100 000 BIOBASED TOP-UPS

QUICKEST ROUTE TO PARIS PROOF HOUSING?

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ABSTRACT

In the light of climate change and environmental challenges such as a nitrogen crisis, a decreasing biodiversity and waterlogging, the Dutch government is trying to build 900 000 homes by 2030 while aiming for a reduction of 55% of CO_2 in the construction industry. Biobased topping-up of existing tenement flats is proposed as a solution to tackle several issues. A literature review revealed that a top-up structure has the ability to limit the Global Warming Potential (GWP) of housing. From a set of seven biobased resources, wood, hemp, flax, straw, miscanthus, cattail and seaweed, it was concluded that the current Dutch stock is not sufficient to construct all 100 000 required top-ups with locally sourced biobased materials. Scaling up to a sufficient amount of resources by 2030 requires the right allocation of material over the Dutch landscape, and for the region of Zuid-Holland the right allocation over a peat region, a clay region and a sand region. This is necessary because this cultivation can help break the nitrogen impasse and boost the biodiversity. Furthermore, most resources do not compete with food production. A design for a top-up could be constructed with materials that were sourced within 50km reach. The comparison of GWPs of different variations on the design for the top-up showed that the variations with biobased insulation do not always perform better as an additional layer of fire-proofing had to be added to the construction. Biobased materials do however have the capacity to store biogenic carbon which should be taken into account. Knowing this, the Dutch government and the province of Zuid-Holland should try to construct as many top-ups with locally sourced biobased materials as possible, since it is the quickest way to Paris-proof housing.

Key words: Top-up, biobased materials, global warming potential, embodied emissions, Paris Proof

CONTENT

GLOSSARY

BE	Biobased economy
CE	Circular economy
DGBC	Dutch Green Building Council
ECI	Environmental Cost Indicator
EOL	End-of-life
EPD	Environmental product declaration
GHG	Greenhouse Gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life-cycle assessment
MTP	Mass timber product
RvO	Rijksdienst voor Ondernemend Nederland

RESEARCH DEFENITIION

1. INTRODUCTION

1.1 Problem statement

Human-caused carbon dioxide (CO2) emissions have led to measurable global climate warming, with temperatures rising by 1.18°C since the late 19th century. The International Panel on Climate Change (IPCC) suggests the most effective strategy to limit warming to 1.5°C by 2100 involves a 45% reduction in human greenhouse gas (GHG) emissions by 2030 and achieving net-zero emissions by 2050 (Pörtner et al., 2022). The Dutch government is targeting to be net-zero by 2050, and for a 60% reduction of GHG in 2030, compared to 1990 (Rijksoverheid, 2021). The construction sector has to contribute to this goal as well since it has a significant share of GHG emissions. In The Netherlands, the construction sector is responsible for 8% of the national CO2 emissions (Dutch Green Building Council & Metabolic, 2023). Biobased materials have the potential to drastically reduce these emissions, since the production of biobased materials is less CO2-intensive than fossil-based products, while at the same time biobased materials store certain amounts of CO2 (in the form of carbon).

The construction sector also accounts for vast resource consumptions. It is estimated that the Dutch building industry is responsible for roughly 50% of the total national use of resources (Ministerie van Infrastructuur en Waterstaat, 2023). The national government therefore aims to be fully circular by 2050 and has set the ambitious goal of using 50% less abiotic resources (minerals, metals and fossil fuels) by 2030. Biobased materials appear to be a hopeful alternative, since these resources are regenerative. It is estimated that the primary use of resources could be reduced by 11% by using biobased materials (Copper8, et al. 2023).

Besides global warming, the Netherlands is facing several other environmental challenges on a national scale of which the nitrogen crisis is the most pressing one. To protect Dutch nature, especially around Natura2000 reserves, agricultural land, which accounts for a significant amount of nitrogen emissions (Adviescollege Stikstofproblematiek, 2020), should be utilized in a different way, so that a reduction of 80% by 2030 could be realized. Growing fibre crops instead of livestock farming is seen as the most promising means to accomplish the needed transition, since fibre cultivation uses less fertilizer and livestock exhaust large amounts of nitrogen.

2030 also marks the date for yet another very ambitious goal, which is to have built 900 000 homes to tackle the housing crisis (Rijksoverheid, 2022) while the available space to actually build these houses becomes more and more limited. The Dutch government recognizes the great potential of topping-up existing tenement flats and has set the realistic goal of 100 000 top-ups by 2030 (Stec groep, 2023). Biobased materials again offer alternatives to the business as usual, because the materials are in general lightweight and construction is faster (Van Der Steen & Rotmans, 2022).

Following on the stated goals and the proposed transitions, the question arises whether it is possible to start scaling up the cultivation biobased materials on vacant agricultural land, as part of the agricultural transition, to be able to fully supply in the need of construction material for the needed 100 000 top-ups. This will be the central question in this paper.

1.2 Research questions

To research this central theme, a **main research question** was formulated:

- *How can locally sourced biobased building materials be used in constructing top-ups in The Netherlands?*

In order to answer the main research question, the following **sub questions** were formulated:

- *Why should the 100 000 needed top-ups be built with biobased materials?*
- *What kind of biobased building materials can be sourced in The Netherlands?*
- *Can the production of biobased building materials be scaled-up to contribute to the construction of the 100 000 needed top-ups?*
- *Does using locally sourced biobased building materials reduce the embodied emissions compared to the conventional material choices?*

Along with desk research, a research-through-design will be conducted following the following **design question**:

- How can locally sourced biobased materials help inform the design for the top-up Smits vastgoedzorg?

1.3 Hypothesis

The hypothesis for this research consists of two parts. On the hand is the believe that the required 100 000 top-up that should be built by 2030, could be constructed with biobased material that are sourced in The Netherlands. This will be researched by exploring the current available stock of biobased materials in the chapter **resources** followed by a proposed strategy to **scale-up** the current cultivation and production of these materials. The second part of the hypothesis is that by constructing these top-ups with locally sourced biobased materials, the embodied emissions will decrease. To prove this, several **designs** are compared on their global warming potential (GWP), to see which designs performs best.

1.4 Objective

There are several objectives to be named in this research.

First of all to create a complete overview of the pros and cons of applying biobased building materials in top-ups in the Netherlands.

The second objective would be to create a status quo on the current quantities of the production of biobased materials in the Netherlands, to which a strategy is formulated to scale-up this production. This strategy contains an analysis of the landscape.

Thirdly a critical standpoint is created on the measuring of the environmental impact of locally sourced biobased materials. LCAs extensively provide data on many environmental impact categories. However, about the interpretation of this data a lot of debate is going on. The background of this debate will be explained, after which a critical standpoint could be taken.

And finally to assess several designs on the GWP, through which the design for the top-up by Smits Vastgoedzorg could be further informed.

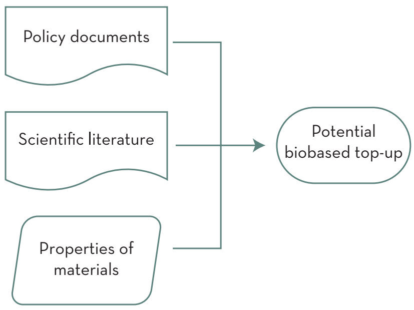
2. METHOD

This research will follow a certain methodology to be able to provide answers to the given research question. First of all, this paper is divided into two main parts. The first part is the literature review, in which the research questions will be answered. To do so a review of scientific literature, market reports, and policy documents (mostly initiated by governmental organizations), was performed. In the second part, the case study, the learned lessons from the literature review will be applied in a case study which in this case an actual design for a top-up by Smits Vastgoedzorg.

In the following chapter, the methodology and the needed data was provided for each chapter of this paper.

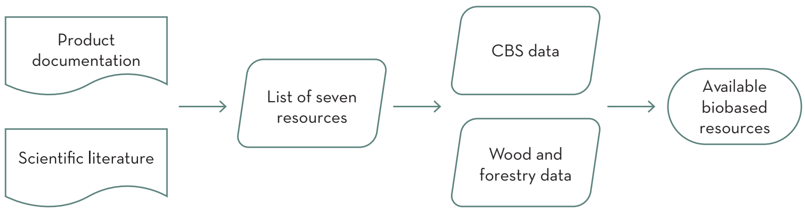
The potential

The first chapter describes the potential of biobased topping-up and will in fact answer three questions, '*why top-up*', '*why biobased*', and '*why biobased top-up*'. The potential of topping up was described by looking at the current policies on this topic, which mostly describe the potential as well. The benefits of using biobased materials for these top-ups are mainly described in scientific literature and market reports which were thus consulted.



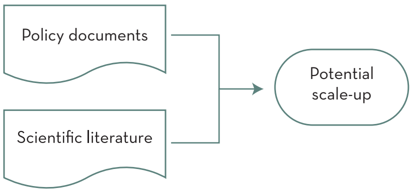
The resources

For the next research question, '*what kind of biobased materials can be sourced in The Netherlands*', a selection of seven promising biobased materials in the Netherlands was created. This list arose from scientific literature and market reports, since in most of these documents there is already a proposed list of materials. It was simply a matter of checking whether these materials are currently sourced in the Netherlands. To quantify the current stock of fibre crops data from the CBS was consulted. Only when the CBS was incomplete or ambiguous, other resources were consulted. The production and processing of round wood is described in the Kerngegevens bos en hout.



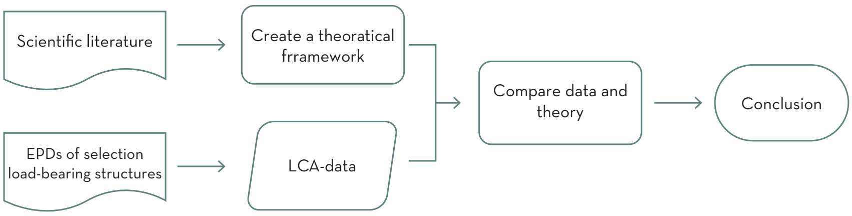
The scale-up

To answer the third research question, '*can the production of biobased building materials be scaled-up to contribute to the construction of the 100 000 needed top-ups*', policy documents on current strategies and scientific resources on the Dutch landscape were used. The national government has released a document which describes the current strategy for scaling up the production and use of biobased materials nationally. The potential of the actual landscape in the region of Zuid-Holland, and of the seven biobased resources is described in scientific reports of mainly Wageningen University.



