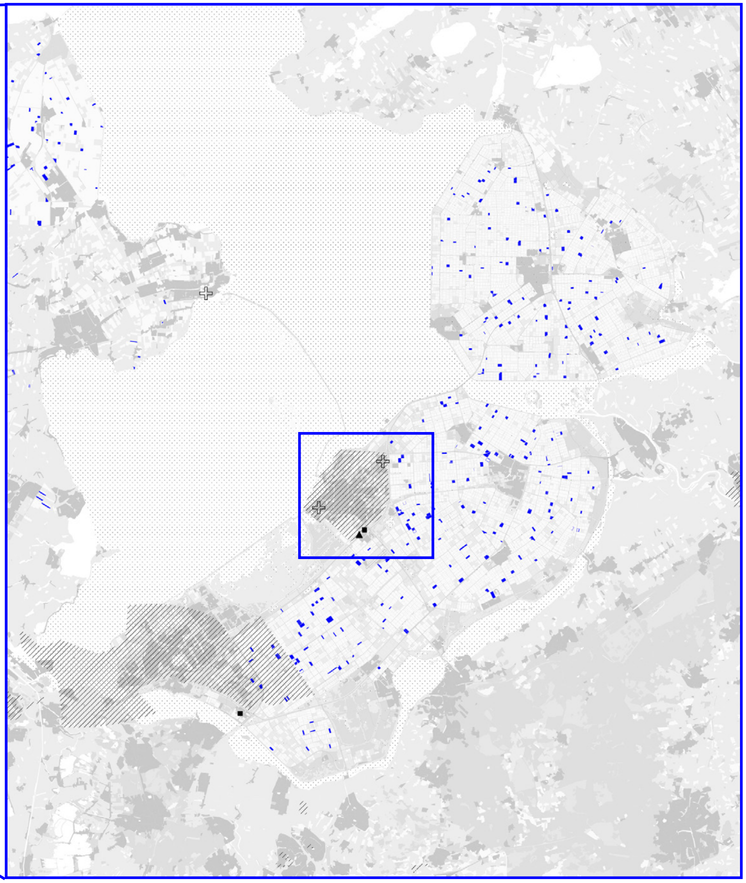


Fig. 87 Site selection: Lelystad, Flevoland

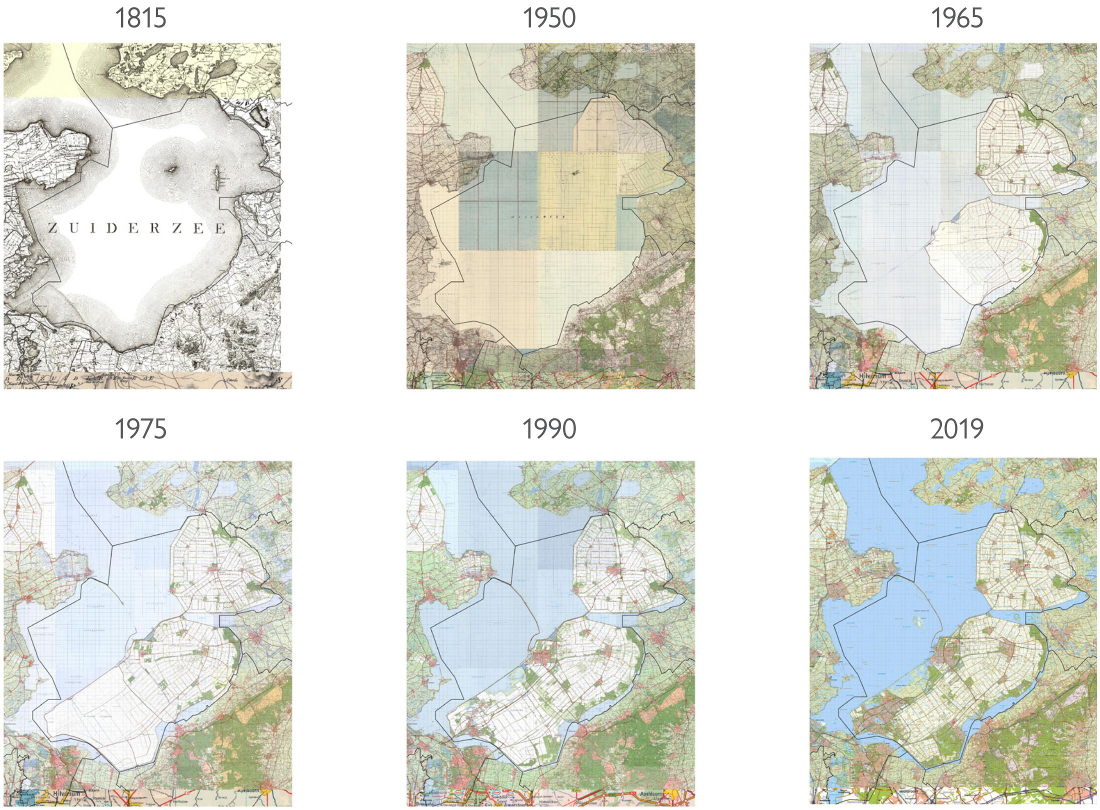


Fig. 88 Historic Development Flevoland (Topotijdreis, n.d.)

Historic Development

Flevoland is the youngest province of the Netherlands and it is manmade. Flevoland has a history of dynamic interplay between land and sea. At the end of the iceage, sealevel rised because of the melting ice. Flevoland would be flooded from time to time. Around 5000 B.C. peat started to develop in this area (Renes, 2019). Around 100 A.D. the sea took over the land again, and Flevoland slowly became part of the Zuiderzee, in this period the top layer of clay was formed. To prevent floods, the Zuiderzee was closed off from the North Sea by the construction of the Afsluitdijk in 1932, subsequently renaming it the IJsselmeer. This allowed for the reclamation of Flevoland from the sea. The Noordoostpolder was reclaimed in 1942, Eastern Flevoland in 1957, followed by Southern Flevoland in 1968 (Baas, 2009).

Fig. 89 Parcel sizes (PDOK, 2023)

Parcel Size

The Noordoostpolder was planned with efficiency for the means at that time in agricultural layout and parceling as the main focus. The planners aimed for 300-meter-wide by 800-meter-long parcels, resulting in standard parcels of 24 hectares. The mechanization of farming during the 1950s and 1960s brought about changes in the layout of Oostelijk Flevoland. Parcel sizes increased to around 45 hectares. In the development of Zuidelijk Flevoland, there was a significant trend toward larger scale operations. The reliance on bicycles and boats seen during the Noordoostpolder development was replaced by cars and trucks. Horse-drawn wagons were substituted with large tractors, enabling parcel sizes of up to 60 hectares (Landschapsbeheer Flevoland, n.d.)

Ecological Structure

Figure 90 shows the ecological main structure in Flevoland. Its primary objective is the conservation and enhancement of natural habitats. The inclusion of corridors is vital for ensuring connectivity within the network. The ecological main structure predominantly aligns with the existing green infrastructure (Figure 91), comprising plants, trees, and shrubs. When designing, it is advisable to leverage the current framework and expand it by establishing new connections, all while preserving the distinctive landscape characteristics.

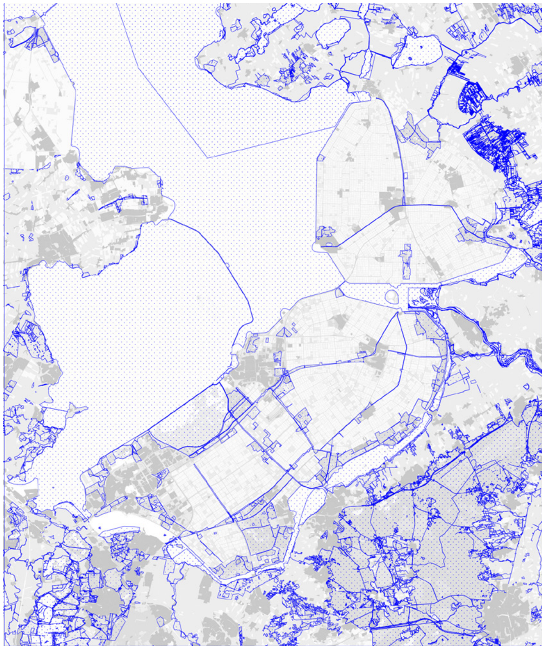


Fig. 90 Ecological Main Structure including Natura2000 adapted from (Interprovinciaal Overleg, 2022)

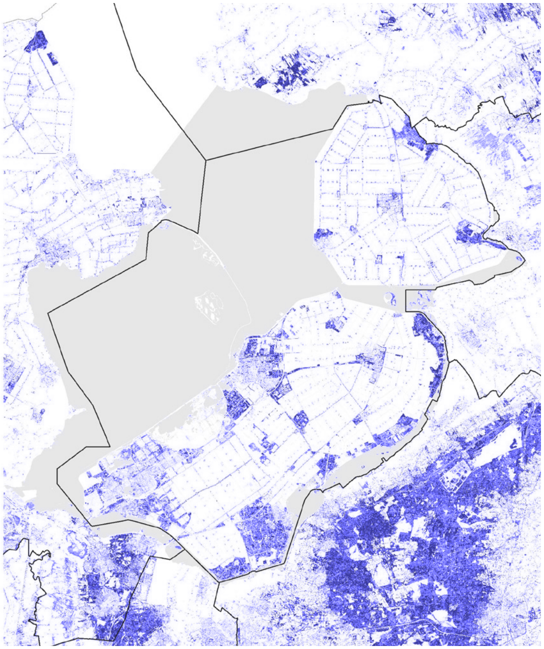


Fig. 91 Green Structure adapted from (Rijksinstituut voor Volksgezondheid en Milieu, 2022)

Landscape Characteristics

The integration of a new production landscape should harmonize with the existing landscape features. Flevoland has a very organized, open and agricultural character. From many points, you have a view across vast stretches of farmland, interrupted only by occasional rows of trees or wind turbines. Trees are strategically positioned along roadways, encircling farms to offer privacy, in designated recreational woodlands on less arable land, and within urban areas. This intentional placement of trees aims to provide shelter for crops. The landscape is frequently likened to the compositions of Piet Mondrian's paintings.

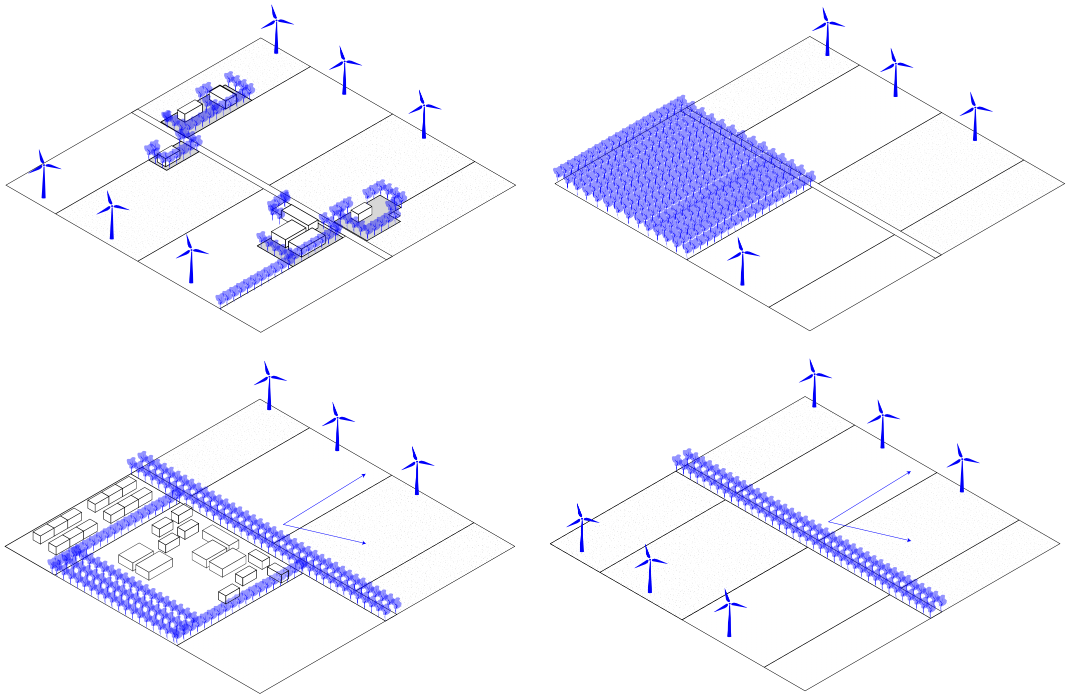


Fig. 92 Isometrics of landscape characteristics

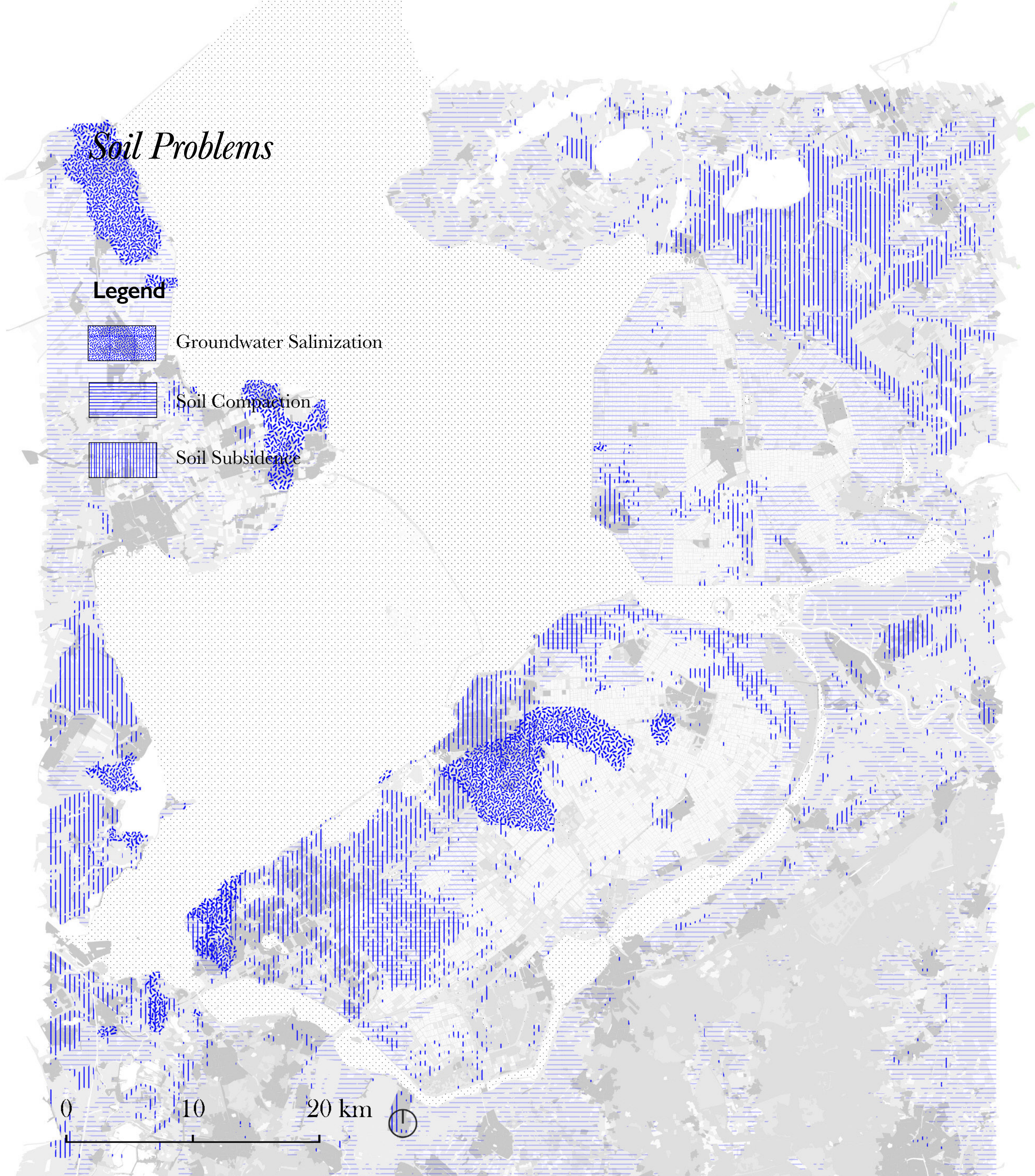


Fig. 93 Soil Problems Map Adapted from (Deltares, 2015) (Deltares et al., 2021) (Wageningen Environmental Research, 2017)

Soil Problems

Flevoland faces several significant soil challenges, illustrated in figure 93. These challenges include soil compaction, soil subsidence, and soil salinization and depletion of soil nutrients, each requiring careful management strategies. Adapted farming strategies are crucial for sustaining agricultural productivity and ecological resilience.

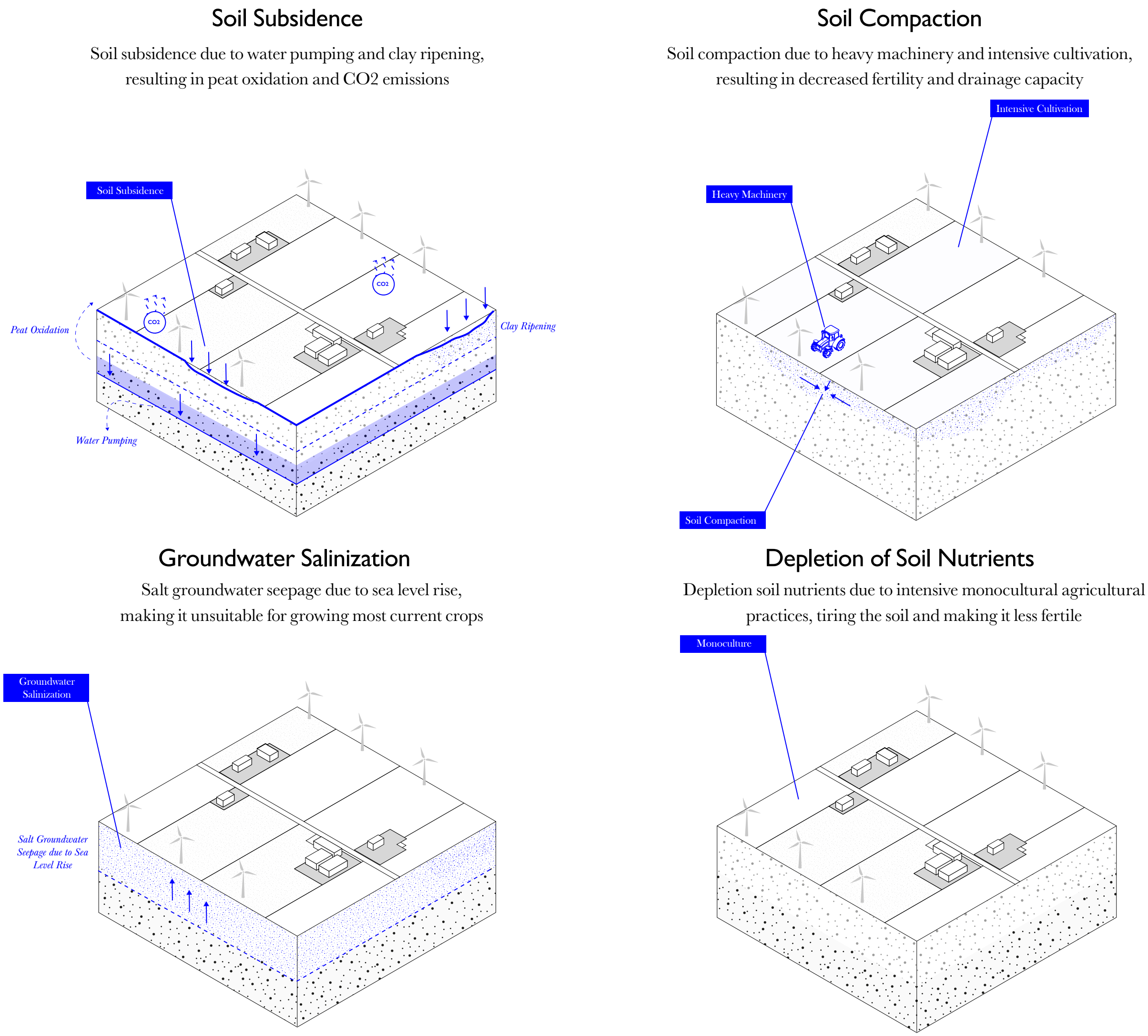


Fig. 94 Isometrics of soil Problems

Designing for Flevoland: Flax - Energy Cooperative

Moving forward to the design for Flevoland. The core concept of the design revolves around the formation of a flax-energy cooperative among stakeholders in the value chain. This cooperative aims to establish a stronger connection between the various entities involved in different stages of the flax value chain. By doing so, it would streamline operations, foster improved communication, and optimize resource utilization across the supply chain. Moreover, involving local communities and stakeholders in cooperative's activities could cultivate a sense of ownership and shared responsibility for sustainable development initiatives.