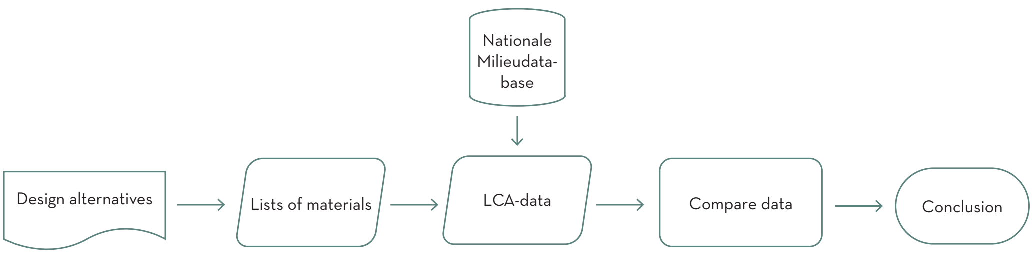
The benefit

The fourth research question will be researched by a literature review combined with a data-analysis. A comprehensive literature study will create a theoretical framework on the environmental impact of biobased materials after which available data on the global warming potential (GWP) of three conventional and five biobased load-bearing structures was examined. With this data it could be checked whether using locally sourced biobased materials actually reduces the embodied emissions compared to conventional material choices.



The design

The final research question, '*how can locally sourced biobased materials help inform the design for the top-up Smits vastgoedzorg*', will be answered by research for design and research by design. A brief look at the current design was taken, after which a scenario for 2023 and a scenario for 2030 will be created. For the scenario of 2023, the student will actively take part in the design process at Smits Vastgoedzorg and help create several alternatives for flooring, walls and the roof and evaluate these alternatives on the environmental impact. For the scenario of 2030 the newly found resources, allocated in the region of Zuid-Holland, will be applied in a visual overview of the design.



3. A CIRCULAR CONTEXT

This paper draws on existing theories on the circular economy (CE), the biobased economy (BE) and life cycle assessment (LCA). Before being able to start with the literature review, it is essential to understand these basic principles.

3.1 Understanding the circular economy (CE)

3.1.1 Basic principles

The concept of a circular economy, initiated by the Ellen MacArthur foundation, represents a shift from the traditional 'take-make-dispose' linear model, which relies heavily on finite resources and energy, to a circular model. Efficiency alone, in terms of reducing resource and energy consumption will simply not be enough. Instead, the circular economy aims to create a system that is restorative, renewable, and minimizes waste. This new perspective is based on systems and cycles. Materials are firstly categorized in biological and technical nutrients. Biological nutrients are designed to re-enter the biosphere and build natural capital, where technical nutrients are designed to circulate without entering the biosphere. This principle of a biological and a technical cycle is summarized in the 'butterfly diagram' (The Ellen MacArthur Foundation, 2013).

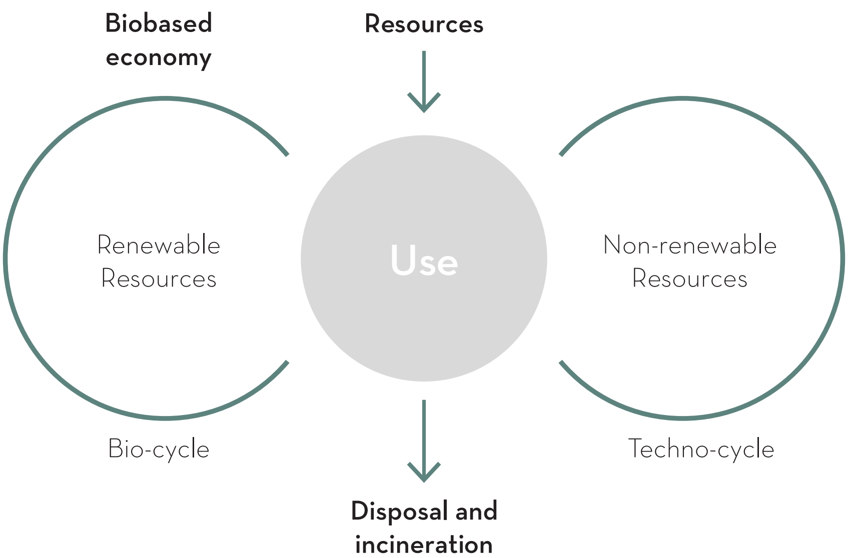


Fig. 3.1 Adaption of the butterfly diagram (The Ellen MacArthur Foundation, 2013)

The Ellen MacArthur foundation also provide several leading but simple principles on which the circular economy is based.

Design out waste

The first principle is 'design out waste'. In a circular economy there is no such thing as waste. Technical materials are designed in a way that they can cycle back into the technical sphere, and biological materials are designed in a way that they can cycle back into the biological sphere.

Build resilience through diversity

The second principle is 'build resilience through diversity'. The general idea about this principle is that diverse systems are resilient systems. Natural systems rely heavily on diversity whereas the industrial revolution on the other hand heavily relies on uniformity and efficiency. These uniform systems are in general more vulnerable.

Rely on energy from renewable sources

Next comes 'rely on energy from renewable sources'. In a circular economy there still needs to be production and manufacturing. It is a necessity in this system that all energy used should be from renewable resources.

Think in 'systems'

The fourth principle is 'think in systems'. Solutions should be found by systems thinking. This involves understanding how parts interact in a larger system and sometimes accepting that, just like in nature, these systems are very complex and the outcomes might be very unpredictable.

Waste is food

And finally 'waste is food'. For the bio-cycle 'waste is food' could be understood quite literally. Used products will be cycled back and used as food for new cultivation. In the techno-cycle this could happen when products are, for example, upcycled.

3.1.2 The R-ladder

An important tool to reach circularity is the R-ladder (The Ellen MacArthur Foundation, 2013). The R-ladder establishes a hierarchy of principles for sustainable use of materials and energy, with the ultimate goal of a circular economy. The principles are: Refuse and Rethink; Reduce; Reuse; Repair, Refurbish, Remanufacture, and Repurpose; Recycle; Recover. They are organized by their impact, with the first principle having the greatest positive impact and the last principle being the least desirable. However, all six principles are better than a linear process where residues are dumped at the end of their lifespan.

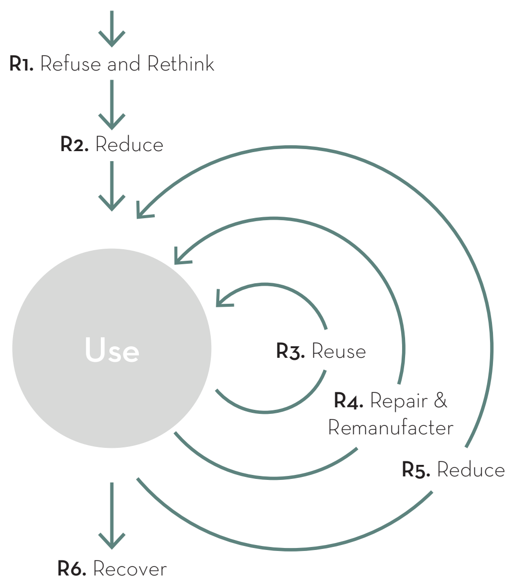


Fig. 3.1 Adaption of the butterfly r-ladder (The Ellen MacArthur Foundation, 2013)

For the sake of clarity and practicality the six Rs could also be grouped into three categories which are:

Reduce (R1 and R2)
Reducing consumption and production and making products smarter and more efficient.

Reuse (R3 and R4)
Extending the lifespan of products and components.

Recycle (R5 and R6)

3.1.3 **Building layers**
In the light of circularity, it should be clear which cycles in buildings are defined. The idea of buildings as entire entities is contradicted by the theory of the 'shearing layers', stated by Stewart Brand (1994). Brand decomposes buildings into six layers which all have different life-spans. By recognizing these layers with different life spans, it will be easier to adapt to them. Adapting and replacing, according to the R-ladder, happens at different rates which are displayed in the figure below.

Site
Geographical setting, urban location, and legally defined lot.

Structure
The foundation and all the load-bearing elements.

Skin
The exterior non-load bearing surfaces, including the insulation layer.

Services
All the installations, from electrical to HVAC.

Space plan
Interior layout with walls, ceilings, floors and doors.

Stuff
Furniture, equipment etc.

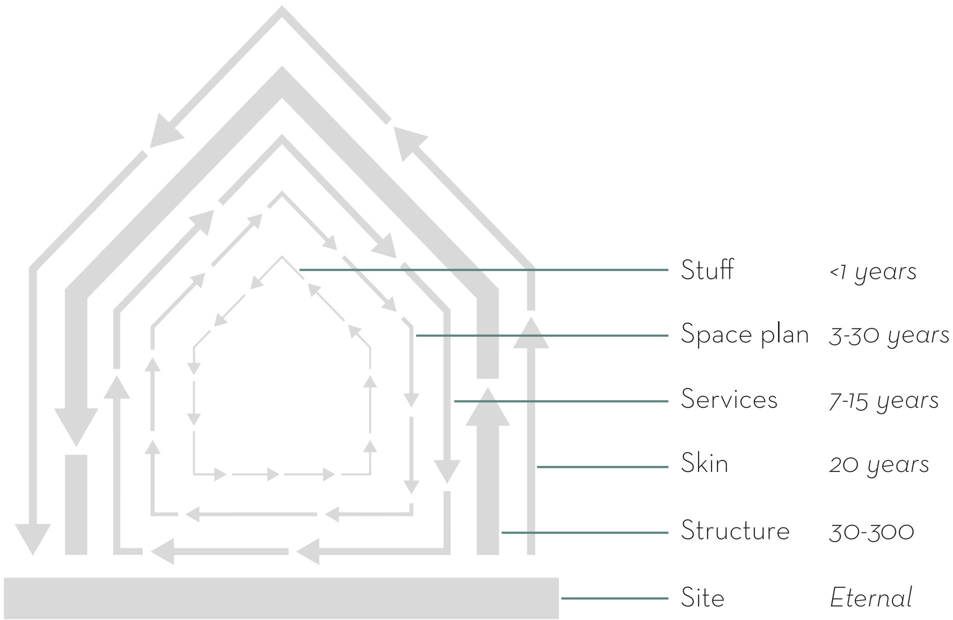


Fig. 3.3 Adaption of the shearing layers (Brand, 1994)

3.2 Understanding the biobased economy (BBE)

The Biobased Economy (BBE) is an economy that utilizes crops and residues from agriculture and the food industry for non-food applications. It is an economy that uses biomass for the production of materials, chemicals, transportation fuels, and energy (electricity and heat).
In the BBE, biological raw materials replace fossil raw materials. A driving force behind this idea is the fact that biomass has the ability to store a certain amount of carbon, where fossil resource only exhaust carbon. These carbon cycles are explained in the following subchapter.

3.2.1 The carbon cycle

Carbon is an essential element of life, found in everything around us. It cycles around in a biological and in a fossil cycle. The short carbon cycle involves carbon moving between various life forms on earth. Around 400 gigatons of carbon flow through this cycle each year. This **biogenic carbon** is released when, for example, vegetation is burned or decomposed, or when the soil is oxidizing. At the same time biomass absorbs a similar amount of carbon which will eventually create a natural balance.

However, human activities are disturbing this natural balance by releasing large amounts of **fossil carbon** into the atmosphere. Burning fossil fuels and deforestation release extra carbon, shifting it from the long cycle (millions of years in fossil fuels) to the short cycle (carbon in the atmosphere). Of the nine gigatons of $CO2$ humans emit yearly, five are absorbed by plants and oceans, but four remain in the atmosphere. This leads to temperature rise, ocean acidification, and ecosystem disruption, exacerbated by wildfires, permafrost thaw, drought, and deforestation (Sobota et al., 2022).

The idea of biogenic carbon and fossil carbon is utilized a lot in LCAs, so it is necessary to properly understand the background of these concepts.

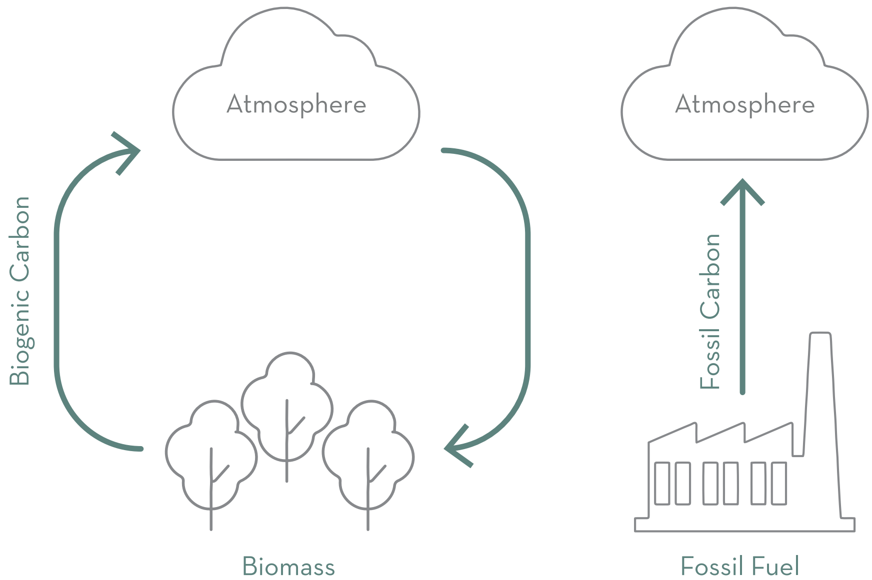


Fig. 3.4 Biogenic and fossil carbon adopted from: (Sobota et al., 2022)

3.3 Life Cycle Assessment (LCA)

All materials have a certain environmental impact which takes place over the entire life cycle of the material. To find this environmental impact, many processes could be consulted and many processes should be considered. That's why the European Committee for Standardization has standardized this assessment for all materials (EN 15084, 2013). In the following subchapter the basic principles of the LCA will be explained, followed by some clarification on certain topics which are used in this paper.

3.3.1 Basic principles

An LCA typically consist of four phases or so called modules:

A. Production and Construction phase

The production phase includes the extraction of materials, transportation to the factory, and the processing of construction materials and products in the factory. The transportation of materials to the construction site and on-site activities are part of the construction phase.

B. Use phase

The use phase involves the energy consumption of the building, maintenance and repairs, the replacement of building elements at the end of their lifespan, and renovations necessary to keep the building functional.

C. Disposal phase

The disposal phase encompasses demolition activities, dismantling, transportation of residual materials, and waste processing.

D. Reuse or Recycling phase

And this final module includes the reuse and repurposing of construction materials when a building reaches the end of its lifecycle. The recycling phase is crucial for emission reduction and is rarely applied in traditional linear construction processes. The transition to a circular construction economy will make this phase increasingly important and largely replace the production and

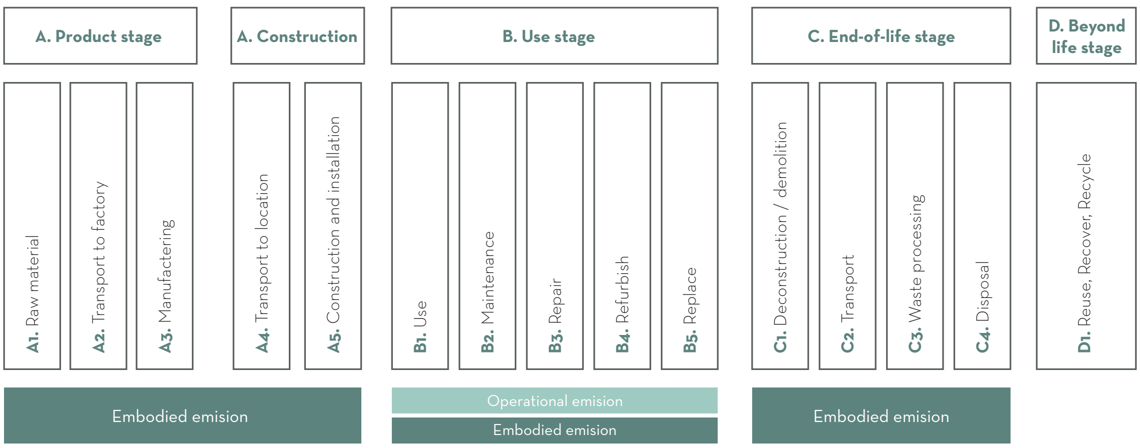


Fig. 3.5 Schematic representation of Life Cycle Analysis (EN 15804, 2013)

Impact categories

LCAs consider in total 11 environmental impact categories. These impact categories could for example be land use, water use, and acidification. The global warming potential (GWP) is part of the LCA as well. This number translates all greenhouse gas (GHG) emissions released in the life cycle, to an equivalent of CO_2 emissions. The GWP is frequently used to measure the environmental impact, however it should be kept in mind that the GWP is only one of eleven categories of environmental impact.

Environmental Cost Indicator (ECI)
The environmental cost indicator (ECI) transforms all the 11 environmental impacts of the LCA into a single comprehensive number, measured in euros. These environmental costs are commonly referred to as shadow costs.

Environmental Product Declaration (EPD)
An Environmental Product Declaration (EPD) consists of the outcomes of a product's life cycle assessment. It is the manufacturer's responsibility to create EPDs for their products, although it is not obligatory. An EPD includes all the information regarding the environmental impact throughout the entire life cycle of a product in accordance with standard EN 15804.

3.3.2 Embodied vs. Operational emissions
Following on the scheme of a standard LCA on the previous page, an important distinction between embodied and operational emissions could be made (Sobota et al., 2022).

Embodied emissions
The embodied emissions of a building are all emissions related to the usage of materials. Embodied emissions are released during the production and construction phase, maintenance and renovations in the use phase, the disposal phase, and, if applicable, the reuse phase. In simple terms, material-related emissions encompass everything emitted to create the physical mass of a building.

Operational emissions
Operational emissions on the other hand are all emissions generated during the use of a building in the form of electricity, gas, water, and heating. When operational energy is generated from fossil fuels or biomass, it results in carbon emissions. To reduce operational emissions, we must minimize our energy consumption and transition to renewable energy sources.

3.3.4 Paris Proof
In the latest IPCC report (2021), various scenarios are presented for global warming due to emissions of GHGs. The IPCC describes scenarios based on the maximum temperature increase. In the Paris Climate Agreement, agreed upon by many countries including the Netherlands, there is a commitment to limiting global warming to 1.5 degrees. This scenario comes with a maximum global budget for GHG emissions of 400 Gt CO2-eq. This obviously impacts the Dutch building sector as well. Nibe and the DGBC (2021) have set out a Paris Proof framework for the Dutch Building sector.

The annual carbon budget of 400Gt could be divided per country. The researchers conclude that the Netherlands has a carbon budget of 909 million tonnes of CO2. Taking into account an average impact of the building industry of 11%, it means that the Dutch building industry has a carbon budget of roughly 100 million tonnes of CO2.

The study then uses LCA data from the *Nationale Milieudatabse (NMD)* (Stichting Nationale Milieudatabase, n.d.), a large national database which collects data on environmental impact of materials, to create benchmarks for all sorts of buildings. The LCA data which is used, only covers the modules A1-A5 which means the source of the material until the finishing of the construction phase. Next, the researchers took an estimation of the total volume of the current building stock, and the total volume of the buildings to be built in the period 2020 until 2050. With this data the benchmarks for construction and for renovation could be created.

Paris Proof – New Construction		embodied carbon kg CO2-eq. per m2			
#	Type of building	2021	2030	2040	2050
1	Housing (single family)	200	126	75	45
2	Housing (multiple families)	220	139	83	50
3	Offices	250	158	94	56
4	Retail	260	164	98	59
5	Industry	240	151	91	54

Table 3.1 Benchmarks new construction (Nibe & DGBC, 2021)

Paris Proof – Renovation		embodied carbon kg CO2-eq. per m2			
#	Type of building	2021	2030	2040	2050
1	Housing (single family)	100	63	38	23
2	Housing (multiple families)	100	63	38	23
3	Offices	125	79	47	28
4	Retail	125	79	47	28
5	Industry	100	63	38	23

Table 3.2 Benchmarks renovation (Nibe & DGBC, 2021)

In this research a strategy for topping-up in 2030 will be created. Regulations currently do not conclusively specify whether topping-up should be considered 'new construction' or 'renovation'. In this research the outcomes will therefore be compared with both, meaning the benchmark for 2030 will be 126kg CO_2 per square meter for 'new construction', and 63kg CO_2 per square meter for 'renovation'.

II LITERATURE STUDY

4. THE POTENTIAL

The province of Zuid-Holland specifically mentions biobased topping-up as a focus point in the transition the building sector needs to make. Apparently, policy makers see the potential of it, but what is this potential? In the following chapter this potential is the central theme.

To research this the potential of biobased topping-up, the following research question will be answered in this chapter.