In addition to managing flax material flows, the cooperative endeavors to contribute to a healthier living environment by promoting biodiversity, nurturing nature, and addressing the impacts of climate change. Through the establishment of renewable energy generation facilities within the cooperative, and by converting biomass derived from flax residues and production waste into renewable energy sources, reliance on non-renewable resources is reduced and local resilience is enhanced.

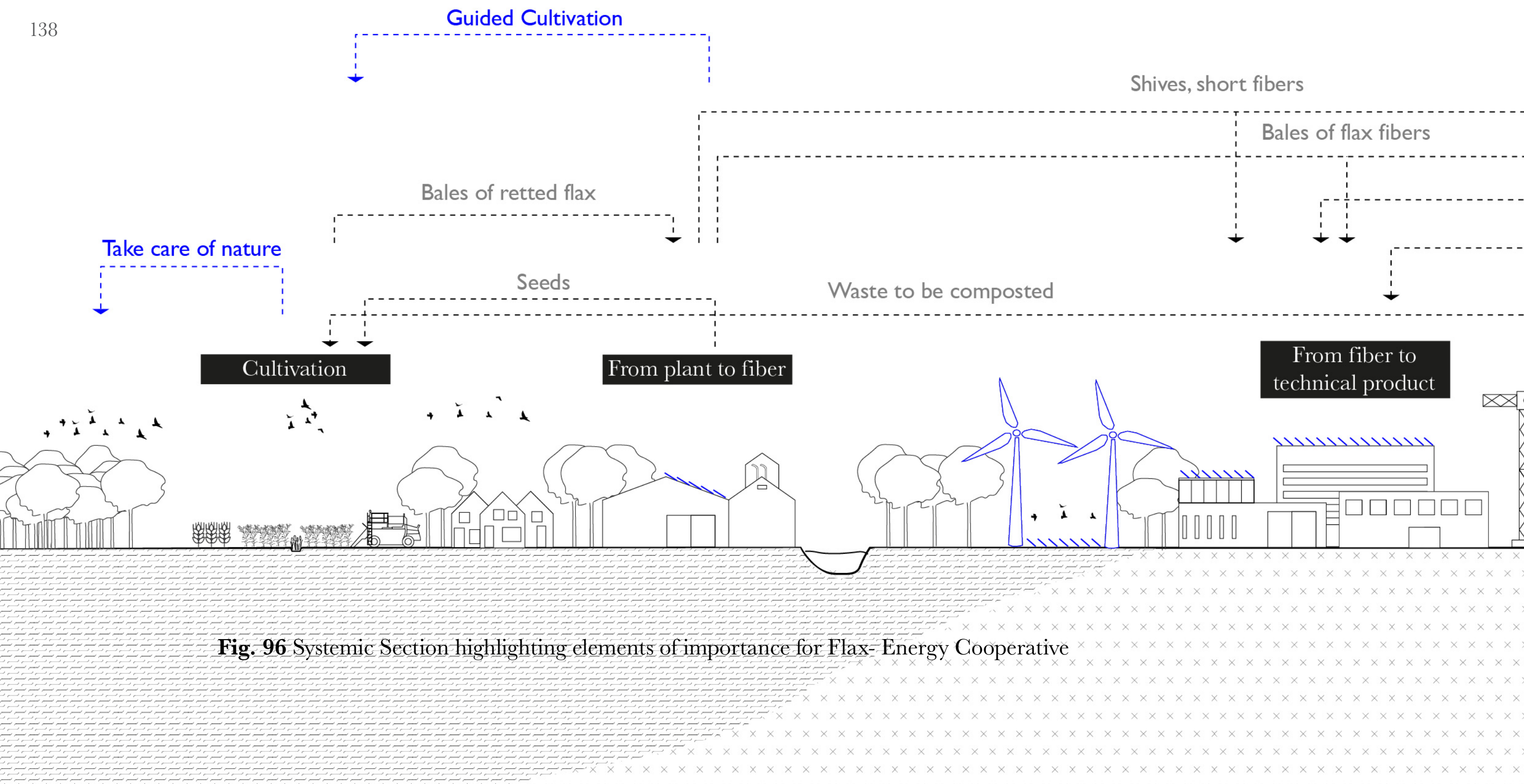


Fig. 96 Systemic Section highlighting elements of importance for Flax- Energy Cooperative

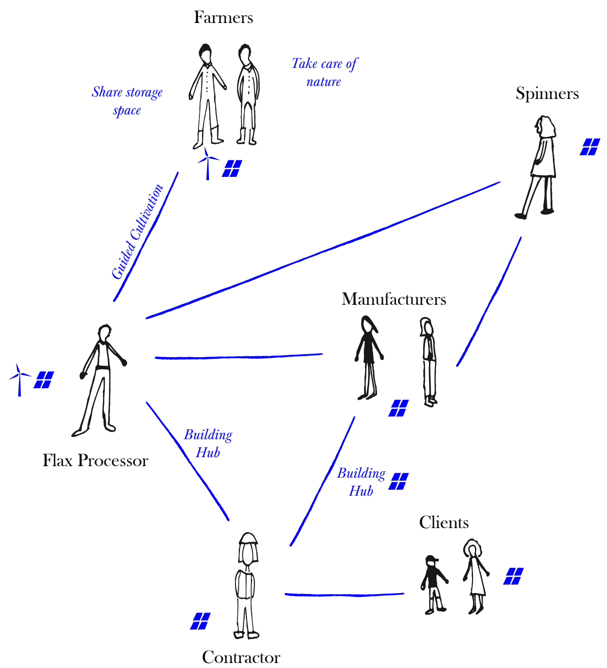
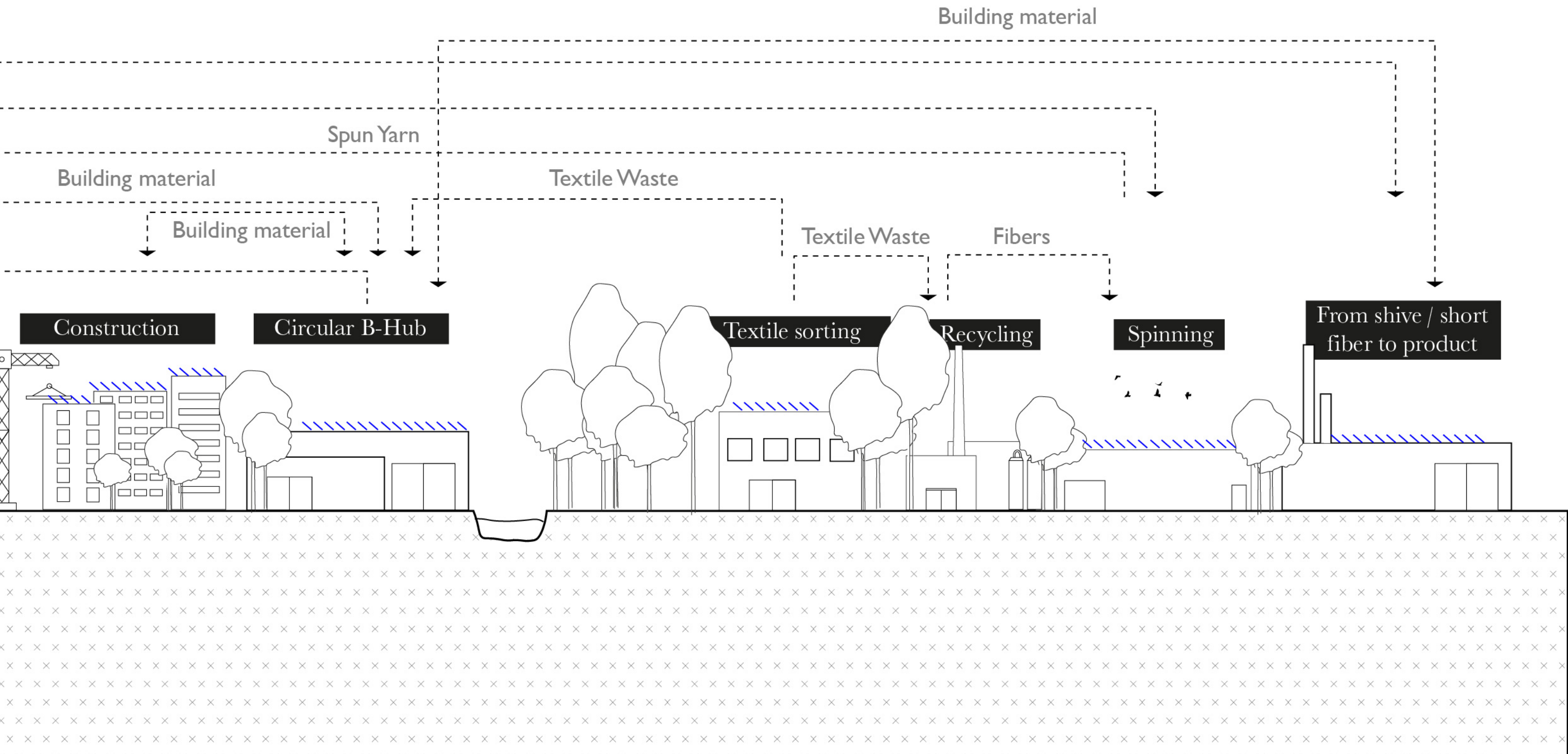


Fig. 95 Illustration Flax- Energy Cooperative



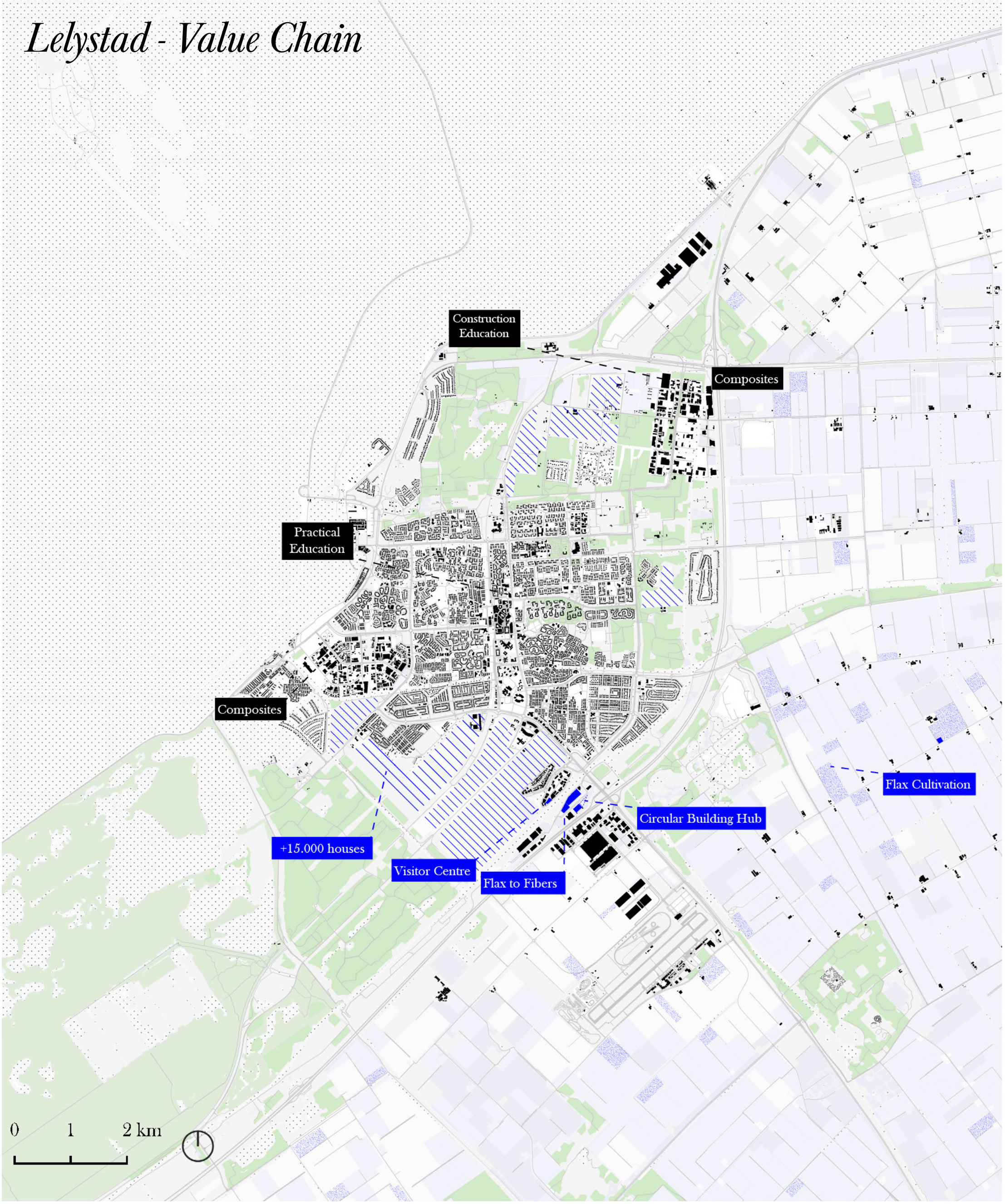


Fig. 97 Map showing exact geographic locations of value chain stages in Lelystad

Lelystad - Spatial Framework

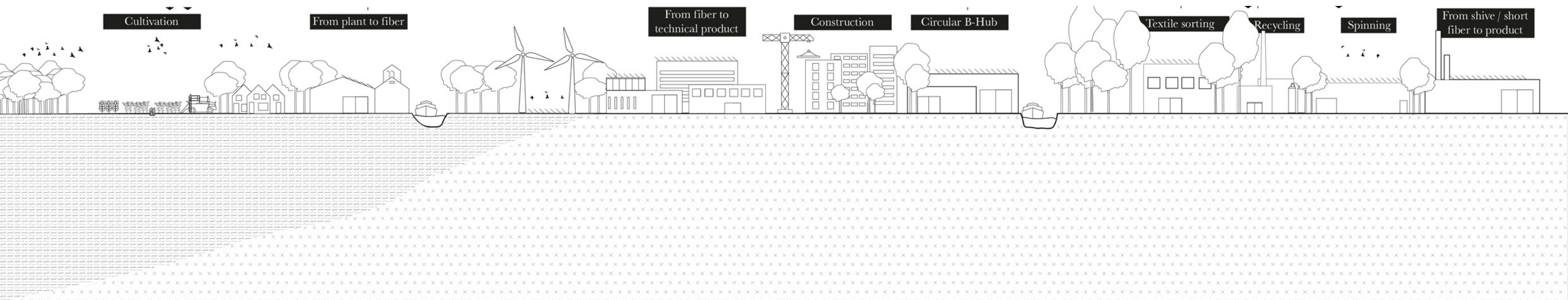
The map on the left page shows the exact geographical location of flax cultivation, the circular building hub and flax processing in the context of Lelystad, a result of the suitability analysis. Additionally it shows the existing infrastructure, that can become part of the flax value chain, including the new construction areas and existing companies working with composites.

In the next section, a pattern language is used to create a spatial framework for Lelystad, Flevoland, which serves an examplary project, to test and showcase how the systemic changes translate to land use changes, how the implementation of the flax industry components relate to the existing context and to see what spatial quality they can bring.

Fig. 98 History Lelystad (vistiflevoland.nl, n.d.)

Implementing Patterns
Transscalar

Fig. 99 Isometric Current Landscape Flevoland



The isometric view on the left page illustrates the existing landscape of Lelystad, while the isometric on this page depicts the landscape transformation following the implementation of the patterns. In addition to the visible representation of the value chain stages, the drawing showcases innovative, climate-adaptive farming methods, and the expansion and strengthening of the ecological network along a recreational "flax route." It still has a dominant open and organized character, yet it is slightly more dynamic as the fields move away from monoculture towards a more diverse cultivation plan.