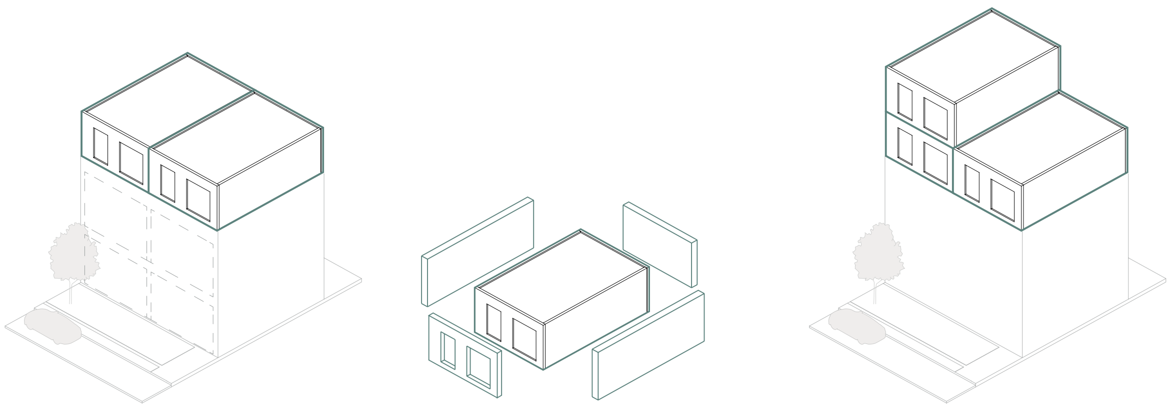
Why should the 100 000 needed top-ups be built with biobased materials?

This research question was translated into three questions: 1) *Why top-up* 2) *Why biobased* 3) *Why biobased top-up*. These three questions will be answered by performing a literature study.

4.1 WHY TOP-UP?

4.1.1 What is topping-up?

Before being able to analyse the potential of topping-up, it should be clear what is meant with this strategy. To do so, a tentative definition was distilled from Stec group (2023), a leading document released by the Dutch government. A top-up is a standardized and scalable addition of at least one level to an existing building.



- **Addition**
- **Standardized**
- **Scaleable**

Fig. 4.1 Definition of a Top-up

4.1.2 The potential of topping-up in The Netherlands

In 2020, the importance of seizing opportunities in existing urban areas was emphasized by the College of National Advisors and other initiators, including the government (College van Rijksadviseurs, 2020). There was a focus on the potential of densification through splitting and adding extra floors to buildings at the edges of cities. This approach would not compromise green spaces or livability due to the spacious layout of these areas. Topping-up and splitting have now become significant topics with considerable attention, including inquiries from the Dutch Parliament (Tweede Kamer). Following this ambition, the Ministry of the Interior commissioned Stec Group (2023) to explore the potential of topping up and splitting. For this research, the conclusions related to topping-up will be used as a theoretical framework.

The main goal of the researchers of this report was to investigate the national potential of splitting and topping-up existing buildings. They conclude that the potential for topping-up in The Netherlands is 100 000 extra homes. The first step was to select 90 municipalities with an urban character. They believe that topping-up has a higher potential in urban environments because of the building heights. Within these 90 municipalities, the Basisregistratie Adressen en Gebouwen (BAG), a data set with the basic properties of all buildings in The Netherlands was consulted. Four requirements were formulated to check which buildings were suitable for topping-up:

- The 90 selected municipalities have an **urban character**, but in these 90 municipalities topping-up can also take place in more rural areas.
- The roof of the building is at least **75% a flat roof**. These buildings are simply easier to top-up.
- The building has the **desired elevation**. For more rural areas the maximum elevation of the building is two levels. For living areas in villages, the maximum elevation is three levels, and for shopping centers of villages the maximum elevation is four levels. For cities there is no such limitation.
- The building was constructed in **1965 or later** since in this year the regulations for load bearing structures were improved.

With these requirements the researchers come to a potential for top-ups of 260 700. However, potential does not always lead to action. The decision was made to link topping-up to renovation. The belief is that when an appartement building needs to be renovated, the will to top-up is higher. Furthermore, the researchers state that for social housing it is easier to top-up than for private housing. Taking these limitations into account, the research comes to a realistic potential of 97 900 top-ups for all the 90 municipalities together (Stec Group, 2023).

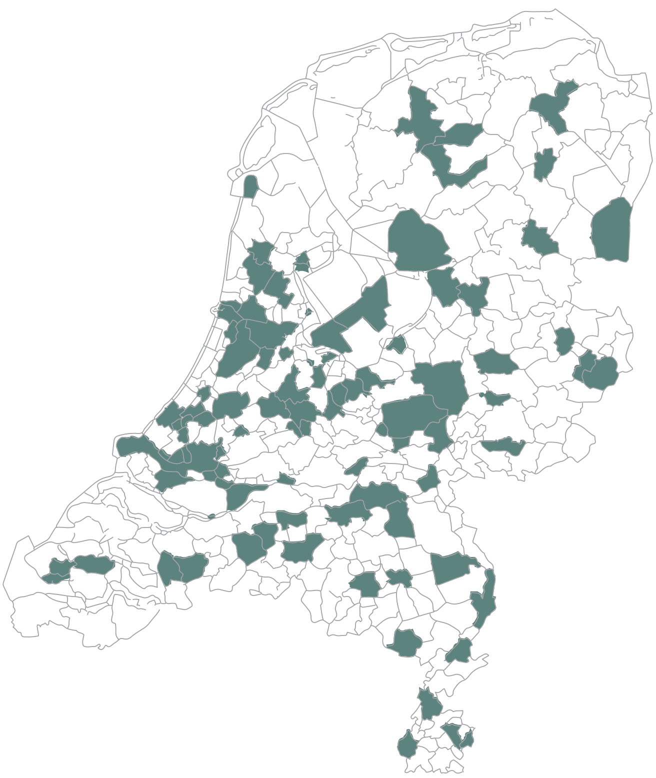


Fig. 4.2 Map with the top-up potential, adopted from (Stec Group, 2023).

4.2.3 The benefit of topping-up

The drive to reduce operational emissions of buildings has led to growth of the embodied emissions both relative as absolute. Large quantities of petroleum-based insulation materials, heavy mechanical installations, and numerous solar panels are used to minimize building energy consumption. In the case of “net-zero-energy homes,” the environmental impact of the used materials is often underestimated, despite initially seeming beneficial. As a result, the overall emissions over a building’s lifecycle may not necessarily be lower. In the graph below it is displayed that in the quest to reach “net-zero buildings” the importance of the embodied emissions increases (LETI, 2020).

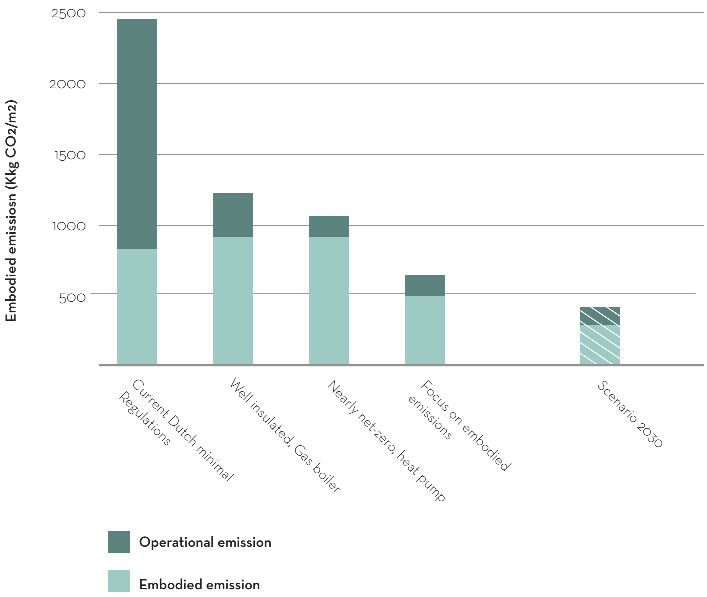


Fig. 4.3 Embodied vs. Operational emissions adopted from (LETI, 2020).

Renovations can make a significant difference in reducing the embodied emissions compared to new construction. In renovations, existing structures are re-used, while new constructions involve building from scratch. During a building renovation, between 50 and 75 percent less carbon is emitted compared to new construction, which is displayed in the graph below (Dutch Green Building Council, 2020). Due to this fact, different benchmarks to meet the Paris climate agreement were made, which was already introduced in the previous chapter.

With the current available literature, it is hard to quantify the embodied emissions of topping-up in general. Later in this paper the calculation will be conducted on the designs for the top-up for Smits Vastgoedzorg, but for now it is impossible to provide a general image of this impact. A few things could however be mentioned. A top-up makes use of existing infrastructure and partly of the load-bearing structure, similar to renovation. It could therefor be said that topping-up is in some way a mix of new construction and renovation, through which it is expected to have reduced embodied emissions.

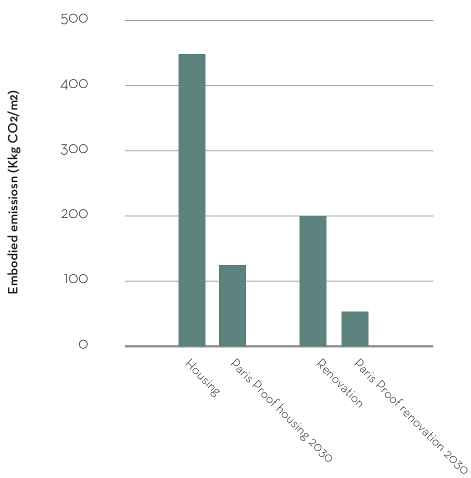


Fig. 4.4 Embodied emissions of renovation, adopted from (Dutch Green Building Council, 2020)

4.2 WHY BIOBASED

4.2.1 What is biobased building?

Before being able to explain why biobased building is a necessity for the construction sector of the future, a definition of biobased should be given. There are several definitions and norms when it comes to biobased building materials. According to Arcadis (2022): 'Biobased products or materials that partly or completely consist of biomass.' So biobased building materials do not necessarily have to be made with just biological raw materials. In fact, most biobased materials contain other materials. All laminated products and bio composites contain some sort of a binder which is still often not a natural binder, and for example insulation materials could contain additives like a flame retardant. These are just examples, showing that it is still really hard to go for 100% biobased. According to the College van Rijksadviseurs (2023) these 100% biological raw materials are:

- Sourced from regenerative cultivation that ensures ecologically healthy conditions at the harvest location, both now and in the future.
- Made from raw materials derived from living organisms that regrow within 100 years after harvest.
- Excludes abiotic raw materials from geological formations, such as sand and clay.
- Can be reused as raw materials in new construction materials or returned to nature later.

In the following subchapters the benefits of biobased building, and the prerequisites of environ-

4.2.2 Reasons to choose biobased materials

There are several reasons to choose biobased materials.