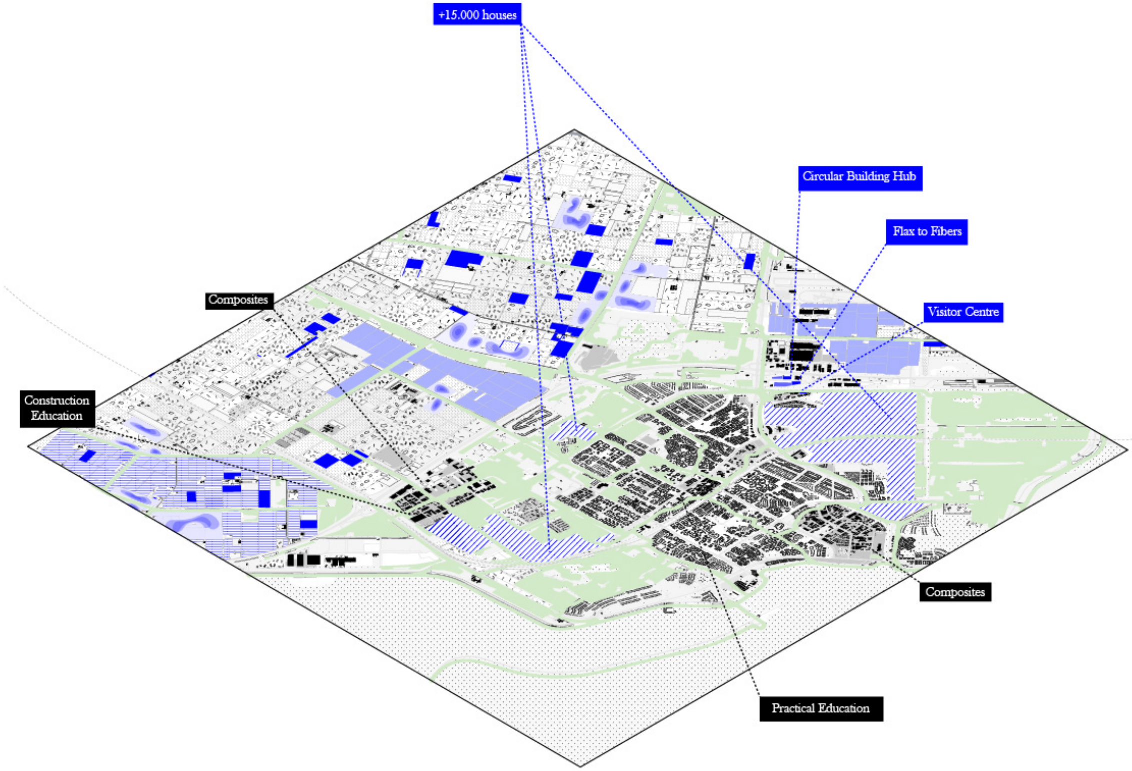


Fig. 100 Isometric Transformed Landscape Flevoland

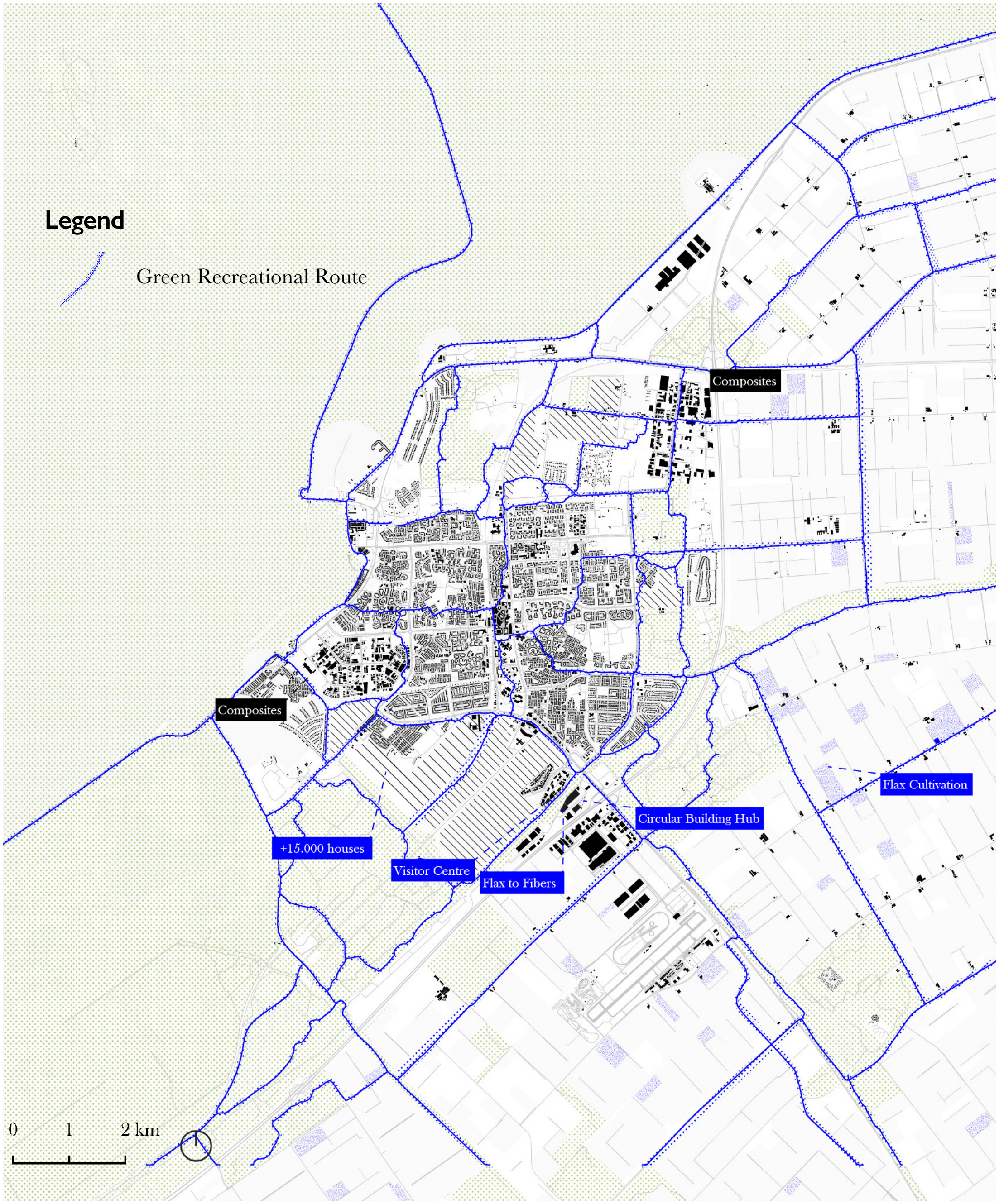


Fig. 101 Green Recreational Route through Lelystad

Green Recreational Route

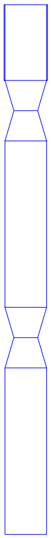
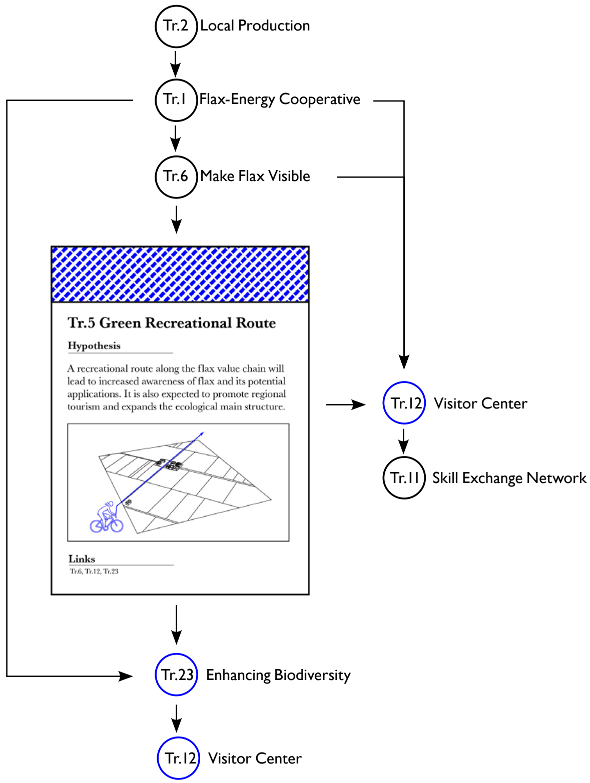


Fig. 102 Signage poles



The map in figure 101 shows how a recreational flax route through nature and along the value chain could be combined with enhancing biodiversity. The green corridors make new connections with the existing ecological structure. The green recreational route contributes to making flax visible (Tr.6). Activities along the flax value chain need to be made visible so the market picks up the products and the general public recognizes the importance. An important stop in the recreational route is the visitor center (Tr.12), called 'flax cafe', in which the process from seed to building material is made visible. The flax cafe could also be a community house for the flax-energy cooperative or could function as meeting point for stakeholders along the value chain or stakeholders who engage in similar kinds of making to facilitate knowledge exchange. Signage poles that are also bee hotels are placed along the Flax Route to increase awareness and to contribute to the biodiversity along ecological main structure.

Implementing Patterns

Cultivation

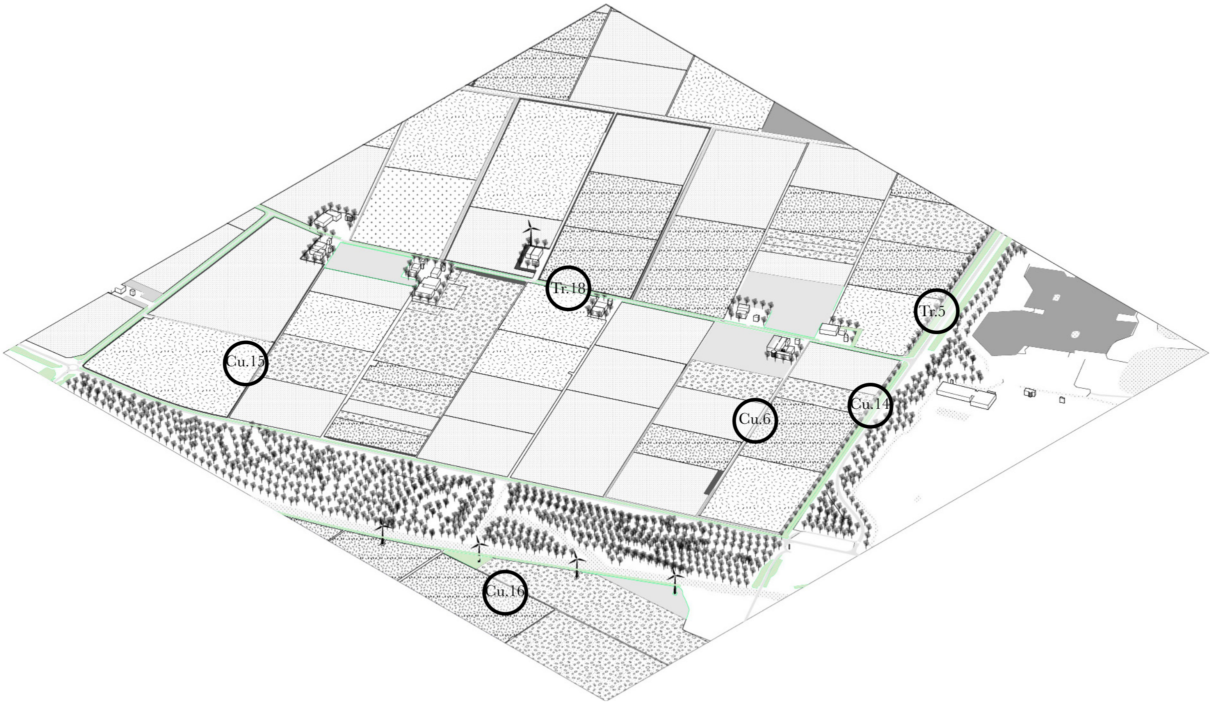
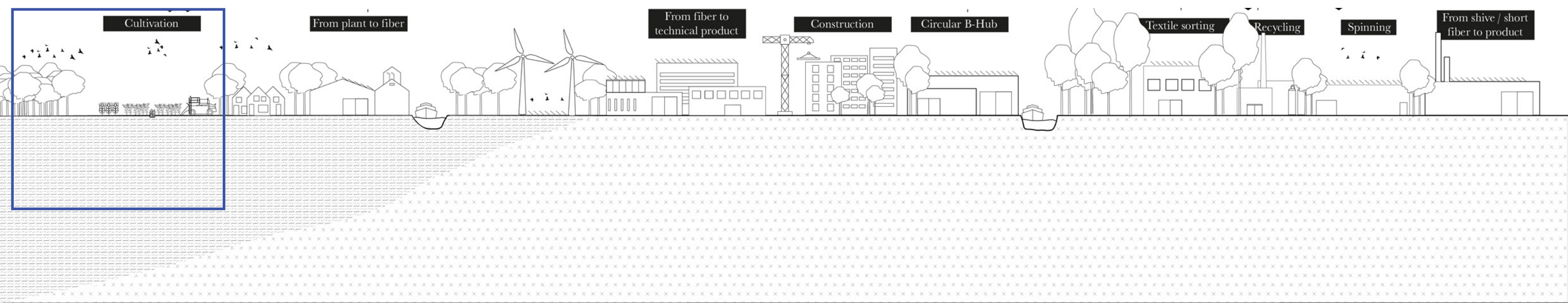


Fig. 103 Isometric current cultivation landscape

- Tr.18 Generating Green Energy
- Cu.14 Reed Edges
- Tr.5 Green Recreational Network
- Cu.15 Wet Cultivation
- Cu.16 Salt Tolerant Crops
- Cu.6 Extensive Cultivation
- Cu.12 Shared Storage Space
- Tr.23 Enhancing Biodiversity



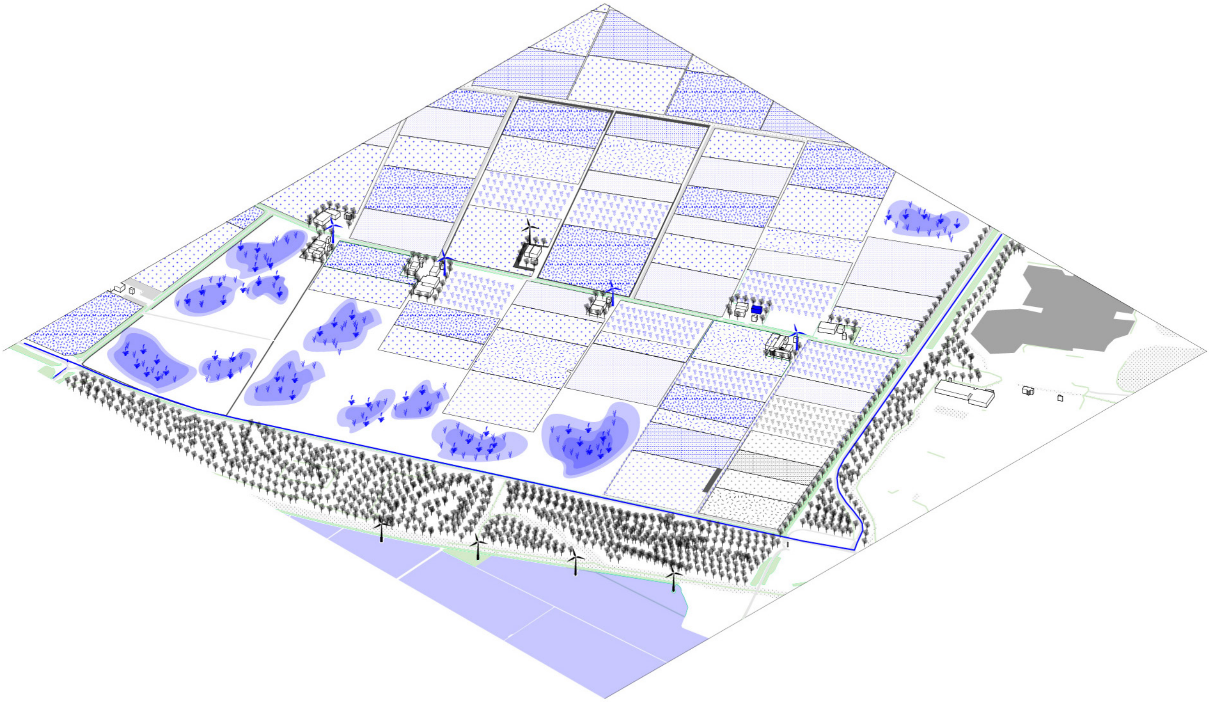
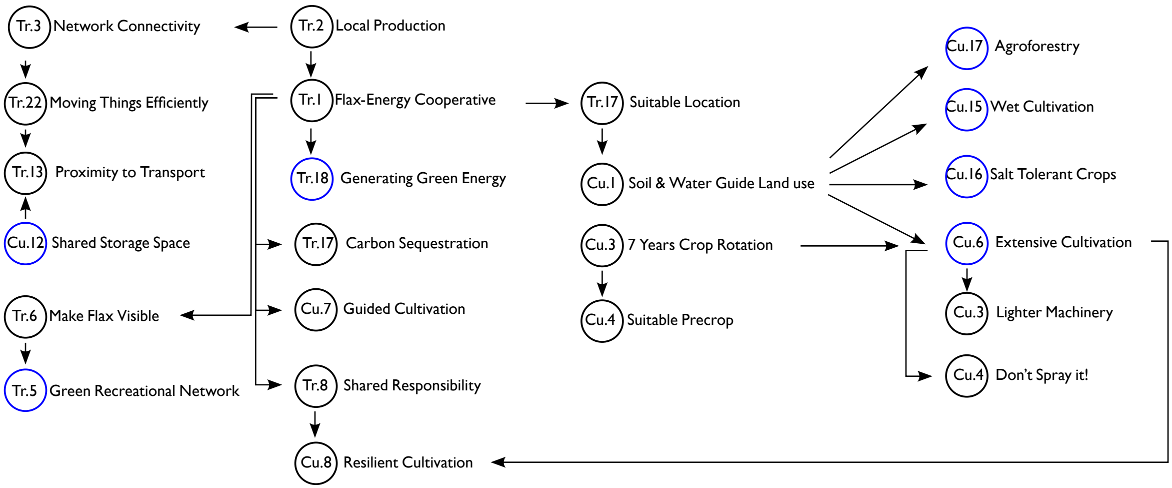
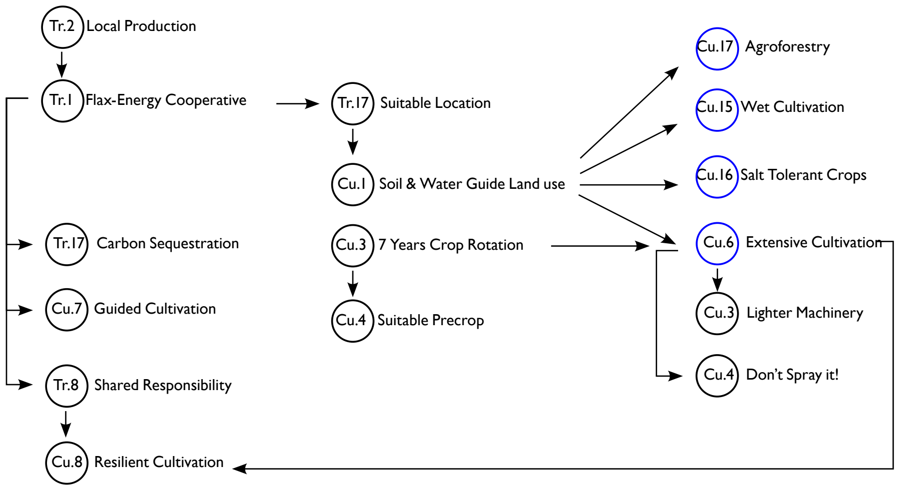


Fig. 104 Isometric transformed cultivation landscape



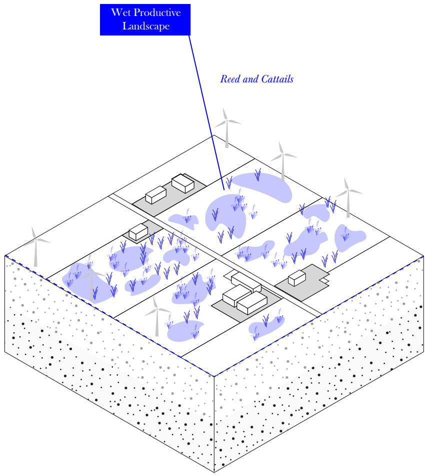
Types of Cultivation

As illustrated in figure 93, Flevoland faces several problems with their soil: Soil subsidence, soil compaction and salinization of groundwater. In order to keep the landscape productive, while adapting to the changing conditions, new ways of farming should be adapted. This includes wet cultivation (Cu.15) as a response to soil subsidence, in which it is not possible to cultivate flax; agroforestry (Cu.15) in combination with flax, which can improve the soil structure of compact soils; salt tolerant cultivation, as a response to the salinization of groundwater, with flax being moderately sensitive to salt; and lastly, strip cropping and crop rotation including flax, replacing monocultural farming and improving the richness of nutrients in the soil.



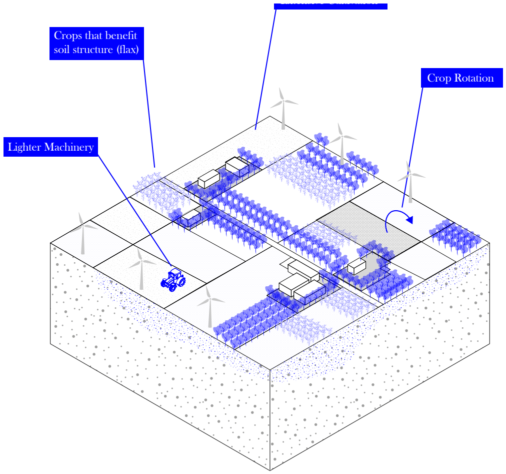
Wet Cultivation

Wet cultivation as response to soil subsidence ,
no flax cultivation possible



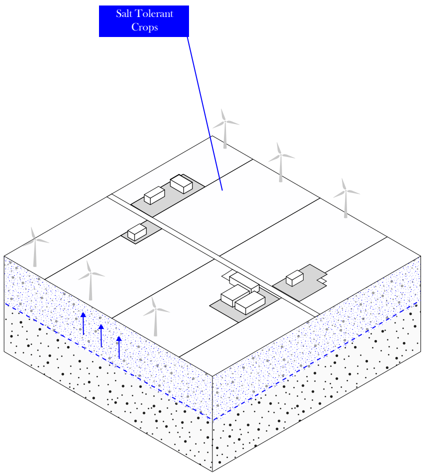
Agroforestry

Agroforestry in combination with flax to improve soil structure,
flax as a part of the solution



Salt Tolerant Cultivation

Salt tolerant cultivation as reaction to salt groundwater seepage,
flax being moderately sensitive to salt



Strip Cropping

Strip cropping and crop rotation to improve soil richness,
flax as one of the many

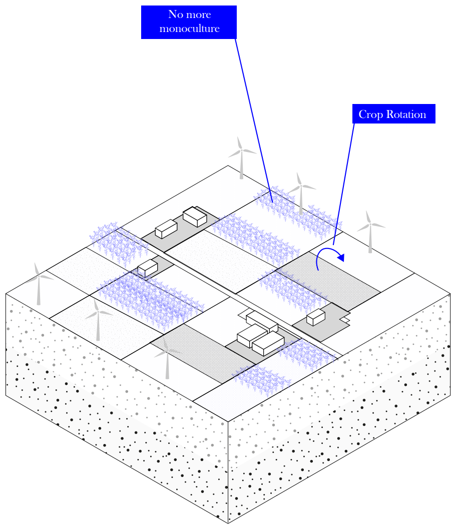


Fig. 105 Isometrics cultivation strategies

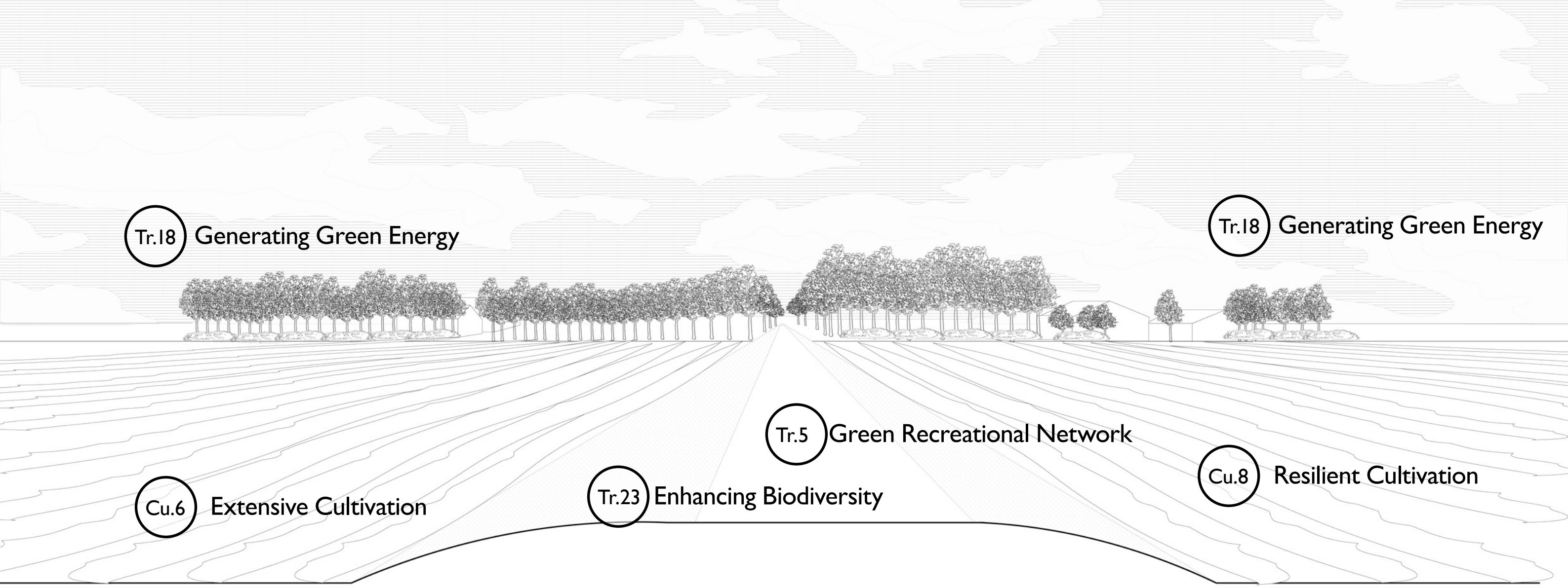


Fig. 106 Current cultivation landscape

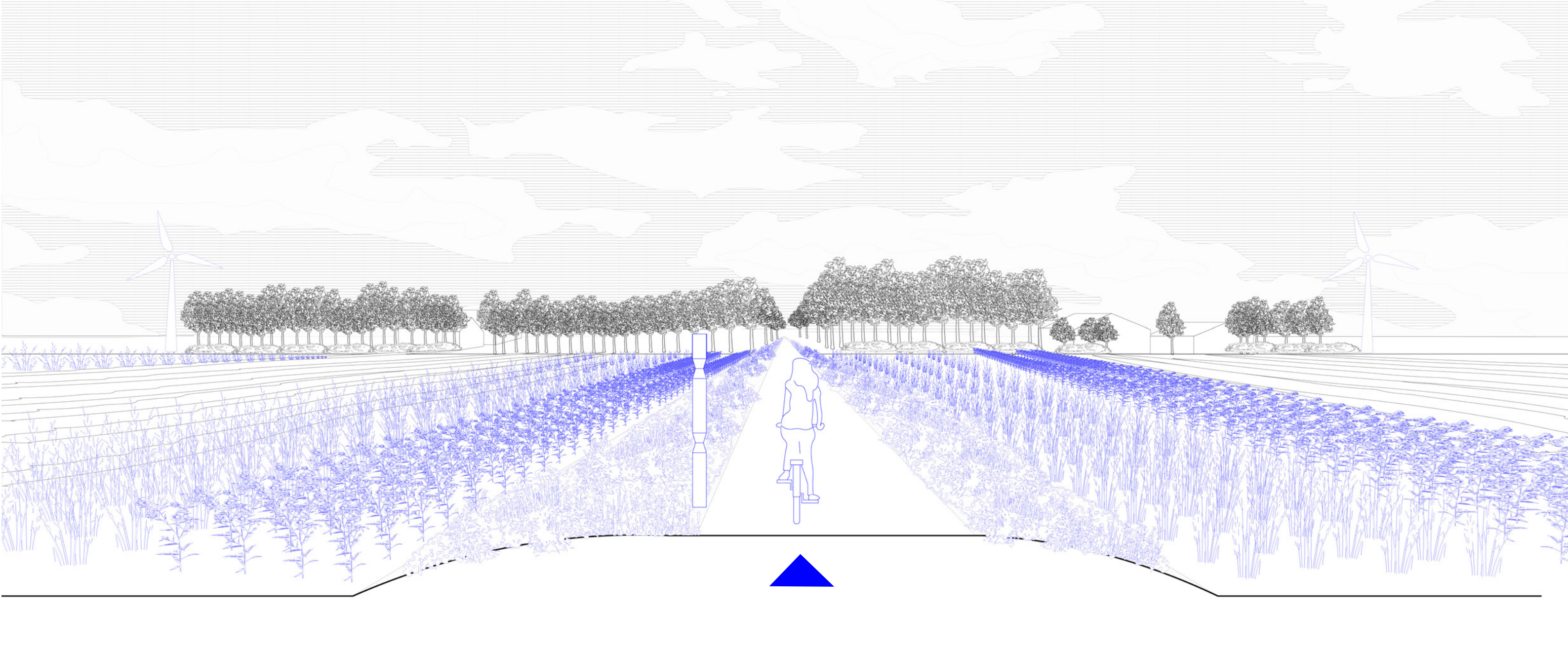
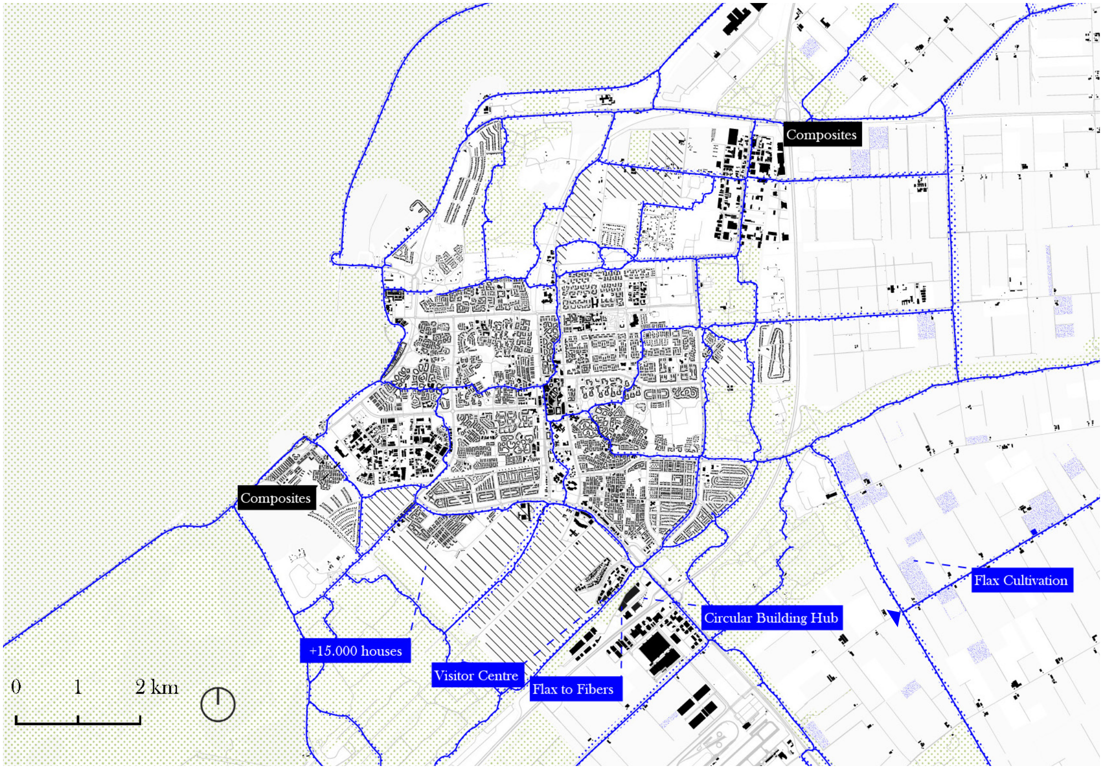


Fig. 107 Transformed cultivation landscape

The drawings on the left page illustrate the existing landscape of Lelystad and the landscape transformation following the implementation of the patterns. In addition to the visible representation of the value chain stages, the drawing showcases innovative, climate-adaptive farming methods, and the expansion and strengthening of the ecological network along a recreational “flax route.” It still has a dominant open and organized character, yet it is slightly more dynamic as the fields move away from monoculture towards a more diverse cultivation plan The beautiful flowering flax fields could attract people to follow the Flax route in june and july. Flax fields fit well in the landscape of flevoland as they do not disturb the widely stretched and open character of the agricultural fields, yet the difersification of crops, using strip cropping, could give the landscape an a bit more dynamic character.



Implementing Patterns

From Plant to Fiber

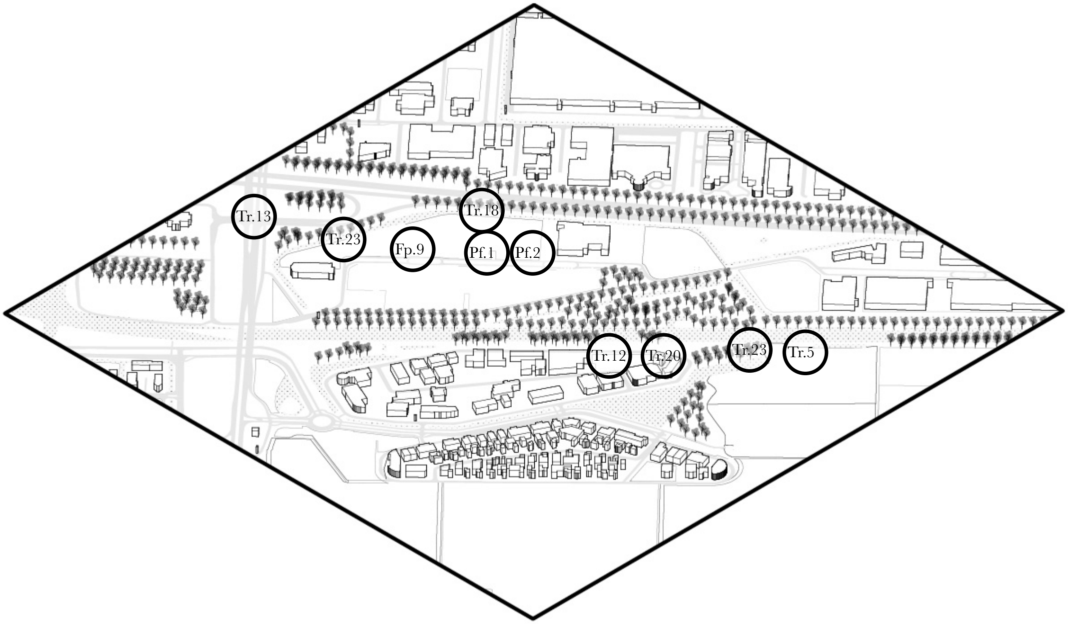
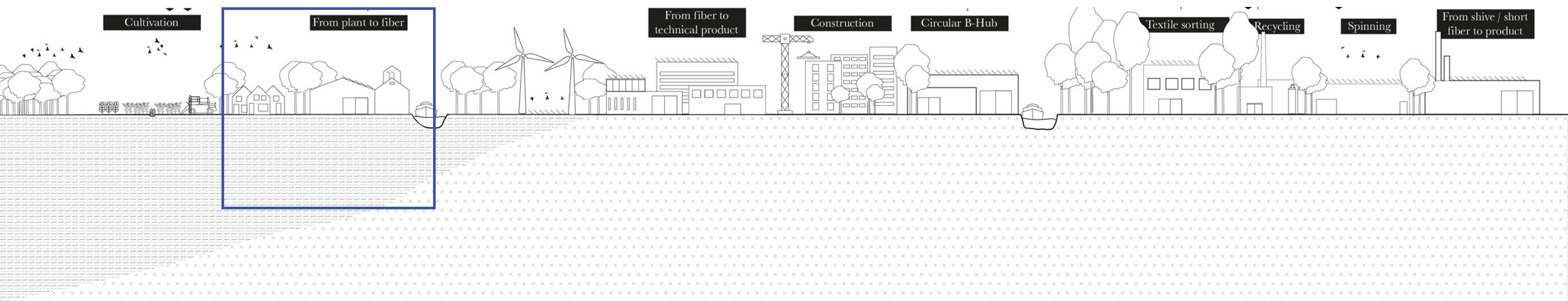


Fig. 108 Isometric current industrial landscape

Tr.18	Generating Green Energy
Tr.13	Proximity to Transport
Pf.1	Storage Space
Tr.5	Green Recreational Network
Tr.12	Visitor Center
Tr.20	Public Facade
Tr.23	Enhancing Biodiversity
Fp.9	Clustering Similar Making
Pf.2	Flax-Hemp Processing



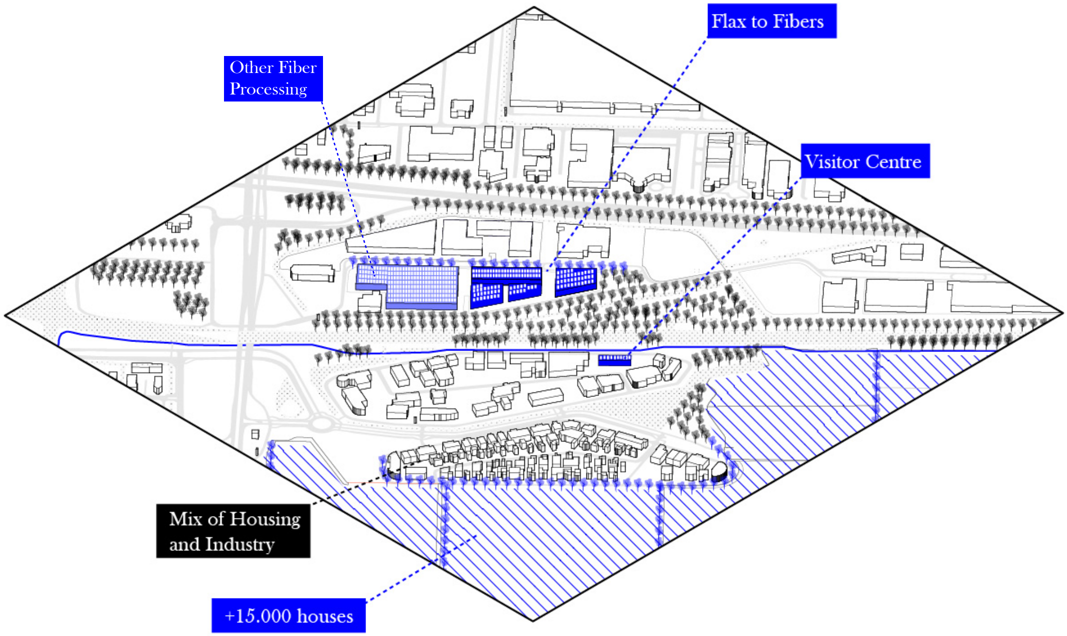
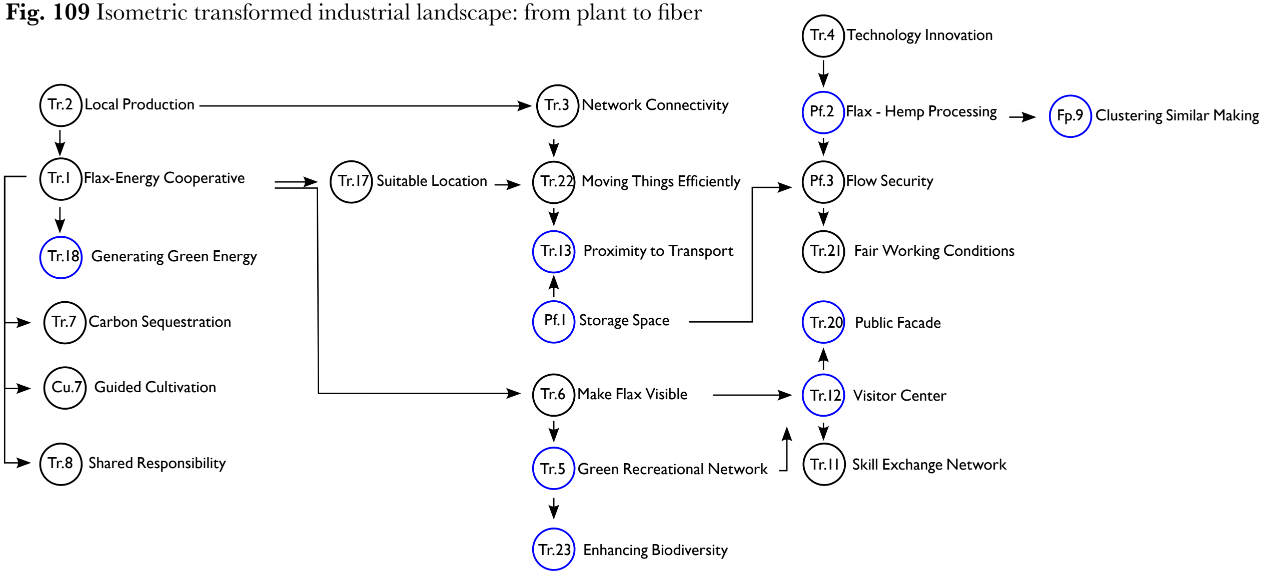