Scarcity of resources

The first reason to choose biobased materials is that there is currently a growing pressure on the available resources, which is for a large deal casued by the construction sector. With an annual consumption of 40,6 Gt back in 2015, it accounted for 44% of the entire global material consumption. The total amount of material which is currently cycled back into the economy is only 7%. It is therefore very probable that by the end of the century the reserves for extractable ores used in the production of metals, as well as oil for plastic, will run out. The most critical available material resources are lead (21 years), zinc (24 years) and cupper (32). Petroleum based products like PVC or bitumen will probably run out by the end of the 21st century. The most ingredients of by far the most beloved construction material globally, concrete, are still relatively abundantly available. However, these materials (sand, cement and gravel) are limited as well, and scientists warn that sand may become scarce due to the enormous extraction (Van der Lugt, 2020).

Regenerative

One characteristic which has a strong connection with scarce resources is that biobased materials have the ability to regenerate. Biomass as a raw material should be able to regenerate within 100 years. It is therefore necessary that the systems that produce biomass remain healthy which could be done in several ways, starting with efficient nutrient management, meaning there should be a balance between supply and uptake of nutrient rich resources. Formerly this was in a lot of cases done by the use of artificial fertilizers. But according to the theory of the CE, the waste in the bio-cycle could also be used as food. Examples of this are when crop residues are left in the field to enhance the soil quality, or when organic waste is turned into soil. By doing so a regenerative system could be achieved (The Ellen MacArthur Foundation, 2013).

Carbon Storage

The third benefit of biobased materials is its capacity to temporarily store carbon. When vegetation grows it converts CO_2 from the atmosphere into carbon which is sequestered in the material. This process is called photosynthesis. This does not mean that plant-based materials have a negative carbon footprint. Taking into account the entire life cycle, the material will eventually either biodegrade or be burned, making it actually carbon net-zero, which is in fact already of course a lot better than conventional building materials. Conventional building materials contain a lot more embodied GHG emissions, due to multiple aspects. To grow, produce, drill, harvest or transport these materials, a lot more energy is needed causing more GHG's. And when these non-biodegradable materials are burned a lot more GHG's are released in the atmosphere making it all together, in general, carbon net-positive materials. (Shogren et al., 2019).

Health and wellbeing

Another argument which is brought up frequently is that biobased materials have a positive influence on health and wellbeing of people. The visible effect of biobased materials called "biophillic design" (Kellert et al., 2011) has been proven to reduce stress and increase productivity. While at the same time there are also building physical benefits of biobased materials. It improves the air quality, it has a high moisture absorption and it also has good acoustic qualities (Visser et al., 2015). These building physical benefits will be touched upon later in this research in more depth.

Less transport

When it comes to transport, there are two important benefits of biobased materials. First of all, there is an increased potential for prefabrication, reducing the need for on-site processing. This results in fewer transportation movements to the construction site and significantly shortens the construction time. It is estimated that due to prefabrication, up to 60% fewer transportation movements are required (College van Rijksadviseurs, n.d.). There is however an additional potential benefit when using biobased materials. For both conventional and biobased materials, currently used in the Dutch construction sector, the origin of the raw material can be from all over the world. The transportation distance of these locations heavily influences the overall environmental impact of the product. The smaller the distance, the smaller the impact. Therefore, an increasing number of crops are being cultivated in The Netherlands. However currently the scale of this production is relatively small (Schik et al., 2022). Upscaling this production, as is being researched in this paper, will likely have a positive influence on the environmental impact.

Less waste

In a 100% circular economy this argument would not have made sense. However, in The Netherlands in 2020 only 13% of all materials used in the economy was re-used (Centraal Bureau voor de Statistiek, 2023). For the other 87% either landfill or incineration is still the end-of-life scenario. Compared to conventional building materials, biobased materials in general have more end-of-life scenarios. This concept is called cascading. Cascading means that biomass is used in a smarter and more efficient way. Although biomass is regenerative, its nutrients are still scarce. Being scarce is of course still better than being finite like resource in the techno cycle, but the efficiency could still be improved by cascading. There are two types of cascading namely parallel and sequential cascading. Parallel cascading happens when simultaneously different parts of the crop are used for different purposes. Take for example the flax plant. Of this plant several parts are used for high quality building products. The bast fibres for insulation material and composites and the shives for particle boards. Sequential cascading means that the material is recycled at the end of its life span. The product should be reused as long as possible (Van Den Oever et al., 2023). Timber could for example be used in demountable structures in which high quality products like glulam beams or CLT panels retain their value. They could then be used in a second high-quality lifespan. Only after a third or fourth life, these elements could be machined into sheet materials. Finally, they could be incinerated through which energy could be produced (Van der Lugt, 2020).

4.2.3 A critical note on biobased materials

Besides these general benefits, a critical note should be made, since biobased materials do not automatically imply beneficial in terms of environmental impact. The underlying idea is that biobased products are natural and renewable, and therefore responsible. However, this is not always the case. Just like with traditional products, the entire chain must be examined to get a comprehensive picture of the actual impact. There is an ongoing debate on how and to what extent the impact in each part of the chain should be taken into account (Schik et al., 2022). The following paragraph provides a more detailed explanation of the labelling of products as environmentally friendly or the opposite.

Responsible cultivation

First of all, responsible cultivation is essential to reduce the environmental impact. Take for example wood. The destruction of ancient natural forests or tropical rain forests for the production of timber should obviously be avoided. Labels like the Forest Stewardship Council (FSC) ensure that the cultivation of forests is done in a responsible manner. Additionally it should be mentioned that in many cases cultivation can lead to soil depletion so this should also definitely be taken into account. Creating a diverse landscape with crops like hemp, miscanthus and cattail increase the soil quality, and can create interesting habitats.

Growth location

Secondly, the growth location could heavily influence the environmental impact. Currently quite a lot of biobased materials that are used in The Netherlands originate in Northern and Eastern Europe. Transporting these materials still cause quite a lot of emissions. This increases the focus on local biobased materials.

Displacement concerns

Another concern about biobased materials which is mentioned regularly is that of displacement. Currently there are several products made from crops that could also be used for food production, like for example sugar cane. Furthermore, the land used for producing biobased building materials, could in fact always be used for food production. This raises the question whether this is a responsible thing to do. Luckily most fibre crops that are currently used in the building industry like hemp, miscanthus and cattail grow in places where the soil is too poor, too dry or even too wet for food production. Furthermore, there should be more attention to cascading. A process in which the byproducts of the food industry are used for the production of building materials. The peels of potatoes or corn can be used in biocomposites. To increase the soil quality fibre crops are currently also used as a rotation crop. This is economically more feasible than completely changing to a different crop.

Pace of regrowth

Next does the pace of growth also play a vital role. All biobased resources have the unique quality of regrowing. The pace of regrowing can however vary substantially. A full-grown oak tree grows back in maybe 50 years where seaweed and mycelium grow back in a month. Most fibre crops regrow within a year.

Biomass in the energy mix

The use of biomass for the production of energy is also putting pressure on the integration of bi-obased materials in the construction industry. Currently, the use of biobased materials as construction materials holds greater value than using the resources for energy production. Unfortunately, the demand for biomass for energy drives up the prices of natural resources, making bio-based products sometimes more expensive than they should be. By cascading the products, by using the biomass multiple times. This means that biomass is only used for energy production when the materials are downcycled until it is unusable in any form as a building material. When the biomass is used multiple times, maximum value is created.

The composition of the product

Products can be called biobased when at least 50% of the product is made from biomass. Needless to say of course that 50% biomass instead of 100% biomass, when for example abiotic substances are added, has a larger environmental impact. Furthermore, biobased products could also be treated in certain ways through which it loses quite a lot of its natural characteristics. This is for example the case with biocomposites. By permanently binding natural fibres in a technical manner the natural material loses some of its natural characteristics, namely its decomposability.

The end-of-life scenario

The end-of-life scenario, though hard to predict, plays a very important role in the life cycle analysis, and the environmental impact of the product. There are two main end of life scenarios for building products. A product could be circular which is the case when a product or material is re-used, repaired, refurbished, remanufactured or repurposed. And a product or material could be disposed of. To understand this process, a distinction between two concepts should be made: A product is compostable when it can be broken down by at least 90% within six weeks in an industrial composting facility. It complies with the EN 13432 standard for compostable materials (European Committee for Standardization, 2000). A product is biodegradable when it can naturally decompose through the action of fungi and bacteria. Wood for example is biodegradable, although it may take many years before the material is completely decomposed.

4.3 WHY BIOBASED TOP-UP?

Besides the general benefits of biobased building materials there are several other benefits that are specifically important when topping-up. The following three benefits will in this chapter be explored further; reduced mass, a high level of prefabrication, and building physical advantages.

4.3.1 Reduced mass

The first benefit is that biobased structures are in general more lightweight than conventional building materials. Traditionally, in The Netherlands, high mass and weight played an important role in the construction sector. Heavy weight structures take care of strength, (sound) insulation and (fire) safety. However, when dealing with existing structures, the maximum mass is rather limited. So therefore, other structures should be explored. Amar & Attia (2018) have conducted a comparative analysis of top-ups throughout Europe, and concluded that currently the most used structural material for top-ups is steel with 53%. Next is timber (26%), followed by reinforced concrete (17%). The final type of structure is composite (4%), with which the authores mean a combination of, for example, steel and timber.

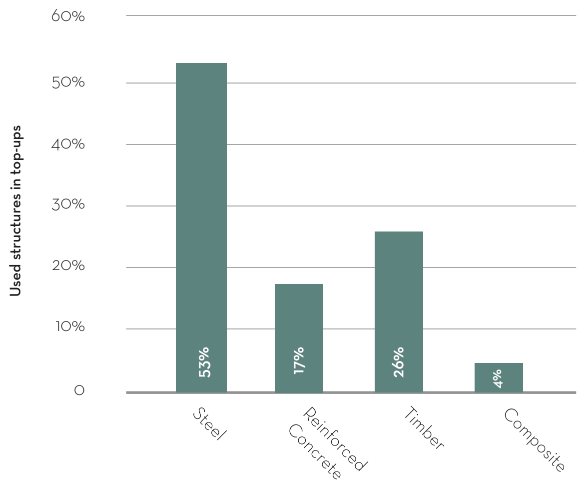


Fig. 4.5 Embodied emissions of renovation, adopted from: (Amar & Attia, 2018)

In the graph below the mass per m2 of three of the four structures used in the previous graph were compared. One other material was considered as well, namely a lightweight bio-concrete like hempcrete. A concrete wall with PIR insulation and brick cladding has, with 440kg/m2, by far the most mass. Next comes the lightweight bio-concrete. These types of concrete use natural fibre instead of gravel which reduces the mass. The mass/m2 of a facade with hempcrete and timber cladding is around 120kg. Third comes a steel structure. This material is used the most frequently for top-ups as is shown in the graph above. The reason for this is mostly the weight, because compared to a concrete structure the weight is almost 10 times less. However, the same goes for a timber stud frame, weighing even less with 46kg/m2. It could therefore be concluded that steel is chosen a lot for a reason, but that when looking at the weight a better option would be a timber stud frame.