Fig. 109 Isometric transformed industrial landscape: from plant to fiber



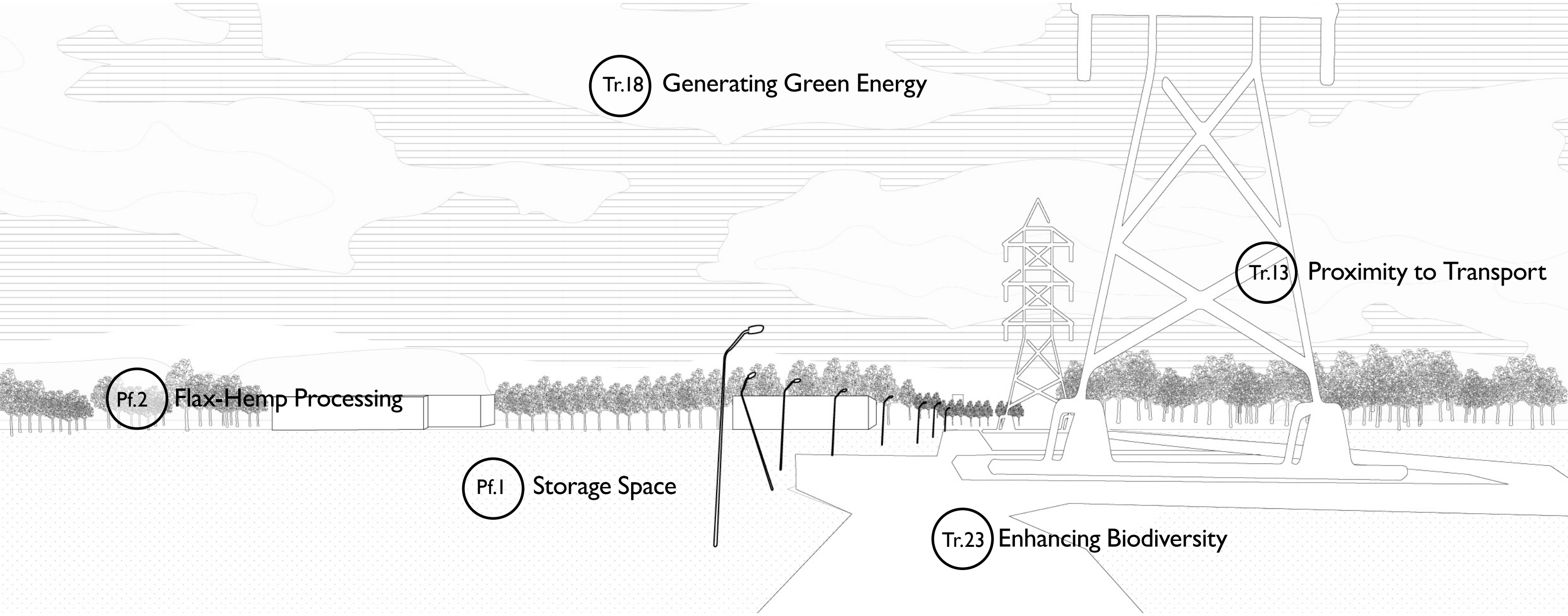


Fig. 110 Current industrial landscape

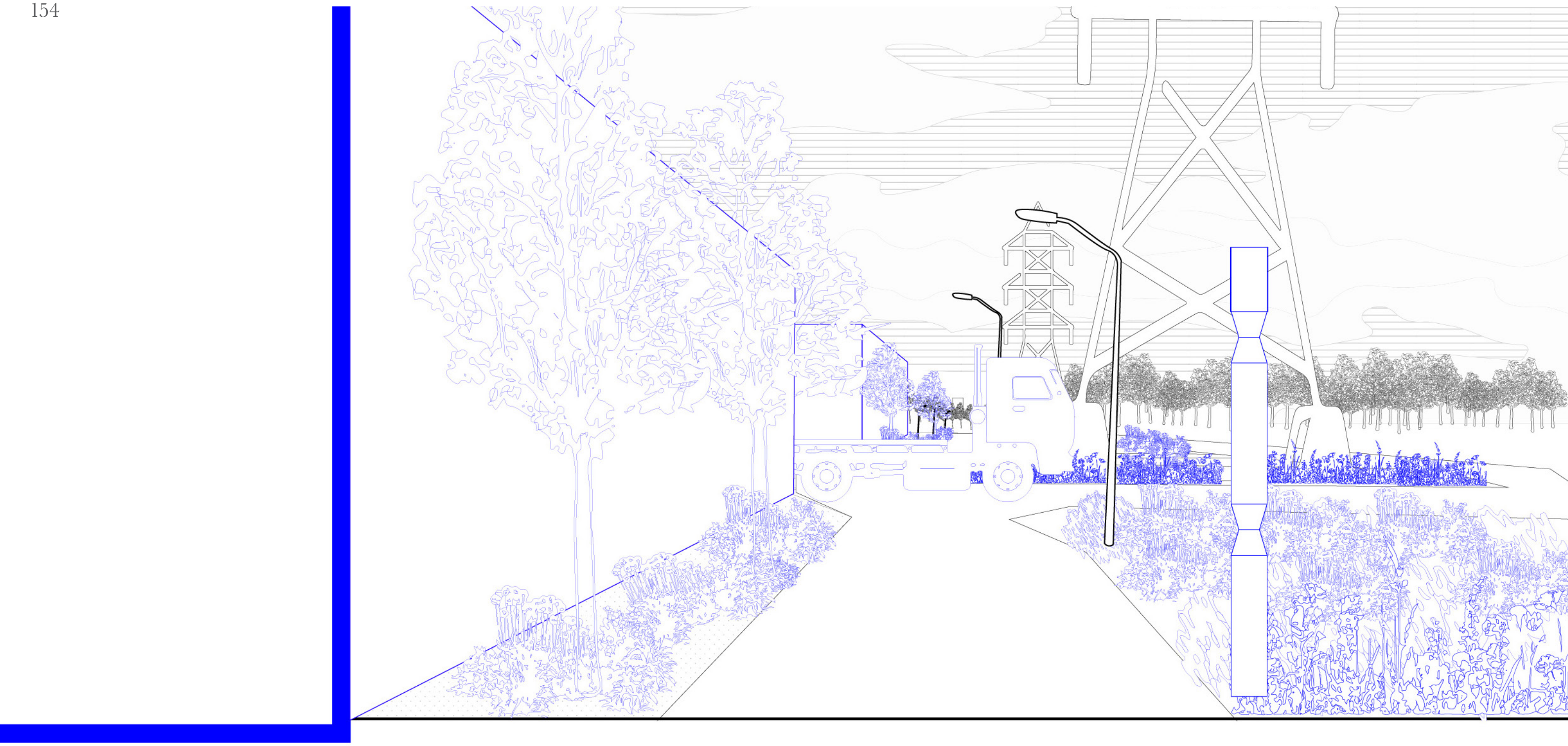


Fig. 111 Transformed industrial landscape with flax processing

The flax processing location is situated in an industrial setting and is focused on efficient logistics. The edges, as well as the grass beneath the electricity poles are transformed into flower rich and biodiverse routes.

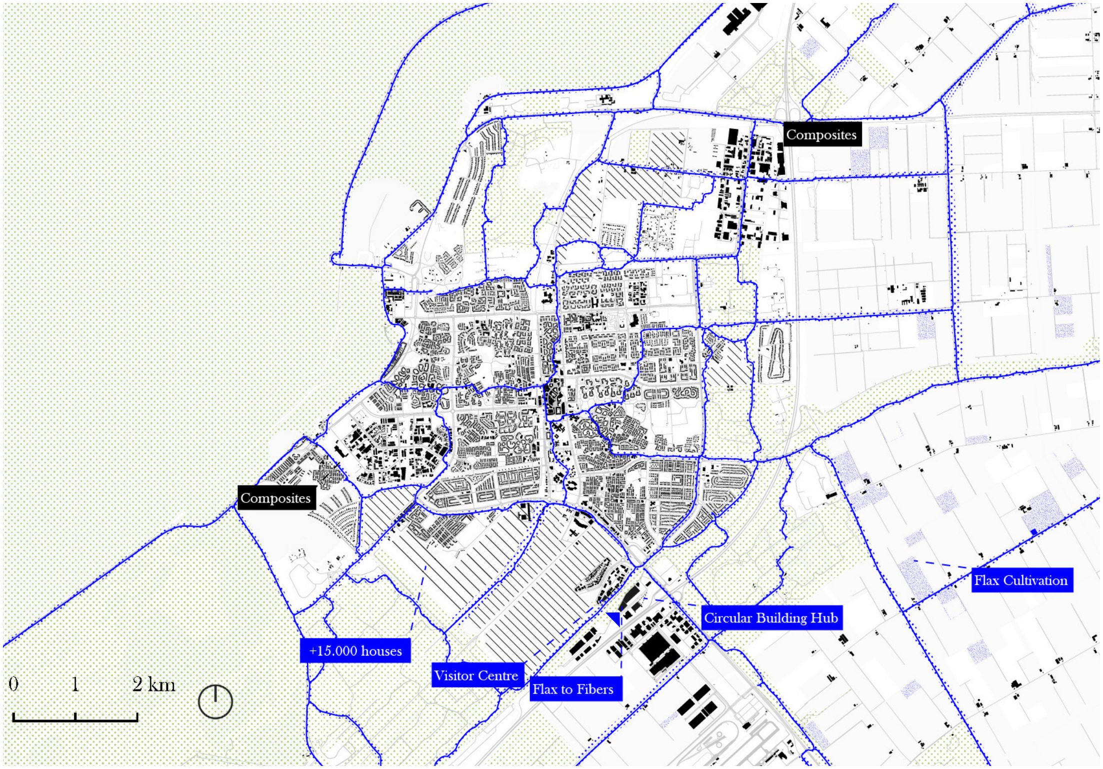


Fig. 112 Current site without flax cafe

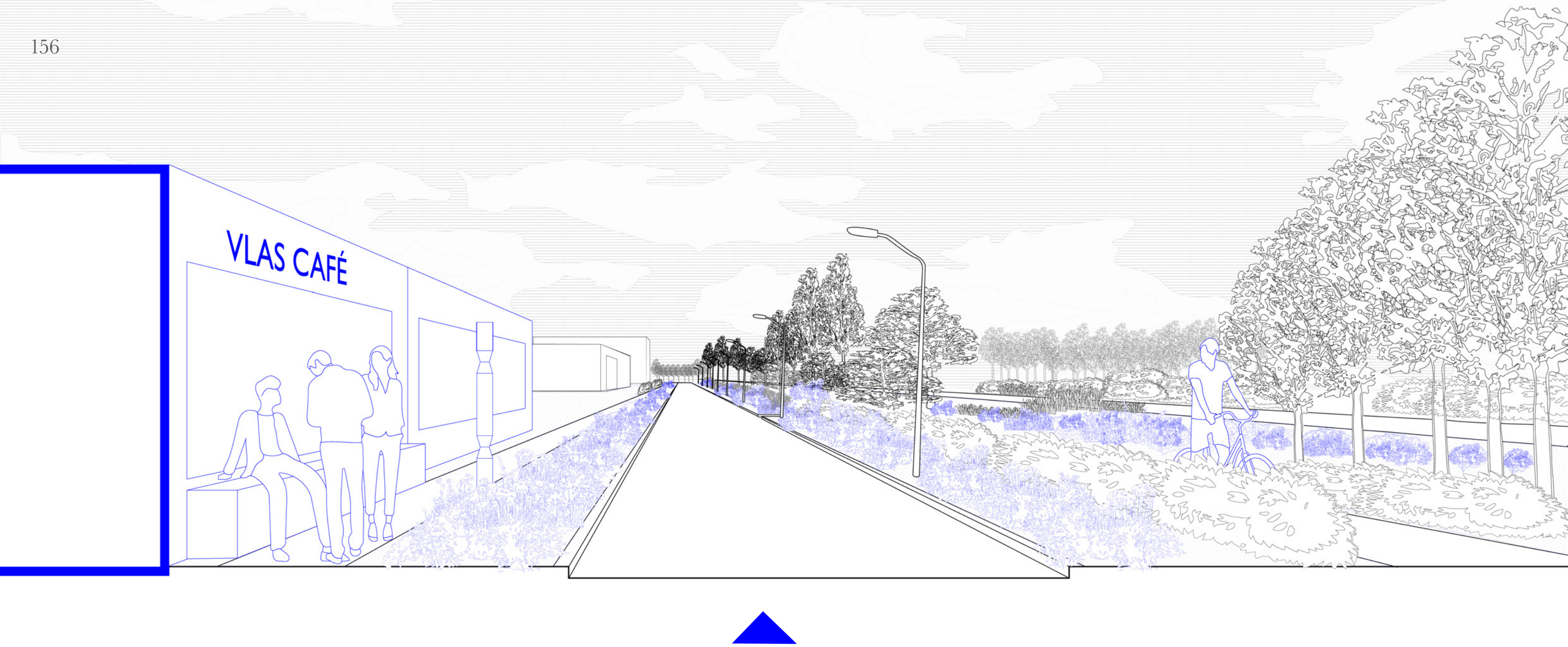
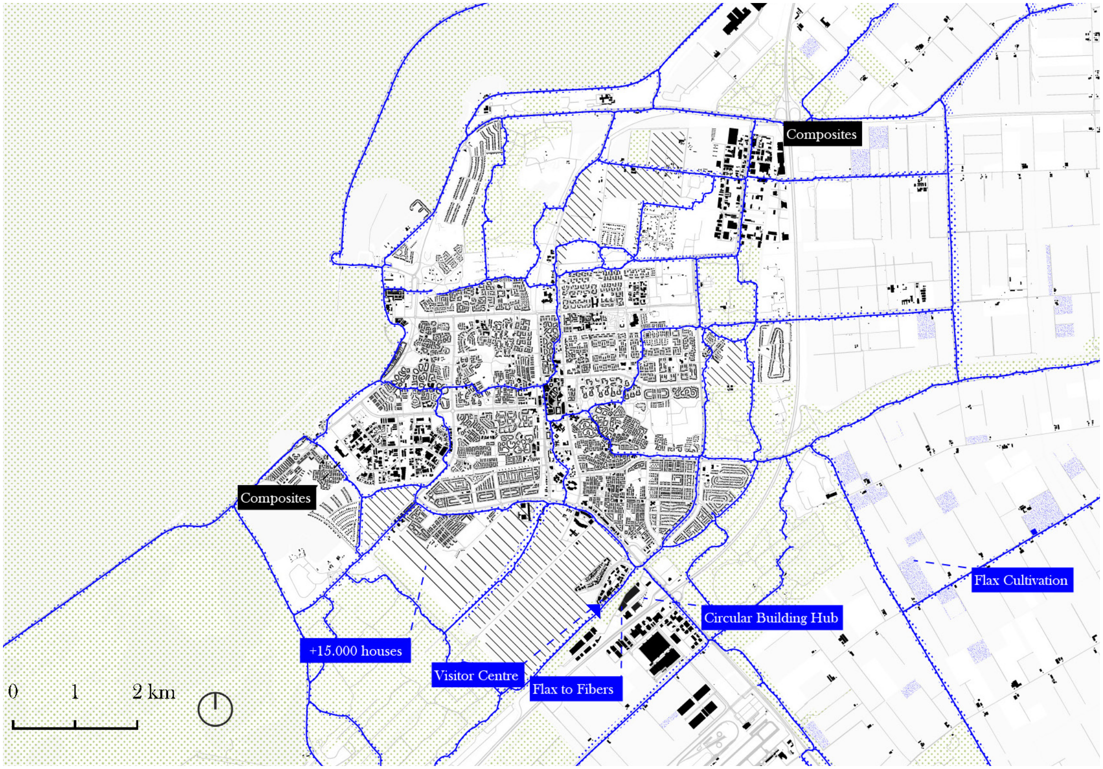


Fig. 113 Transformed site with flax cafe

The Flax Cafe, an important stop along the green flax route, has a public facade and attracts people to come in. On the grass edges, a variety of flowers and plants are planted to improve the biodiversity along the flax route.



Implementing Patterns

From Fiber to Product

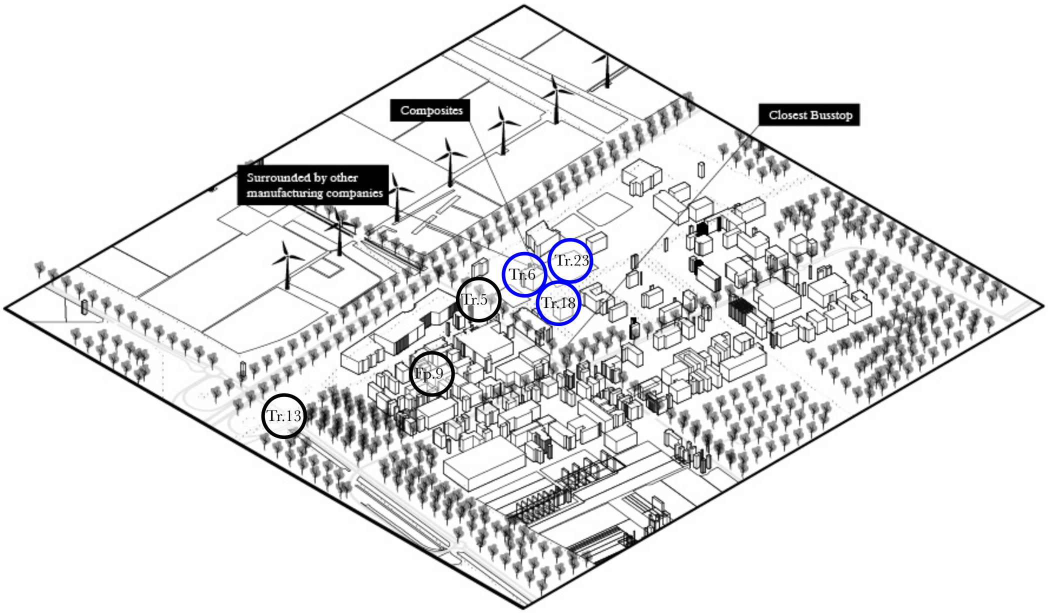


Fig. 114 Isometric current situation: from fiber to product

Tr.18 Generating Green Energy

Tr.13 Proximity to Transport

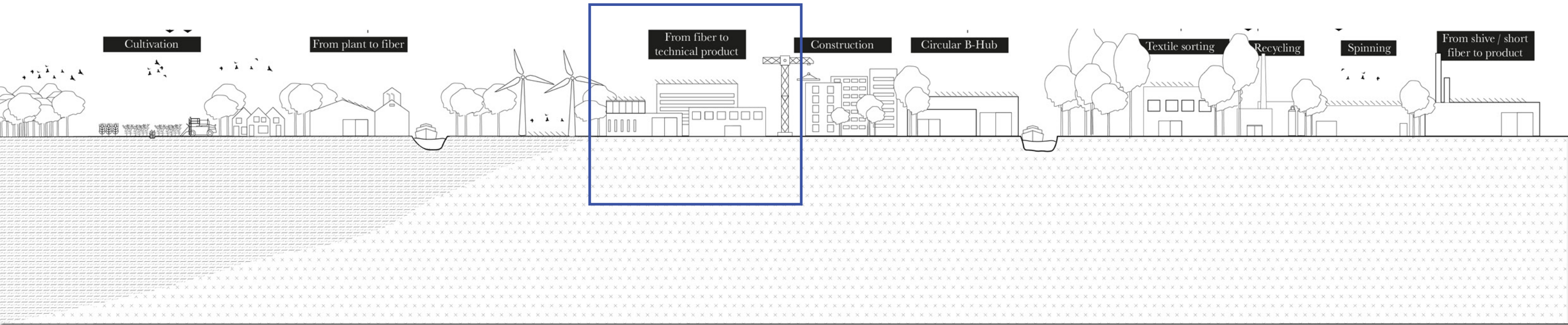
Fp.5 Storage Space

Tr.5 Green Recreational Network

Tr.23 Enhancing Biodiversity

Fp.9 Clustering Similar Making

Tr.6 Make Flax Visible



As the manufacturing of composites was already present in the context, measures only include adopting the manufacturing in the green recreational route, enhancing biodiversity and generating green energy.

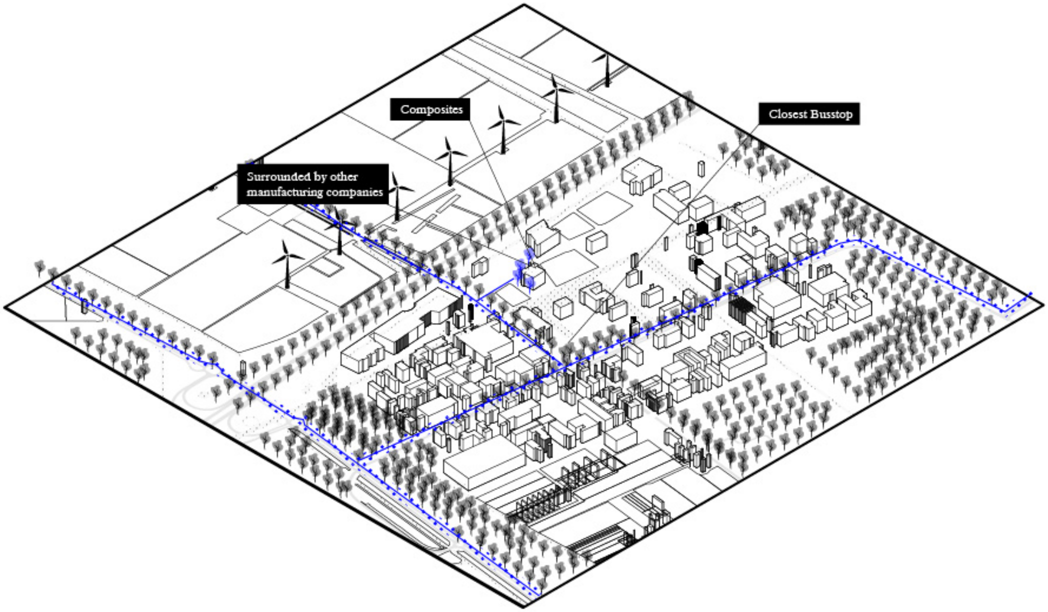
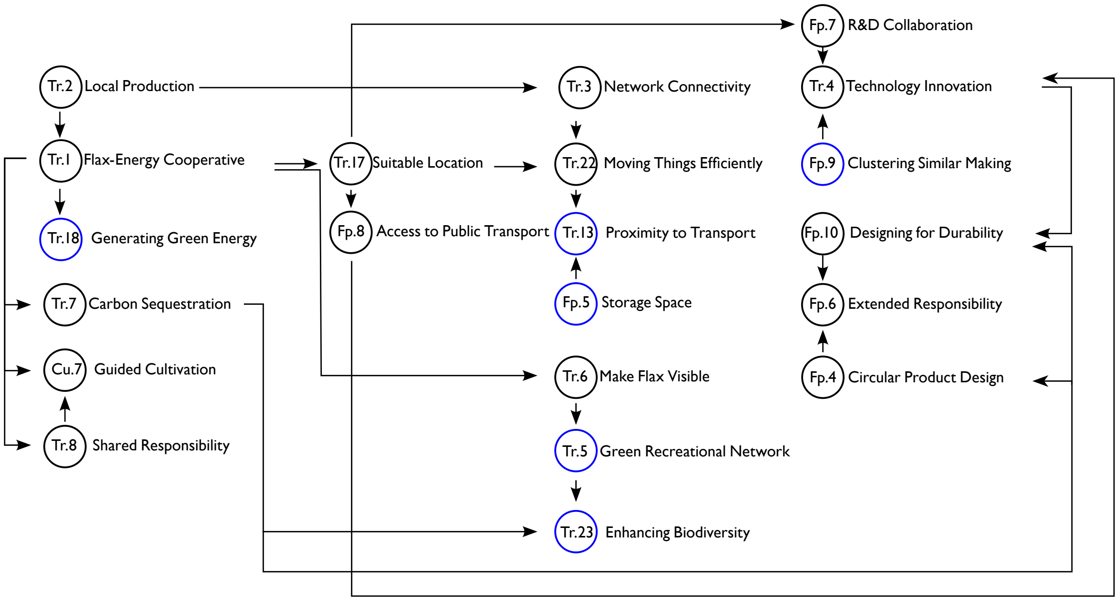


Fig. 115 Isometric transformed situation: from fiber to product



Implementing Patterns

Circular Building Hub

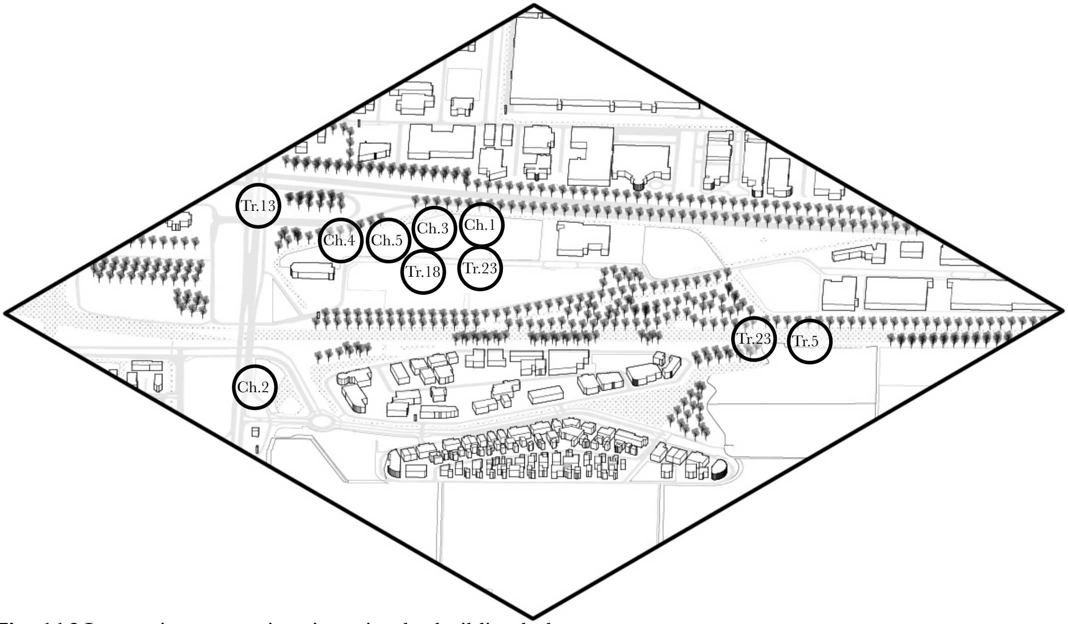
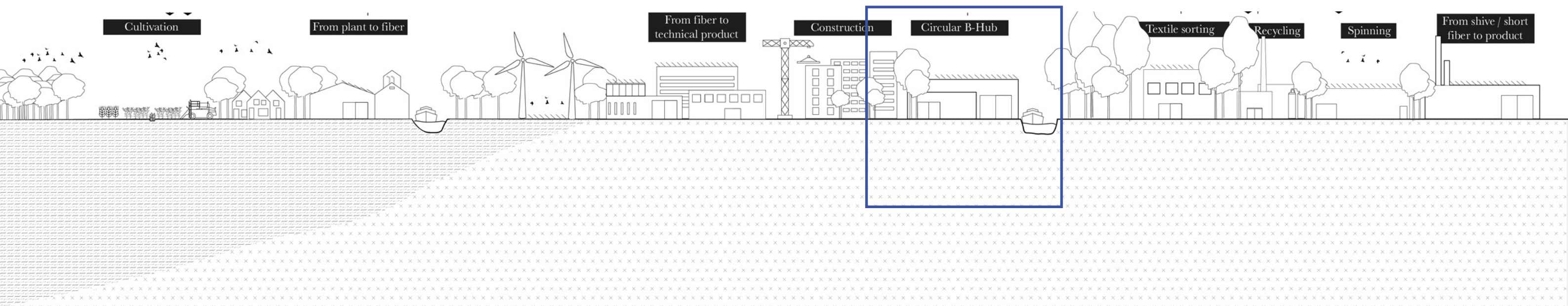


Fig. 116 Isometric current situation: circular building hub

- Tr.18 Generating Green Energy
- Tr.13 Proximity to Transport
- Ch.4 Storage Space
- Tr.5 Green Recreational Network
- Ch.1 Circular Building Hub
- Ch.3 Located on City Edge
- Ch.2 Accessable City Infrastructure
- Ch.5 Room for Expansion
- Tr.23 Enhancing Biodiversity



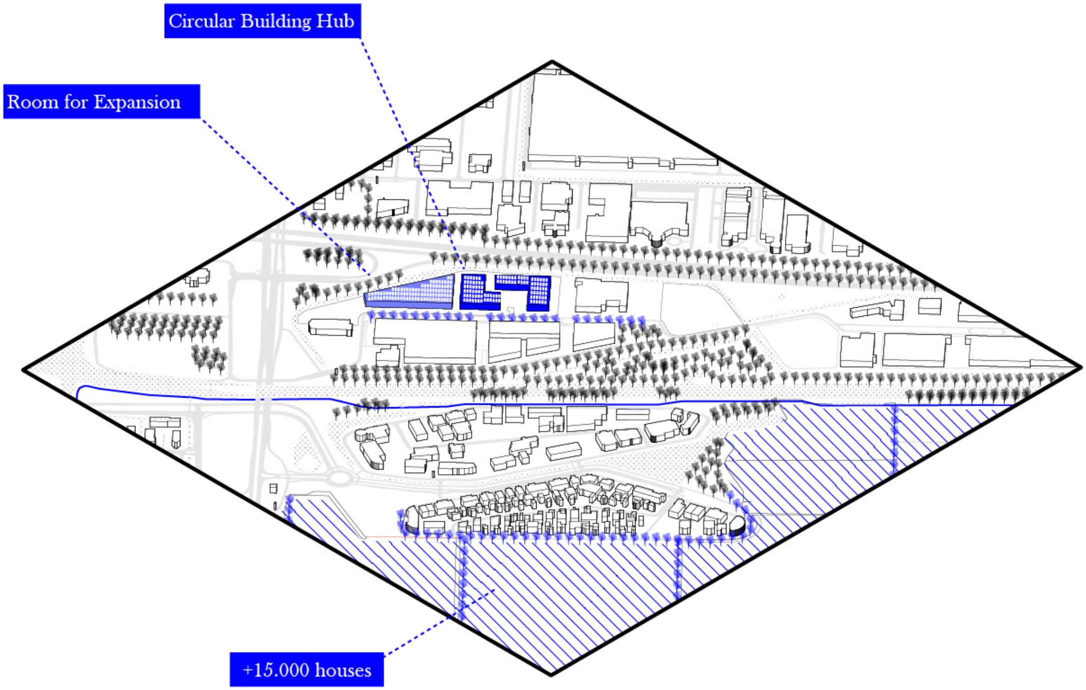


Fig. 117 Isometric transformed situation: circular building hub

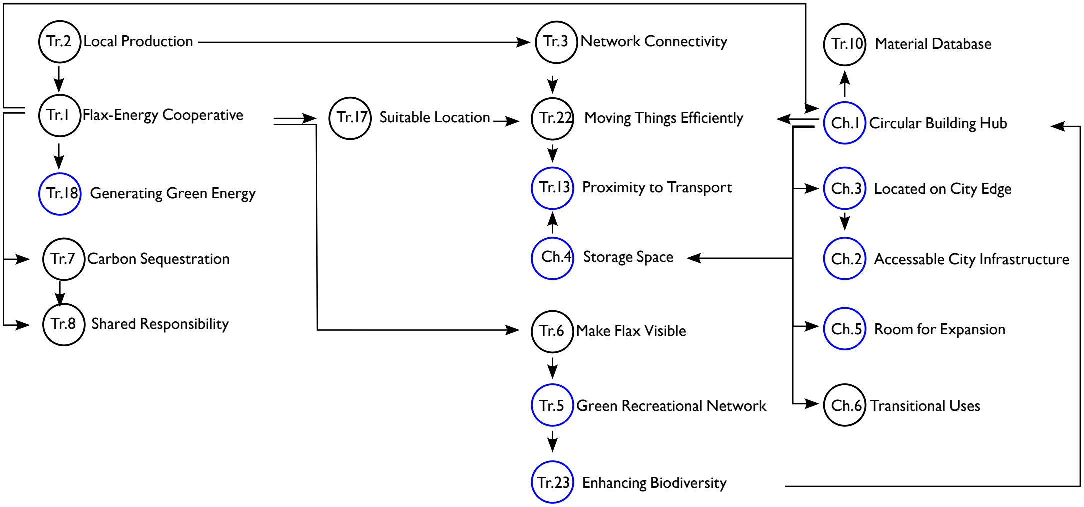
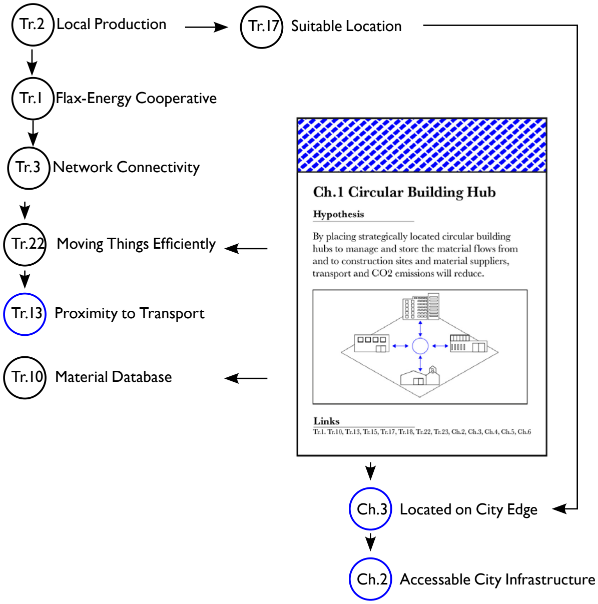


Fig. 118 Infrastructure Connections Circular Building Hub

Infrastructure Connection Circular Building Hub



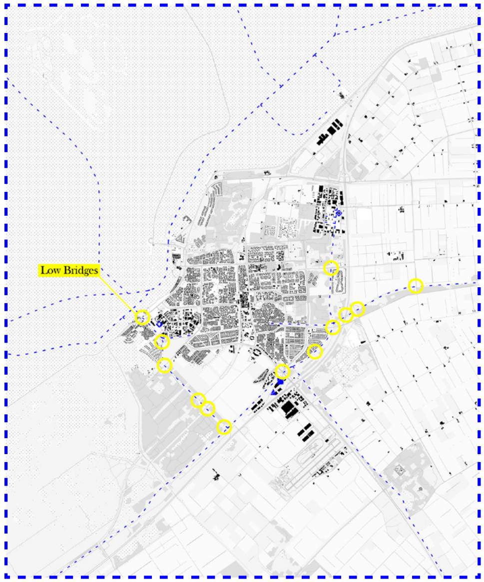


Fig. 119 Low bridges make water transport impossible

The main reason to install circular building hubs (Ch.1), is to effeciently manage and store the material flows from and to construction sites and material suppliers, reducing transport and CO2 emissions (Tr.10)(Tr.22). The preferred mode of transport is via water (Tr.13), and even though the circular building hub is situated along the water, transport via water is not possible because the bridges on the route are too low to allow for transport ships to pass.