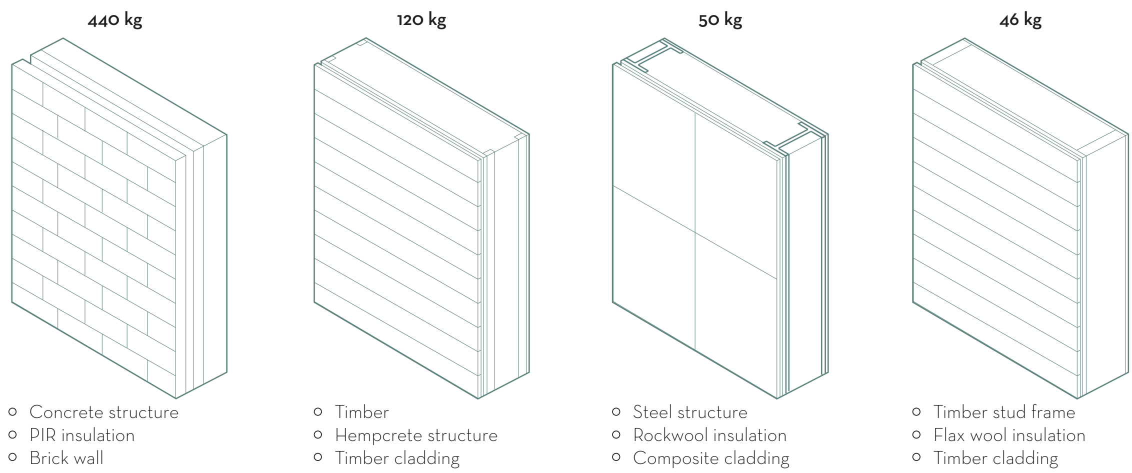


Fig. 4.6 Lightweight structures

4.3.2 **Prefabrication**

Before explaining why biobased materials are very suitable for prefabrication, it should be made clear why prefabrication is beneficial and preferred in the first place. In literature a distinction is made between offsite and onsite assembly, where offsite assembly consists of entire 3D units, and onsite assembly could consist of 2D or 1D elements (Amer & Attia, 2018).

Offsite assembly involves the construction of building elements into 3D modules, which are then transported and installed on existing building rooftops. This approach is time-efficient, with installation taking just three days, making it ideal for busy areas. These prefabricated units, ranging from containers to residential modules, are fully factory-manufactured, including structural components. Before installation, on-site preparations, like roof clearance and joint mounting, are essential. However, interior and exterior finishing, electrical work, and sanitation occur onsite. In contrast, assembling 2D elements like walls and slabs on rooftops takes more time and involves precise factory fabrication. Additionally, prefabricated 1D elements, such as beams and columns, require on-site assembly, which can be time-consuming and may pose challenges if the existing roof must remain functional during construction.

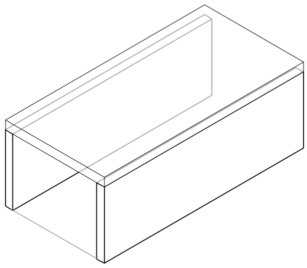
For complex designs, onsite assembly is more suitable but often demands a longer construction period on the site. Assembling prefabricated elements is better for non-modular, larger architectural designs, with easier transportation and lifting. Prefabrication comes in two forms: 2D elements (walls, ceilings, and floors) and 1D elements (beams, columns, or frames). While it offers benefits, onsite total construction and prefabricated element assembly take more time than other methods.

The best practice, prerequisites, benefits and drawbacks of all systems were summarized in the graph below.

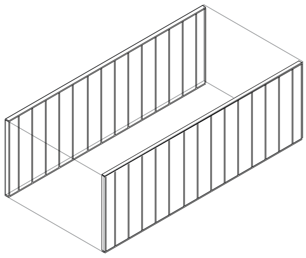
	Off-Site Assembly	On-Site Assembly	
	3D Units	2D Elements	1D Elements
Best Practice	• In dense neighborhoods and busy traffic • Buildings busy with Occupants • Neighborhood with relatively wide streets	• Stacking with special requirements and complex designs [35] • Doable for dense neighborhoods and busy traffic	• Less urbanized or inhabited areas • Unoccupied buildings or tolerant neighbors and / or occupants [36]
Prerequisites	• Ready system on the roof to rest the modules on • Precision in manufacturing • High standard transportation and lifting cranes [37] • Off-site manufacturer	• Precision in manufacturing • Predesigned assembly method and joints • Rooftop preparations	• Additional space (on the rooftop or a courtyard on the side) for onsite assembly and rooftop lifting
Benefits	• The fasted method for roof stacking [37] • Higher Quality for off-site construction	• Relatively fast method for construction • Reduces the amount of onsite construction wastes	• Easy to transport and lift on the rooftop if needed. • Higher flexibility in assembly and placement on the roof • More design variety
Drawbacks	• Transportation and lifting of modules • Preciseness of manufacturing • The existence of a factory to produce accustomed modular units • Less onsite modifications flexibility	• Highly sensitive to errors resulted from miscalculation or prefabrication • Limited with number of design options based on the modularity of prefabricated elements	• Takes more time to assemble on site and install on the roof [36]

Fig. 4.7 Evaluation of prefab methods (Amer & Attia, 2018)

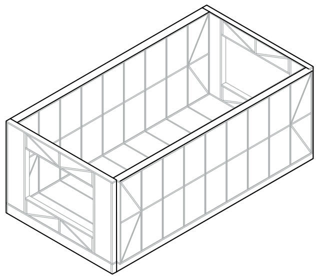
There are several biobased solutions that are very suitable for prefabrication, mostly due to properties of timber. It's a lightweight and dimensionally stable material, and easily cut and shaped with precision in a controlled factory environment. This results in pre-cut and pre-fabricated components that fit together on-site. Furthermore, the lightweight nature of timber simplifies transportation and handling.



- Slabs made from cross-laminated timber (CLT)



- Timber stud frame



- Timber straw panel

4.3.3 Buidling physical benefits

Thermal properties

When looking at the thermal properties of insulation materials there are several metrics that should be taken into account showcased in the table below.

#	Property	Amount	Unit
1	Density (ρ)	Mass per unit volume	kg/m3
2	Thermal conductivity (λ)	Indicates the transport of energy through a body of mass as the result of a temperature gradient	w/mk
3	Specific heat capacity (c)	The heat energy needed to raise the temperature of 1 kg of material by 1 K.	j/kgk
4	Thermal resistance (R)	The ratio of the temperature difference across an insulator and the heat flux through it.	M2K/W
5	Overall heat transfer coefficient (U)	Rate of transfer of heat through 1 m2 of a structure divided by the difference in temperature across the structure.	W/m2·K

Table 4.1 Thermal properties

Visser et al. (2015) performed an extensive comparetive analysis on the building physical benefits of biobased building materials. This work was used as a basis for this paper. It was checked however whether the material had a potential source in the Netherlands. If not, or when the environmental impact was just too high, the material was left out of this comparison.

#	Material	Density (ρ)	Thermal conductivity (λ)	Specific heat capacity (c)
1	EPS	15-30	0,032 – 0,040	1200
2	XPS	20-60	0,030 – 0,040	1200
3	PUR/PIR	15-80	0,020 – 0,040	1400
4	Glass wool	20-140	0,032 – 0,040	840
5	Rock wool	25-400	0,032 – 0,050	840
6	Wood fiber	70-140	0,040 – 0,055	2100
7	Hemp fiber	24-60	0,040 – 0,048	1800
8	Flax fiber	15-60	0,038 – 0,050	1600
9	Sheep wool	18-30	0,035 -0,040	1700
10	Cellulose	35-60	0,039 – 0,045	2200
11	Cotton	45	0,038	1300
12	Straw	110	0,060	2100
13	Grass	53-68	0,042	2200

Table 4.2 Thermal properties biobased insulation (Visser et al., 2015)

In general, the thermal insulation is quantified with the thermal conductivity (λ), indicating the amount of energy conducting through the material as a result of a temperature gradient. Table 3.2 shows that the thermal conductivity of natural insulation materials is in general similar to mineral-based materials like rock wool or glass wool and synthetic materials like polystyrene.

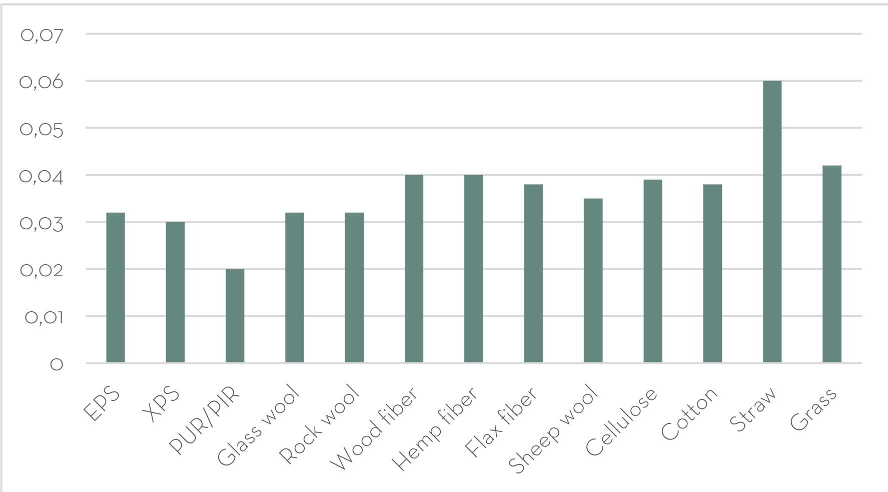


Fig. 4.8 Thermal properties biobased insulation (Visser et al., 2015)

Besides the thermal conductivity there is another important performance indicator for the thermal insulation, namely the specific heat capacity. It describes how much heat the material can accumulate. A higher specific heat storage means a higher capacity to accumulate, through which the material will release the heat to a cooler environment at a slower pace. This phenomenon is called phase shift. In general, biobased insulation materials show a higher specific heat capacity than conventional materials, meaning they can store more heat and release the heat at a slower pace. This is beneficial because in summer when the fluctuation of the temperature inside will therefore with biobased insulation be much less than with conventional materials. This is shown in the graph below. Eventually this means that less active cooling is needed which is specifically beneficial for top-ups because the top-floors of a building always heat up faster due to direct solar radiation on the roof (Biobeest, 2022).