The circular building hub is situated next to the A6 (Tr.22) and the new construction area (Ch.3) and has good acces to the city infrastructure (Ch.2)

Implementing Patterns

Construction // Urban

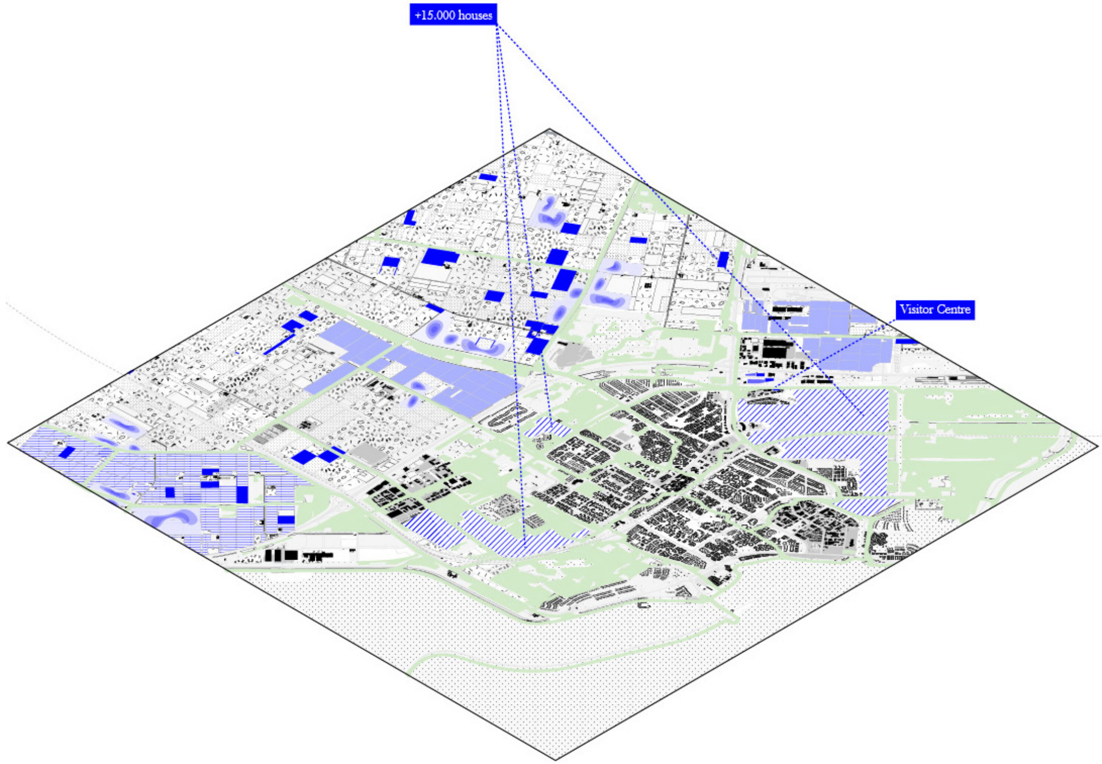
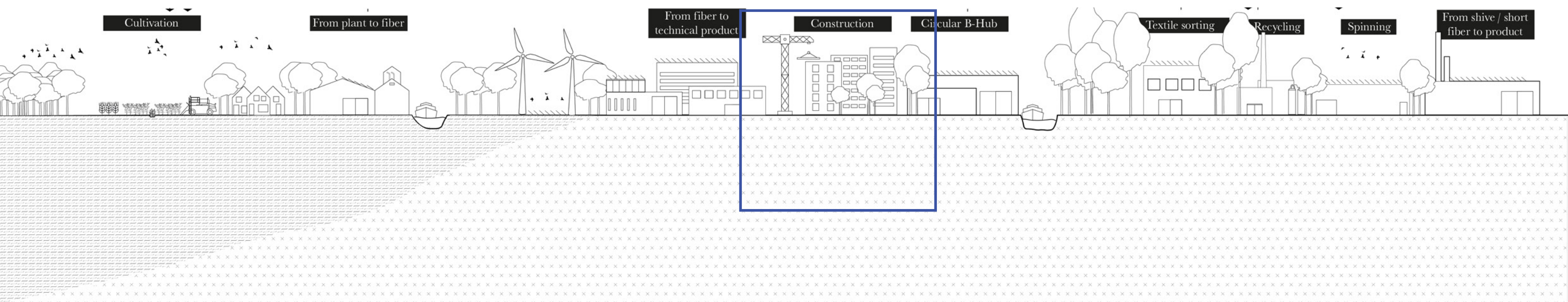


Fig. 120 Transformed landscape Lelystad, highlighting the urban



Whereas the patterns regarding the construction stage of the flax value chain are very much system flows related, this project does not dive deeply into the design of the new neighbourhoods. However, it does touch upon the connection between the industry and the living and sustainable urbanization.

The area inbetween the site on which the circular building hub and flax processing facility can be found and the new construction site is a combination of industry and housing, blurring the boundary between the two functions. Moreover, the industry is shielded by a row of trees, which are part of the ecological main network.This boundary is embraced by making it part of the flax route (Tr.5) and locating a flax visitor center (Tr.12) along the boundary.

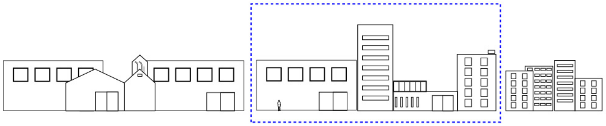


Fig. 121 Blurred boundary between industry and housing

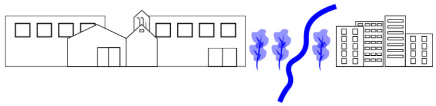


Fig. 122 Ecological boundary between industry and housing

The infrastructure and ecological network present, naturally create boundary a for urban growth. These boundaries should be respected and the rural hinterland should stay productive. To enhance biodiversity (Tr.23), create a nice living environment and making the final product of the flax value chain (the built environment) visible, a green recreational route (Tr.5) also crosses through the new neighbourhood.

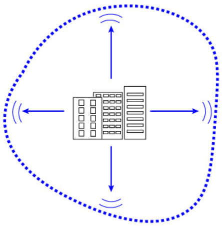


Fig. 123 Limits to urban growth

Fig. 124 Green Recreational Route

Chapter 10:

Evaluation

How can alternative spatial futures be assessed?

Evaluation

This section evaluates the alternative spatial futures that are painted in this thesis. The thesis can be seen in the context of the national spatial strategy (NOVI) as a part of the 'National Program for Biobased Building' (Ministry of the Interior and Kingdom Relations et al., 2023) which aims to establish an objective knowledge base and to create design strategies for sustainable urbanization and restoration of landscapes and rural areas.
In the 'National Program for Biobased Building', several challenges confronting todays society are posed and biobased building is presented to potentially be an integral solution for these challenges. The evaluation is based on the way the design responds to these challenges, which take into account the sustainability of the implementation of a flax based value chain for a cricular biobased building sector:

- Reducing CO2 emissions: Examining how the adoption of flax-based building materials can contribute to mitigating carbon emissions within the construction sector
- Circular Economy: Delving into the potential of a flax-based value chain to foster resource efficiency and minimize waste within the building sector, supporting the transition towards a circular economy
- Nitrogen Reduction: Evaluating how flax cultivation for the building sector can reduce nitrogen pollution and its detrimental impacts on ecosystems
- Biodiversity & Soil and Water Quality: Investigating how the integration of flax value chain can promote biodiversity conservation and enhance soil and water quality, vital for ecosystem health
- Anticipating Waterlogging & Drought: the assessment considers the resilience of flax cultivation in mitigating the impacts of waterlogging and drought, thereby strengthening agricultural sustainability
- Housing Demand: Assessing how the integration of flax-based materials can meet the rapid demand for housing while aligning with sustainability goals
- Spatial Quality: Evaluating how the design connects and coördinates the different challenges while also achieving spatial quality

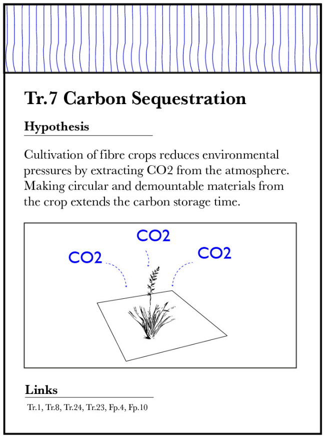
Reducing CO2 emissions

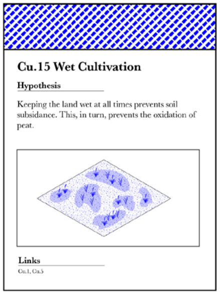
During the cultivation of flax, carbon dioxide is naturally sequestered. When flax is utilized to create durable, demountable, and circular products, it prolongs the period during which carbon dioxide is stored.

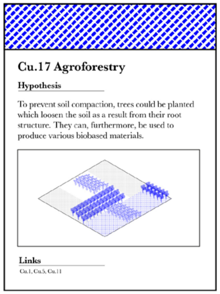
In the first scenario, flax is primarily cultivated for its long fiber to be used in composites. Only residual streams of flax are utilized for insulation material. The remaining of the demand for insulation materials can be answered using other biobased materials, thereby reducing CO2 emissions associated with conventional insulation materials and composites, but flax only being responsible for a small part of the CO2 sequestration in the whole.

The second scenario expands the cultivation area of flax and utilization of flax-based materials by also replacing traditional textiles. This broader adoption has the potential to further decrease CO2 emissions across various sectors, aligning with broader emission reduction objectives. Additionally, with more residual materials available in this scenario, there is a greater potential to use flax to meet the demand for insulation materials, further enhancing its contribution to CO2 reduction efforts.

In implementing the patterns in the Lelystad case, additional measures are implemented to mitigate CO2 emissions. To counteract soil subsidence, which leads to CO2 emissions, the strategy involves creating wet productive landscapes to retain carbon dioxide. Furthermore, in instances of soil compaction, agroforestry is opted for, providing another way to capture CO2.







Circular Economy

For a circular flax value chain, circularity operates on the level of materials and components and buildings as assemblies, but it also operates in space through different scales and through different sectors. In both the scenarios spaces that facilitate circularity are implemented. From flax processing spaces to circular building hubs, connected to a material database, which are installed to facilitate re-use and repair streams amongst others. Both scenarios also emphasize cross-sectoral circularity, using waste streams from the textile industry for the building scetor. Non spatial measures to enhance circularity include extended producer responsibility

Drawing from the theory on circularity and a biobased economy in Chapter 3, this thesis advocates for a more holistic approach to resource management. Recognizing the metabolic interactions between human activities and natural systems, the design takes the social and ecological dimensions into account. It does so by enhancing biodiversity along the value chain, implementing a green recreational route to make the flax value chain visible and strengthen the ecological network, and adapting ways of farming to make it resilient to the changing landscape.

Additionally the idea of a flax-energy cooperative is implemented. Firstly, the cooperative integrates various stages of the flax value chain, promoting efficiency and resource optimization. Secondly, it offers an approach to sustainability that does not view of nature as merely a set of ecosystem services. By fostering collaboration among stakeholders in the flax value chain, the cooperative shifts the focus from solely extracting resources to nurturing a symbiotic relationship with the environment.

Nitrogen Reduction

Flax cultivation can contribute to nitrogen reduction by promoting crop rotation and reducing the need for synthetic fertilizers, and by serving as a more sustainable earning model to livestock farming. However, on plots with a high soil stock of nitrogen and soils with strong nitrogen mineralization, the risk of lodging is too great. These plots are therefore less suitable.

Nitrogen emissions in the construction sector occur at the construction site (NOx), during the production phase in factories (NOx and NH3), and during transportation (mainly NOx). Because biobased building materials are a lot lighter than conventional materials, emissions can be reduced. However, the scenarios do not explicitly incorporate strategies for mitigating nitrogen emissions during the production and processing phases of flax-based materials.

Considering the relatively small scale of flax cultivation compared to traditional agricultural practices, the overall impact of flax on nitrogen reduction may be modest in both scenarios. Nonetheless, when viewed within the context of broader shifts towards biobased building materials and more sustainable agricultural practices, incorporating various crops into the biobased materials sector has the potential to make meaningful strides towards reducing nitrogen emissions and fostering a more sustainable future.

Biodiversity and Soil and Water Quality

Intensive monocultural agriculture practices that use pesticides and other methods to maximize the yield put pressure on biodiversity. The use of nutrients in current agricultural practices also negatively affects the groundwater and surface water quality.

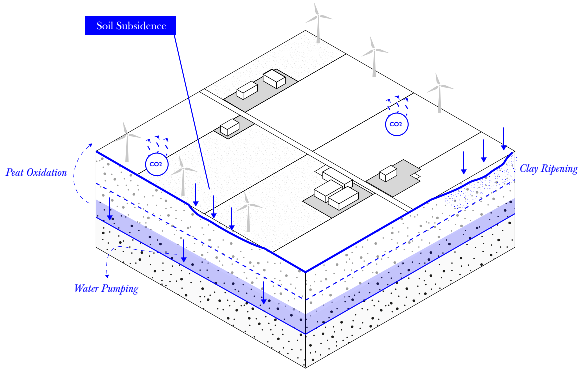
The cultivation of flax in crop rotation with other crops and in a form of stripcropping can enhance biodiversity and it improves the soil structure because of its deep roots.
Compared to crops like potatoes, flax typically requires less chemical crop protection and has a lower risk of polluting soil and water with nutrients, and with smart, eco-friendly cultivation practices, it may even eliminate the need for chemicals entirely. However, when comparing it to hemp, it's worth noting that hemp cultivation often requires no chemical crop protection at all.

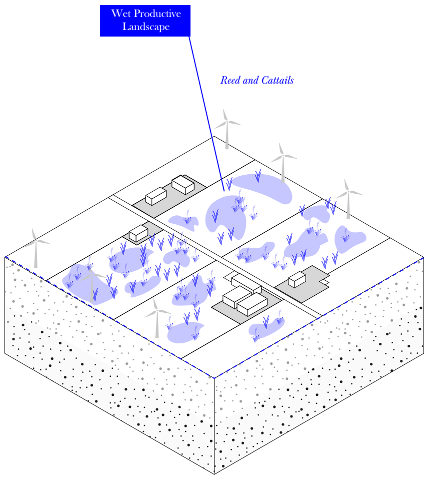
In the case of Lelystad, an additional effort is made to improve biodiversity by combining the cycling network with strengthening the ecological network.

Anticipating Waterlogging & Drought:

Flax cultivation requires good moisture-retaining soil and is preferably grown on clay soil. Flax is hardly irrigated, but it does require water shortly after sowing. In times of drought, extra irrigation may be necessary. Additionally, flax is not very tolerant to heavy rainfall, making the crop not the most resilient to heavy rainfall. However, flax cultivation does enhance the soil structure, leading to better moist retaining properties of the soil.

In the application of Lelystad, responding to waterlogging is taken into account in certain places, by responding to it with a wet productive landscape, not including flax cultivation. Other than that the scenarios do not explicitly address water conservation or drought mitigation strategies





Housing Demand

Both scenarios acknowledge the need for sustainable solutions to address the housing demand. By promoting the use of flax-based materials, they offer alternatives to conventional construction materials, potentially reducing the environmental footprint of housing projects. Flax also has the advantage that it is a rather fast-growing crop.

And in the first scenario the amount of land needed for composites is also not too high, and could easily be integrated in a crop rotation. However, this scenario may face challenges in meeting the ambitious housing demand targets on such short notice due to the significant investment that are required in research, development, and infrastructure to overcome barriers and facilitate widespread adoption.

For the second scenario, flax cultivation is maximized in a sustainable manner, and in this scenario a lot more insulation material (coming from flax) would come free yearly. However, alongside the challenges that the first scenario also faces, installing a local spinning and weaving sector, which requires knowledge, a lot of employment and large investments, will be difficult to realize on short notice.

Spatial Quality

The design is built upon the belief that the integration of a new production landscape should harmonize with the existing landscape features, therefore the context is analyzed. Flevoland has a very organized, open and agricultural character. In the design, the landscape still has a dominant open and organized character, yet it is slightly more dynamic as the fields move away from monoculture towards a more diverse cultivation plan and the landscape is more resilient to changing conditions.

Another design principle that enhances livability and biodiversity, is a recreational flax route through nature and along the value chain. The green corridors make new connections with the existing ecological structure.

Lastly, the design adresses the edges between functions and determines limits to urban growth.

Chapter 11:

Conclusion and Reflection

Conclusion

This chapter concludes the research by answering the research question: '**How could a flax based value chain be spatially facilitated to sustainably contribute to a circular bi-obased building sector?**' To answer this question, first the subquestions will be answered.

1. What are the potential applications of flax and what are the required processes to come to the products?

Flax has always been grown primarily for its long fiber, which is used to make linen for the textile industry, but it has a wide variety of applications. To 'free' the different components of flax, it goes through a process of cultivation, harvesting, rippling, retting, scutching, hackling, spinning and weaving.

These elements can then be used to create a variety of building materials (illustrated in figure 20). The demand for insulation material is the largest. Adressing this demand. secundary streams from the flax value chain, like the shives and short fibers, can be used to make insulation material. However, it would not make sense to expand the cultivation area of flax for insulation applications, since there are multiple other crops, like Miscanthus, Hemp, Grain straw and Reed, that require less space, processing, expertise and machinery and that are less expensive.

Flax shows most potential to be applied in composites, with diverse applications ranging from facade panels to bridge components. Fiber reinforced composites get applied in the constructior sector because of their high strength and stiffnes. Flax bast fiber has an advantage to the other crops because of its strong reinforcing properties.

2. What are the spatial, environmental and socio-economic dimensions of the flax industry and how has it developed over time?

The aim of this question is to understand the context and the industries' evolution to enable informed future decision-making and design.

North Western Europe (Province of Zeeland to Normandy) has a rich history in the flax industry and still plays a significant part in the industry to this day. The evolution of the flax value chain in the Netherlands, is shaped by shifting market demands, technological innovations, and environmental considerations. To analyze this history, the concept of socio-ecological metablism is used to understand the social and ecological implications of implementing a flax value chain, as well as analyzing how the socio-ecological context interacts with the metabolic flax chain in other ways.

Cultivation of flax requires certain soil and climate condtions, in the Netherlands, and the rest of North Western Europe, on clay soil, these conditions are naturally suitable, which explains the concentration of flax in these regions.
The flax industry finds its beginnings as a manual cottage industry meeting local clothing needs and was relatively late with mechanization. The concentration of manual facilities in specific provinces reflected socio-economic responses to seasonal unemployment, engaging local populations in flax cultivation and processing during different seasons.The industry faced challenges, such as water pollution and bad working conditions.
Industrialization eventually led to the establishment of steam-driven flax factories, improving working conditions but also altering the socio-economic landscape of the industry.

Economic factors, like international trade dynamics, influenced the flax industry and made the industry flourish in the second half of the 19th century and the mid of 20th century. However, in the second half of the 20th century, the tide definitively turned against flax. The competition from synthetic fibers grew stronger, and the quality and price of cotton became increasingly attractive to consumers, making linnen an old-fashioned and luxury item.

Today, flax production in the Netherlands represents only a fraction of its historical levels. Two clusters of flax cultivation can be recognized, a larger one in Zeeland and a smaller one in Flevoland. In Zeeland there is also a cluster of companies that take care of the first processing of flax (breaking and scutching). The absence of spinning facilities necessitates exporting scutched flax to countries like China and India for further processing in the textile industry. The production of flax-based building materials also remains limited in the Netherlands.

Conluding, the historical development of the flax industry reveals sensitivity to external market forces and technological advancements. As our society has to transition towards biobased economies, there may be renewed opportunities for the flax industry, particularly if local value chains are established to mitigate the impacts of international trade dynamics. Additionally, the resilience of flax cultivation to climate change effects should be considered in future planning and decision-making processes.

3. What are spatial principles, environmental and socio-economic requirements for a sustainable circular flax supply chain?

The first step to answer this sub-question, is to formulate the future that we are working towards. In November 2023, the Dutch Government published the program 'National Approach to Biobased Building' (Ministry of the Interior and Kingdom Relations et al., 2023), in which concrete intended results for 2030 are given. Looking backwards from this generated desired future, a strategy on how this future can be achieved can be created. This method is also known as backcasting. It involves analysing and experimenting with different ways to achieve this future (Abou Jaoude et al., 2022). There are two potential futures formulated. In the first scenario, resulting in 3891-4357 ha flax/a, flax is primarily grown for composites and only residual streams are used for insulation material.
In the second scenario requiring 25.331-26.081 ha fiber production/a, flax is not only used for the building sector but also to sustainably replace 25% of the textiles with flax or hemp, resulting in more residual streams for insulation in the building sector.

To envision the future flax value chain, a systemic secion is constructed (see figure 57). The systemic section helps to understand the relation between the physical built environment, flows, and socio-ecological factors.