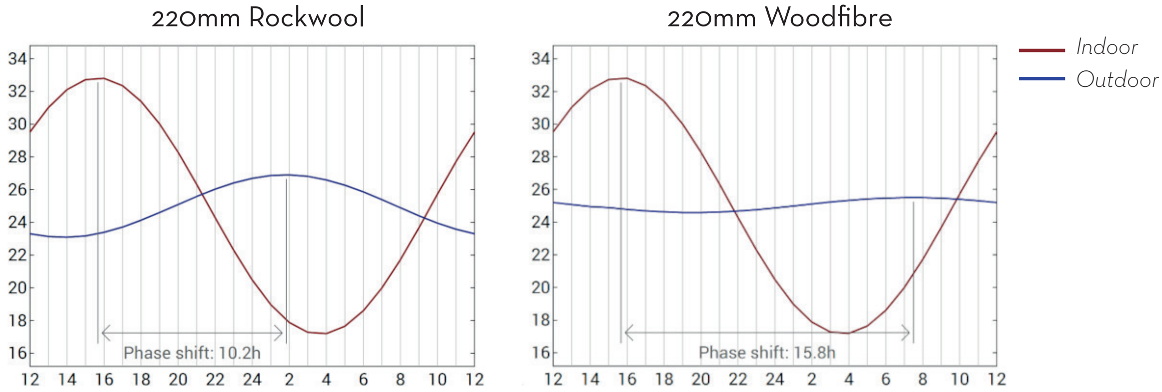


Fig. 4.9 *Phase shift (Biobeest, 2022)*

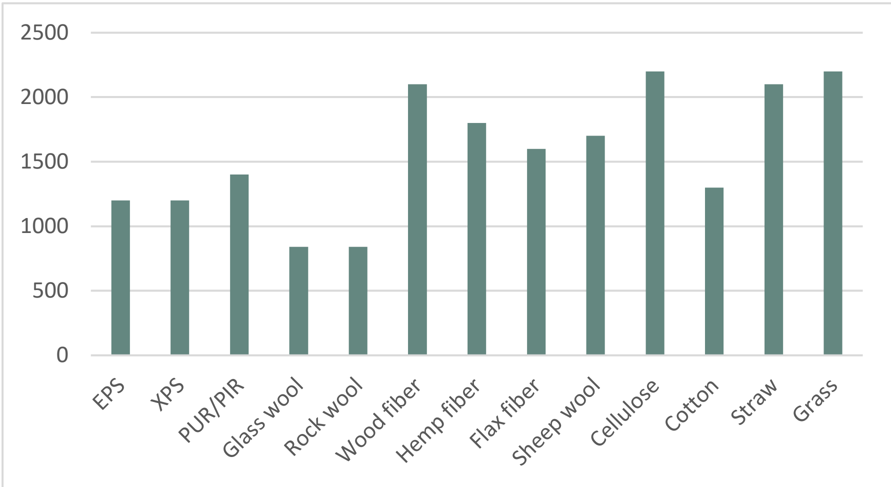


Fig. 4.10 *Phase shift (Biobeest, 2022)*

Vapour open construction

An often-made statement is that a high indoor comfort is linked to a low relative air humidity. The use of the right building materials can help stabilize indoor relative air humidity and biobased materials have some interesting properties when it comes to indoor comfort. Biobased insulation materials are often linked to vapour-open construction. But what is the difference between conventional construction and what are the benefits?

The conventional construction method is almost always damp-proof. This means that the insulation layer is covered with a damp-proof sheet to prevent moisture from condensing between the layers. Through these layers the insulation material will always remain dry. However, inside the building the relative humidity will be higher because only a small amount of moisture could naturally leave the building through small openings in the wall. If damp-proof systems are not ventilated well enough there will always be mould growth.

The opposite of damp-proof is vapour-open construction. In this case the insulation is by itself vapour-open and is not covered with damp-proof sheeting, through which sufficient moisture is able to conduct through the insulation layer to the outside air. The building is in fact able to breathe like this. Excess moisture is drained, so it will keep the relative humidity low and will prevent mould growth. It is important to note here that a vapour-open construction thus depends on two matters namely, the properties of the insulation material and on whether there is a damp-proof sheeting.

When looking at the properties of the insulation material it is fair to conclude that there are some materials that have the ability to conduct water vapour. Natural fibres can absorb and release moisture equivalent to 30% of their weight while fossil or synthetic insulation materials only a fraction of this. This means that biobased insulation materials are able to absorb water-vapour with influencing the product or losing its ability to insulate where this will happen with fossil or synthetic materials.

So what does a vapour open construction look like? Vapour-open constructions are much like a breathable fabric that keeps rain out while allowing moisture to escape. To create a vapour-open structure, a specific layering system is essential. It begins with an outer layer that retains rain but is vapour-open to release moisture from the structure. Following this, an insulation layer made from natural fibres is needed to transport moisture from the indoor environment to the outside air. And on the interior side of the system ideally a vapour-open plasterboard and a vapor control membrane would be applied. This system allows indoor moisture to pass through the foil, where the insulation material's fibres accumulate and transport it to the outside air. This results in more stable indoor relative humidity (Visser et al., 2015).

It should also be noted that there is an ongoing debate on whether a vapour-open construction is even possible when it also needs to be airtight for thermal insulation. In general, with the right layering and materialising it is possible to create a vapour-open and airtight structure.

#	Material	Vapour diffusion resistance factor (μ)
1	EPS	20-100
2	XPS	80-300
3	PUR/PIR	30-200
4	Glass wool	1
5	Rock wool	1-2
6	Wood fiber	1-2
7	Hemp fiber	1-2
8	Flax fiber	1-2
9	Sheep wool	1-2
10	Cellulose	2-3
11	Cotton	1-2
12	Straw	2
13	Grass	1-2

Table 4.3 D (Visser et al., 2015)

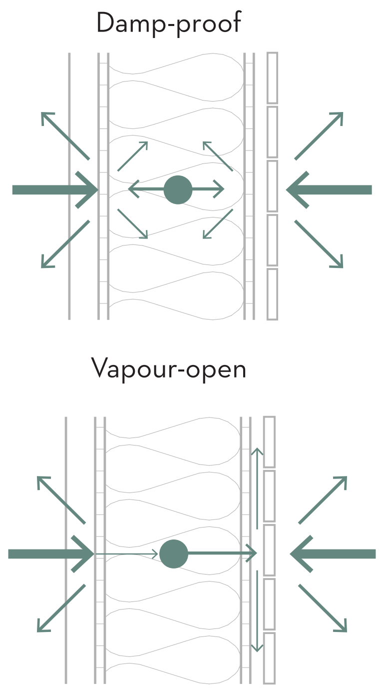


Fig. 4.11 Damp-open construction (Het bewuste stel, 2020)

4.4 CONCLUSION

This chapter started off with one research question, '*why should the 100 000 needed top-ups be built with biobased materials*', which was diluted over three smaller questions; *1) Why top-up, 2) Why biobased, 3) Why biobased top-up*. A literature review was performed to be able to answer these questions.

The first question, '*why top-up*', was answered by comparing the current policies on topping up, with actual data. Topping-up is considered a promising means to tackle multiple problems, due to land-use issues and an increasing demand for housing. This has led to a national strategy of enhancing the construction of top-ups, which culminates in the goal of building at least 100 000 top-ups by 2030. Topping-up is at the same time considered as an important measure to minimize the embodied emissions in the construction of housing. There is currently little data available on topping-up since it is a relatively new topic. However, data shows that renovation drastically reduces the embodied emissions by roughly 50%. This is largely due to the high impact of concrete in structures. Top-ups make use of existing structures, which will inherently leed to lower embodied emissions. Later in this paper, more accurate calculations will be provided.

The second question, '*why biobased*', was answered by performing a literature study. Biobased materials offer important environmental benefits and are a necessity in a circular economy. At the same time, biobased does not always imply that these benefits are all met. A list of conditions and prerequisites under which a biobased material is actually environmentally friendly, was given. It is important to always consider these conditions, since there are several biobased materials with a significant higher GWP than conventional materials.

The third and final question, '*why biobased top-up*', was answered with the help of a literature review. Biobased structures are in general lightweight which is important when topping-up and using existing structures. Biobased materials allow a high level of prefabrication which is important when topping-up existing flats, since it shortens the construction phase and with that limits the impact on the residents. And next, biobased materials offer a range of building physical benefits such as its thermal capacity, and its vapour diffusion.

By answering these three questions, the research question of this chapter, '*why should the 100 000 needed top-ups be built with biobased materials*', was answered. Biobased top-ups are simply said, the quickest route to Paris Proof construction of housing. With the additional benefits in terms of construction and health and well-being, an holistic story was created that pleas for the construction of the needed 100 000 top-ups with biobased materials.

5. THE RESOURCES

For centuries people in The Netherlands have built their houses with renewable, biobased building materials like timber, straw, reed and hemp, which were, due to technical developments, replaced by non-renewable, abiotic alternatives like brick, concrete, steel and plastics. People have started to realise however that this these have a large impact on the environment with its excessive exhaust of GHG's and depletion of non-renewable resources (Van der Lugt, et al. 2023). In the previous chapter, it was suggested that a circular and biobased economy could limit these negative environmental impacts. The Dutch building sector could, for this purpose look back on its long-standing tradition with biobased materials and continue to build on it. In this chapter, seven of these materials are analysed to see what the Dutch landscape currently has to offer.

This chapter will answer the following research question:

What kind of biobased materials can be sourced in The Netherlands?

To answer this research question a literature study was conducted on seven currently available biobased resources in The Netherlands:

- Wood
- Flax
- Hemp
- Straw
- Miscanthus
- Cattail
- Seaweed

For every material, the resource and the manufacturing into a product will be described. Next, the annual yield of the material in The Netherlands and in the region of Zuid-Holland is checked. Note that this was only done when data on this yield was available, which was unfortunately for several resources not the case.

Assumptions

To be able to interpret the provided numbers in the following chapter, some assumptions and boundaries need to be made. First of all, a rough notion of the amount of timber used in a top-up should be defined without already looking into a detailed design. According to Pablo van der Lugt (2023), a generic timber appartement contains roughly **20m3** of timber. The amount of insulation materials was derived from a specific design for a top-up of 100 square meters provided by Smits Vastgoedzorg, and will roughly be **35m3**. It should be taken into account that for reaching the goal of **100 000** top-ups by 2030, the annual production of top-ups, starting from 2023 should be **12 500**.