The next step was to perform a suitability analsyis to geographically allocate the different components of the flax value chain in the Netherlands. Analysing land use suitability by formulating decision criteria, informed by the systemic section and literature review, overlaying maps and ranking the suitability of land for a certain land use, helps to optimize the benefits of an area and to ensure sustainable land use. Decision criteria range from restrictive factors, links to infrastructure and to clustering opportunities.

Since urban environments are complex systems, and spatially facilitating a circular flax value chain is a complex task, requiring knowledge from different sectors and technologies and on different scales, implementing a flax value chain cannot simply be reduced to geographically allocating functions to the most suitable land. To achieve circularity, a pattern language can be used as an instrument for interdisciplinary mediation. The patterns are classified as socio-economic, spatial or flow related, or potentially a combination and are organized along the value chain. By aligning patterns with the stages of the flax value chain, it provides a structured and systematic approach to understanding and modifying the system. It also ensures that all critical stages of the value chain are adressed and that interdependencies and connections between the different stages are clear. Eventually, it will also help to translate systemic changes to land-use changes. Socio-economic patterns primarily address the social and economic aspects of the flax value chain system. Flow-related patterns focus on the movement, exchange, and transformation of resources, materials, information, or energy within the flax value chain and limiting environmental impact. Spatial patterns focus on geographical allocation of functions, interventions in the physical built environment and what qualities they bring.

4. How could a circular flax supply chain be sustainably integrated in the territorial context of the Netherlands and how does it influence the landscape and built environment?

To answer this question, a pattern language is used again to create a spatial framework for Lelystad, Flevoland. This approach facilitates the translation of research insights into practical design solutions, serving as a bridge between theory and implementation, as each pattern consists of a hypothesis, theoretical foundation, and practical implications, accompanied by sketches or examples. These patterns are interconnected, forming a cohesive pattern field that describes the relationships between different design interventions.

The formulated patterns were then implemented on the case of Lelystad, Flevoland, which serves an examplary project, to test and showcase how the systemic changes translate to land use changes, how it relates to the existing context and to see what spatial quality they can bring. In the process of designing for an actual case and implementing the patterns, new patterns get developed again and previously made patterns get re-evaluated.
In this step, the dynamic nature of the design process became evident, where iteratation and adaptation are essential for achieving sustainable and contextually appropriate outcomes.

Overall, the suitability analysis and the set of patterns serve as a basis to sustainably integrate a circular flax supply chain into the territorial context of the Netherlands, while leaving room for flexibility. But it requires an understanding of local spatial and socio-economic characteristics for each step of the value chain to land sustainably in the context of the Netherlands.

5. How can alternative spatial futures be assessed?

This section evaluates the alternative spatial futures that are painted in this thesis by examining their implications on:

• Reducing CO2 emissions: Both scenarios demonstrate the potential of flax-based materials to contribute to mitigating carbon emissions within the construction sector. By utilizing flax in durable, demountable, and circular products, carbon dioxide sequestration is prolonged. While the first scenario primarily focuses on using flax for composites, the second scenario expands its application to textiles, further enhancing its contribution to CO2 reduction efforts across sectors.

• Circular Economy: The scenarios highlight cross-sectoral circularity, utilizing waste from the textile industry for building. The thesis advocates for holistic resource management, integrating social and ecological dimensions. A flax-energy cooperative integrates various stages of the value chain, fostering collaboration among stakeholders and shifting the focus towards a symbiotic relationship with the environment.

• Nitrogen Reduction: Flax cultivation has the potential to contribute to nitrogen reduction through crop rotation and reduced dependency on synthetic fertilizers, however, the impact may be modest due to the relatively small scale of cultivation. Moreover, strategies to mitigate nitrogen emissions during the production and processing phases of flax-based materials are not explicitly addressed in the scenarios. Nonetheless, integrating flax cultivation into biobased materials sectors presents opportunities for reducing nitrogen emissions and promoting sustainable agricultural practices, but this should be done alongside other measures to reduce nitrogen emissions.

• Biodiversity & Soil and Water Quality: Flax cultivation, particularly when practiced in crop rotation and strip-cropping systems, can enhance biodiversity and improve soil structure with its deep roots. Compared to intensive monocultural practices, flax cultivation requires fewer chemical inputs, reducing the risk of soil and water pollution.

• Anticipating Waterlogging & Drought: Flax cultivation requires good soil moisture retention and is susceptible to heavy rainfall and drought, but enhances soil structure, improving moisture retention properties. While the scenarios do not explicitly address water conservation or drought mitigation, incorporating flax cultivation into certain landscapes, alongside measures like wet productive landscapes, can contribute to water management strategies.

• Housing Demand: Both scenarios recognize the need for sustainable housing solutions and offer alternatives to conventional construction materials. Flax's fast-growing nature and potential for widespread adoption present opportunities to reduce the environmental footprint of housing projects. However, challenges such as research, development, and infrastructure investments may impede the realization of ambitious housing demand targets.

• Spatial Quality: The design prioritizes the seamless integration of new production landscapes with the existing context. Flevoland's open and organized character serves as the foundation, with the design introducing subtle changes to enhance resilience and diversity. The inclusion of a recreational flax route fosters biodiversity and livability by connecting green corridors with the existing ecological network. Lastly, the design carefully manages the interface between different functions, setting boundaries for urban expansion while ensuring landscape cohesion.

Concluding, flax shows great potential to sustainably contribute to a circular biobased building sector, by replacing synthetic fibers in fiber reinforced composites and utilizing residual streams for insulation alongside with promoting more sustainable agricultural practices. However, it should be noted, that in this case flax only plays a small role in the broader material demand needed to transition to a circular biobased sector. Other crops should be considered to meet the large insulation demand as well as other building materials. Flax could also play a role in transitioning to a more sustainable textile sector, but in the Netherlands, when sustainably growing flax, flax can only account for a replacement share of approximately 5% of the current demand. For achieving larger replacement shares, other crops, like hemp should be considered.
Considering the effects of climate change and challenges the different landscapes in the Netherlands face, other crops and materials must also be considered to meet the demands of the transition to a circular biobased building sector and to respond to climate change effects. This uncertainty in which crops might play a role in the biobased economy and what technical innovations may come, requires for adaptable urban design and further research on the spatial implications of a circular biobased economy given different raw materials.

The answers to the subquestions lead to the main question:

'How could a flax based value chain be spatially facilitated to sustainably contribute to a circular biobased building sector?'

Drawing upon theory on the circular and biobased economy this thesis emphasizes that a truly circular economy requires more than just utilizing biobased materials and closing material loops; it necessitates systemic changes that address broader socio-economic and environmental concerns. Therefore, this thesis uses the lens of socio-ecological metabolism to understand the social and ecological implications of implementing a flax value chain, as well as analysing how the socio-ecological context interacts with the metabolic flax chain in other ways.

Furthermore, the analysis highlights the need for a thorough understanding of the spatial, environmental, and socio-economic dimensions of the flax industry and its potential applications. From cultivation practices to construction site, each aspect of the value chain must be carefully considered to ensure sustainability and circularity throughout the value chain. The thesis outlines the potential applications of flax and the required processes to transform it into various products. While flax holds promise across multiple applications, it is particularly well-suited for use in composites due to its strong reinforcing properties and only residual streams should be used for insulation material.

By formulating concrete scenarios and backcasting from desired outcomes, the groundwork for informed decision-making and strategic planning is laid out.
In order to to optimize the benefits of an area, to ensure sustainable land use and to suitably allocate functions of the value chain on certain geographical locations, a suitability analysis is performed. This analysis exists of formulating decision criteria, informed by the systemic section and literature review, overlaying maps and ranking the suitability of land for a certain land use. This results in a national map of the Netherlands pinpointing the different locations of steps of the flax value chain for each scenario.

To translate the insights of the research into practical solutions, the use of pattern language is proposed. By breaking down complexity into manageable blocks of knowledge, pattern language enables interdisciplinary mediation and facilitates the translation of research insights into tangible design interventions. By aligning patterns with different stages of the value chain and considering socio-economic, spatial, and flow-related factors, a structured approach to system modification and land-use optimization is developed.

Moreover, this research extends beyond theoretical frameworks to practical implementation, as demonstrated by the application of pattern languages in the case of Lelystad, Flevoland. Through iterative design processes and the development of a spatial framework, the thesis has showcased how systemic changes can sustainably translate into tangible land-use outcomes that bring spatial quality.

In conclusion, while flax holds significant potential to contribute to a circular biobased building sector, its role is just a piece of the broader puzzle. Other crops and materials must also be considered to meet the demands of the transition. Uncertainties regarding future crop utilization and technological innovations necessitate adaptable urban design strategies to ensure resilience and sustainability in the evolving biobased economy.

Reflection

Relation between graduation topic and master track.
My graduation topic, "Weaving Flax Fiber into the Territorial Fabric: A Spatial Design Exploration on the Potential Role of Flax in a Circular Biobased Building Sector," has a clear link with both the studio topic and the broader framework of my master's program. Within the studio "Metropolitan Ecologies of Places (MEP)," the focus lies at the intersection of Environmental Technology & Design, Landscape Architecture, and Spatial Planning and Strategy, which aligns very well with my spatial exploration of the sustainable integration of the flax value chain within the built environment.

As the project is a part of the Urbanism track, I approach my research through a combination of urban design, landscape architecture, spatial planning, and engineering. Aligning with the goals of the Urbanism Track, I integrate social, cultural, economic and political perspectives with the natural and man-made conditions of the site, by exploring how a flax based value chain could be spatially facilitated to sustainably contribute to a biobased building sector.

The overall master's program, MSc Architecture, Urbanism and Building Sciences, serves as the foundation of my project. My project has a very interdisciplinary nature, addressing contemporary challenges in architecture, building sciences, and urban planning, by integrating flax based materials into the built environment. By situating my research within this master's program, and working in a multi-disciplinary way, I aim to contribute to creating integrated solutions for a more sustainable built environment.

Societal, professional and scientific relevance
My graduation topic, "Weaving Flax Fiber into the Territorial Fabric: A Spatial Design Exploration on the Potential Role of Flax in a Circular Biobased Building Sector," holds significant relevance for the larger societal, professional and scientific framework.
The reliance on conventional materials and practices in the construction and agricultural sector has negatively impacted the environment and Dutch society. Because, issues associated with these dependencies include the nitrogen and carbon dioxide crisis, degrading soil & water quality, loss of biodiversity, the need to become less reliant on depleting fossil fuels, the need to build 1 million houses before 2030, potentially an extra 1 million before 2050, combined with the need to refurbish 7 million existing houses. We cannot keep building the way we do now. The transition to a circular biobased building sector holds the potential to mitigate these environmental and societal challenges related to the current construction and agricultural practices. Moreover, the research aligns with global initiatives and commitments toward sustainable development, as outlined in agendas like the United Nations Sustainable

Development Goals.

Relation to NOVI and NOVEX

The thesis can be seen in the context of the national spatial strategy (NOVI) as a part of the 'National Program for Biobased Building' which aims to establish an objective knowledge base and to create design strategies for sustainable urbanization and restoration of landscapes and rural areas. Alongside the National Program for Biobased Building, which was recently published, €200 million was reserved to build up several biobased building value chains before 2030.

In this program, several challenges confronting todays society are posed and biobased building is presented to potentially be an integral solution for these challenges. My research integrates socio-ecological metabolism principles and utilizes systemic design and pattern language methods to come to a strategy to spatially facilitate and modify a circular flax based value chain. With this research I contribute to the body of knowledge in the professional and scientific field on the spatial implications of a circular biobased building sector.

I compared the spatial outcome of my design with the urbanization concept of Flevoland 2050 (Provincie Flevoland et al., 2023) and is a part of the NOVEX programme. The urbanization concept is still rather abstract, but touches upon themes like green corridors, soil and water quality and states the ambition to develop education programmes for circular and biobased building and to grow fiber crops for the building sector. Since there is no detailed plans drawn yet, there is no friction with my proposal. The proposal would actually fit very well within the the urbanization concept.

Reflection on methodology and relation between research and design

My research was very much focused on creating a deep understanding of the flax value chain and what role it could play in the transition to a biobased building sector. By understanding the intricacies of each stage in the value chain, I was able to identify which were the missing links in a future flax value chain. This narrow focus on developing a deep understanding of the flax value chain could also be considered a limitation. While this detailed understanding informed my design decisions and recommendations, it may have restricted the scope of my analysis to some extent. A more general approach might have involved considering a broader range of factors beyond the intricacies of the flax value chain alone and would have resulted in a better understanding of what the complete picture and spatial impact of a circular biobased building sector would be. This became most evident when I was implementing the patterns on the case of Lelystad. Even though I had divided the patterns in socio-economic, flow and spatial categories, the spatial categories did not focus enough on what spatial qualities the flax value chain could bring, making it difficult to make a desirable design. Here the iterative process of developing patterns came in, as this ‘bump on the road’ led me back to the drawing table, altering the descriptions of the patterns to make them more spatial and to the development of new patterns. Each pattern shows whether it was derived from theory, analysis or design.

As identified when looking into the theory on circular and biobased economy, a circular and biobased value chain, does not necessarily make for a sustainable value chain. The application of the socio-ecological metabolism theory and systemic design encouraged a holistic and systems-oriented approach to my design/recommendations. Instead of focusing solely on individual components of the value chain, the broader socio-economic and environmental context was considered, identifying interconnected relationships that influence the entire system. An example of this is that when we are looking into the agricultural transition to grow crops for biobased builing, we should not replace one monoculture for another, depleting soil nutrients and lacking biodiversity.

The suitability analysis conducted to determine the optimal allocation of different components within the flax value chain across the Netherlands was pointed out to be a bit arbitrary by my first mentor. While the resulting maps for each stage of the value chain provide a detailed overview of industrial site suitability, it’s important to acknowledge that alternative point systems, decision criteria, or input layers could have been employed, potentially yielding different outcomes.

Although the resulting maps serve as valuable guiding tools, it’s essential to recognize that they represent one possible configuration among many. To address this inherent variability, I made an effort to maintain transparency throughout the analysis process, providing readers with the necessary information to form their own informed judgments.

Besides the challenges I faced when developing the pattern lanuage, creating a pattern language with patterns related to flows, socio-economic factors, and space, which was organized along the value chain, enabled me to make targeted recommendations at each stage of the value chain and also to understand how each recommendation links to others, also at different stages in the value chain. The pattern language also helped me to translate the theory into design.

Implementing the pattern language on the case of Lelystad, Flevoland, which serves an exemplary project, was very useful to test and showcase how the systemic changes translate to land use changes, how it relates to the existing context and to see what spatial quality they can bring. In the process of designing for an actual case and implementing the patterns, new patterns got developed again and previously made patterns get re-evaluated. In this step, the dynamic nature of the design process became evident, where iteratation between research and design, and adaptation are essential for achieving sustainable and contextually appropriate outcomes.

Chosen lense

While I extensively focused on understanding the systemic dynamics of the flax value chain and how it could be spatially integrated into the built environment, there was perhaps less emphasis on considering how these changes might impact the experiential aspect of the landscape.

In other words, while I delved into the technical and logistical aspects of spatial facilitation and system optimization, there was less emphasis on how these changes might be perceived and experienced by individuals within the landscape, including local residents, farmers, manufacturers, and so on. How might these various stakeholders perceive and respond to changes in the landscape resulting from the integration of the flax value chain? Or what qualities do they perceive as valuable?

Another question that arised during this year: what if I had chosen a different crop? What if I had chosen to focus on hemp instead of flax? Hemp requires similar processing steps and shows potential in similar applications as flax, yet is grown in different regions of the Netherlands. A similar approach could have been adopted, although some alterations would have to be made for it to fit the requirements and characeristics of hemp. A large part of the infrastructure could still be the same, only the cultivation would happen on the sandy soils in the Eastern parts of the Netherlands. I expect that it is possible to cultivate hemp on a larger scale than flax, as the sandy soils are faced with less challenges compared to the clay soils.

In order to be resilient and flexible in which crops we will use for the biobased built environment, I think it is wise to explore all the options and to plan for flexibility and adaptability.

Transferability

Reflecting on transferability prompts consideration of how these findings and methodologies could be applied or adapted to different contexts or regions in or beyond the Netherlands or for a different crop.

Firstly, the systemic approach adopted, which involved analyzing the spatial, environmental, and socio-economic dimensions of the flax industry, is transferable to other geographic locations where flax cultivation or similar biobased industries exist or are being considered. By understanding the historical evolution, current status, and potential future trajectories of the industry, stakeholders in other regions can gain valuable insights into the opportunities and challenges of integrating flax or other crops into their local economies.

Secondly, the use of backcasting and scenario planning methodologies can be applied in various contexts to envision and strategize for sustainable futures. While the scenarios in this thesis were tailored to the specific goals and targets of the Dutch government's biobased building program and the research by Wageningen University & Research, similar approaches could be employed in other regions with their own unique policy frameworks and sustainability objectives, in the case that this information is there. If this is not the case I would advice to adopt a maximization method, researching how much of the crop could maximum be cultivated sustainably, to paint a picture of what is a potential future. By engaging stakeholders in the co-creation of future scenarios, decision-makers can develop more robust strategies for transitioning to circular and biobased economies.

Additionally, the suitability analysis and pattern language approach offer transferable methods for optimizing land use and spatial planning in diverse landscapes. While the criteria and patterns may need to be adjusted to account for local conditions and priorities, or for the requirements of the specific crop, the underlying principles of the organization of the pattern language and systematic design can be applied across different contexts to support the sustainable integration of biobased value chains.

Conluding, while the core methodologies and principles are transferable, careful consideration and adaptation are necessary to ensure the applicability and effectiveness of this approach in new contexts, as the transferability of my findings can be influenced by factors such as cultural norms, regulatory frameworks, and resource availability in different regions.

Recommendations for further research

Based on the research conducted and the findings presented, several recommendations for further research can be proposed:

- Exploration of other crops: While this thesis primarily focuses on the spatial facilitation of a flax-based value chain, further research could investigate the integration of multiple crops within the biobased building sector. Comparing the spatial requirements, environmental impacts, and economic viability of different crops could provide valuable insights into optimizing land use and resource allocation.
- Social and Economic Dynamics: While this thesis touches upon some socio-economic

dimensions, further research could explore the social and economic impacts of transitioning to a circular biobased building sector. Understanding how the implementation of the flax value chain affects local communities, what jobs become redundant, job creation, and economic development is crucial for ensuring just outcomes.

- Technological Innovations: Investigating technological innovations and process optimization techniques within the flax value chain could enhance efficiency and sustainability. Research focusing on advancements in cultivation practices, processing methods, and material engineering could unlock new opportunities for improving the sustainability of the process and performance of flax-based products.

Personal Reflection

I would like to conclude with a personal reflection on this graduation year. Looking back on my learning process. Delving into a topic and material that were relatively unfamiliar to me initially, I have had the privilege of expanding my knowledge and expertise in ways that have been very enriching. The process of immersing myself in this subject has been immensely rewarding, allowing me to not only think of concepts theoretically, but also to engage with them on a practical level. Growing and holding the material myself.

In today's world, there often exists a gap between theory and practice, with disconnects between policymakers, academics, designers and practitioners. Recognizing this, I felt a strong need to get a thorough understanding of the system and material I was working with in real-world contexts.

Additionally, I gained new insights on the role and importance of space in a circular and biobased economy. But also on how this dimension is currently very underrepresented in research. This made the research a bit more in difficult in some ways, yet also showed the importance of contributing to this knowledge base.

Fig. 125 m2 flax on campus

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