5.1 WOOD

Until the 19th century timber was the dominant building material in Europe. The industrial revolution led to its replacement with non-renewable mineral and fossil materials, due to its improved technical performances. In the 20th century, timber regained prominence due to advancements in laminating technologies leading to the introduction of for example plywood, MDF, and OSB, enabling efficient tree utilization and forest productivity. Sustainable forest management and reforestation efforts further boosted European timber sources. Automated strength assessment methods, such as laser scanning, enhanced timber quality, driving increased use in construction, particularly timber frame construction, in the late 20th century. And in the last two decades developments continued with the introduction of high-performance engineered Mass Timber Products (MTP) like Cross Lami-nated Timber (CLT) and Laminated Veneer Lumber (LVL) (Van der Lugt et al., 2023). But what timber products are currently produced and used in The Netherlands, and what kind of timber is the Dutch forestry even able to produce. These questions will be answered in the following subchapters.

5.1.1 Resource

As of today, the Netherlands is a large consumer of all sorts of wood products. Most of this wood is not sourced nationally. Currently the Netherlands is importing 4.6 million cubic meters (92%) of its timber and timber products. Of these 4.6 million cubic meters, 82% originates from Europe. The remaining 18% is imported from other parts of the world of which in 2021 4% originated from tropical forestry. 7% originated from Russia or Belarus, which is since the invasion of Russia in Ukraine not reliable source anymore.

Europe currently has around 160 million hectares of forest, which covers 36.9% of its total land area. It is estimated that these forests contain approximately 28.3 billion cubic meters of timber with an annual growth rate of around 800 million cubic meters. To put it in perspective, European forests produce enough wood to build a timber-framed house every second and enough for a CLT house every 2.5 seconds. Depending on the country and forest type 65% of the annual growth is harvested on average. This means that not only there is enough wood available every year, but also an additional 300 million cubic meters of wood is added to European forests annually. Approximately 155 million cubic meters of the harvested timber in Europe (in 2020) are processed into sawn timber, which is used in various applications, including construction (Probos & Centrum hout, 2023) . Therefore, there is still significant potential for scaling up timber construction in the Netherlands or even in Europe as a whole. The question for now is whether there is also enough timber in the Dutch forest.

The Netherlands itself has only a small forest area (373 480 hectares), primarily managed for nature conservation and recreational purposes, rather than wood production. In 2021 only 8%, which is 390 000 cubic meters of the timber use in construction originated from the Netherlands (Probos & Centrum hout, 2023). Plans to increase wood harvesting from Dutch forests have been developed for decades, but in reality, the opposite is happening: the annual yield is decreasing (Lerink, 2023). The graph on the following page illustrates the volume of our annual wood harvest, as measured in Dutch Forest Inventories (Schelhaas et al., 2023).

What the graph also shows is the distinction between coniferous and deciduous trees. In general, coniferous trees grow in colder areas and have more straight logs, where deciduous trees grow in more warmer climates and have less straight logs. The Dutch forest is in this sense a well-balanced forest because the percentage of coniferous trees is 51% and of deciduous trees 49%. Important coniferous trees that grow in The Netherlands are pine, larch, spruce and douglas, and important deciduous trees are oak, beech, berch, poplar and willow. Most of these trees grow mature in 50 years. However, poplar and willow are fast growing trees which could be harvested within 25 years from planting.

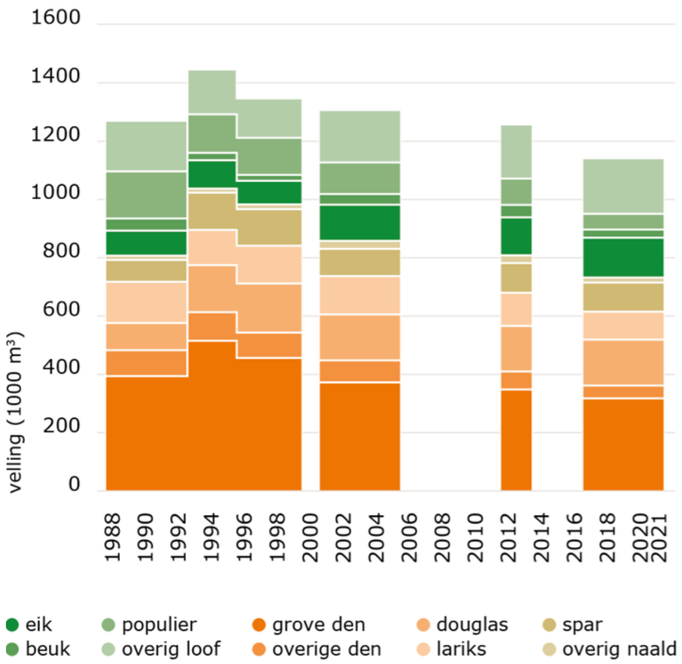


Fig. 5.1 Harvest of wood in The Netherlands (Schelhaas et al., 2022)

Not all wood is used in the construction sector. Wood is also used for other products like paper or firewood. Of the 1,15 million m3 of wood that was harvested from the Dutch forests in 2021, only 390 000 m3 ended up as construction wood. This wood could be processed into three different semi-finished products namely strands, veneers and timber. Of the 390 000 m3 of harvested construction wood, only 148 000 m3 ended up as actual timber of which 110 000 m3 (74%) was coniferous and 38 000 m3 (26%) was deciduous. As a reference, the average amount of timber used for appartements is 20 m3 (Van der Lugt et al., 2023), which means that in 2021 the Dutch forests were able to produce timber for only 7 400 appartements.

5.1.2 Manufacturing

As was mentioned in the introduction of this subchapter, several developments took place in the last century on mass timber. Due to the need for more homogeneous, high-performance properties, engineered wood was introduced. Engineered wood is an umbrella term for several categories of mass timber products. There is large variety of mass timber products, which could also be categorized in different ways. For this research the categorization by Pablo van der Lugt (2020) was slightly adopted to fit in the storyline. In the following subchapter the manufacturing process, products and applications of four product groups of engineered wood will be summarized. For most of these Mass Timber Products (MTP) the quantities are given by the Kerngegevens bos en hout in Nederland (2022). In the graph on the following page the different MTPs with its quantities are displayed.

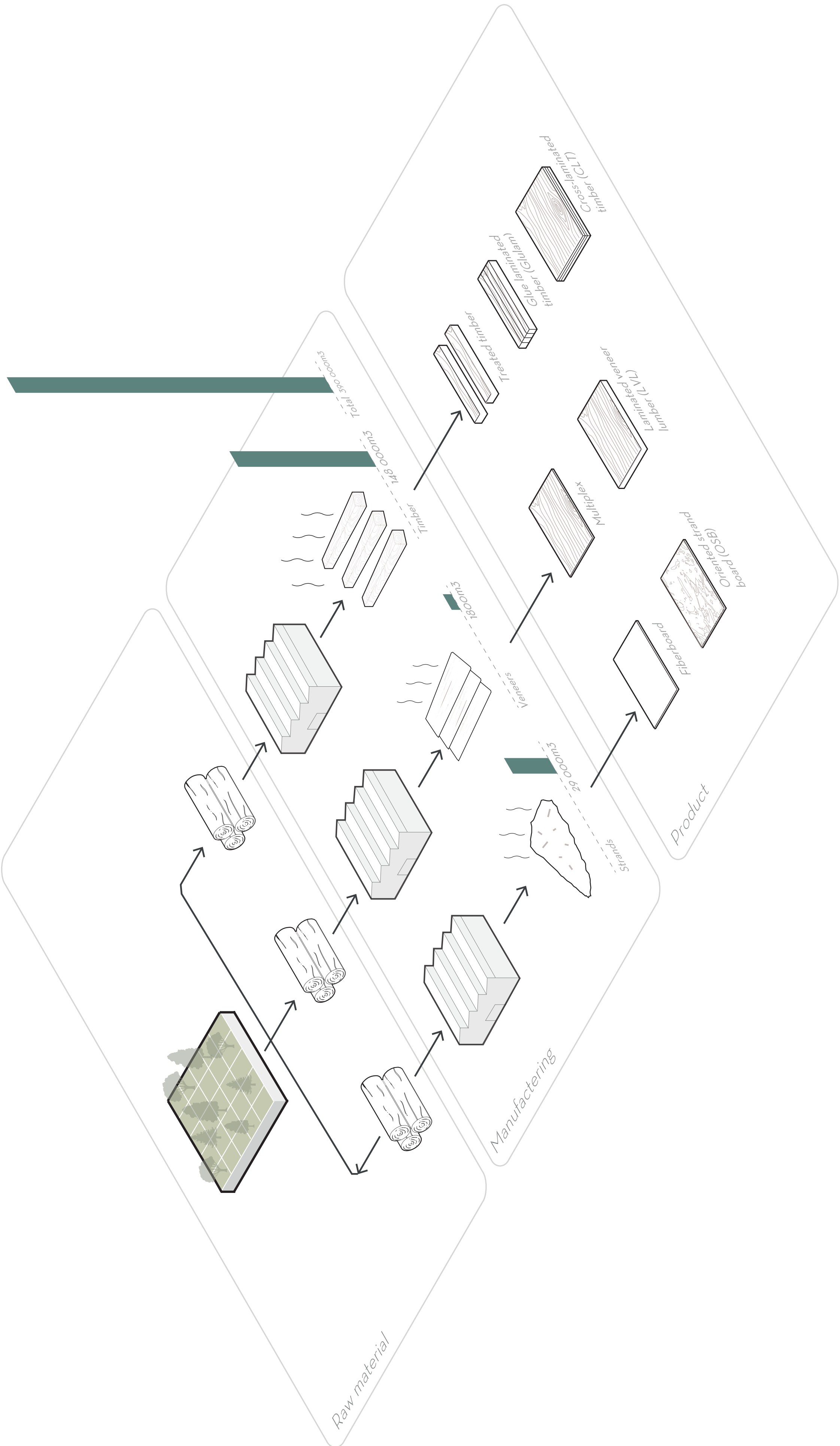


Fig. 5.2 The use of wood in the Dutch construction sector (Kerngegevens bos en hout in Nederland, 2022)

#	Product	Volume (m³)	Percentage
1	Total amount wood	390 000	
2	Loss (due to sawing and manufactering)	211 200	54,2%
3	Strands	29 000	7,4%
4	Veneer	1 800	0,5%
5	Timber	148 000	37,9%

Table 5.1 The use of wood in the Dutch construction sector (Kerngegevens bos en hout in Nederland, 2022)

This table shows that of the total 390 000 m3 of wood that is used for the construction industry, only 172 800 m3 ends up in wood products, which means there is a conversion factor of 44%. This conversion factor describes the amount of wood which is lost in manufacturing through sawing and processing of the material. It comes without saying that this loss is significant and reducing it will increase the total availability of material. The saw loss could differ per type of MTP. In the graph below six types of MTPs are displayed with the amount of wood which is needed to create 1m3 of the product. As you can see, glulam and CLT require the most wood namely almost 3 m3, where OSB require only 1,2m3 which means the conversion factor gets close to 100% (Pramreiter et al., 2023).

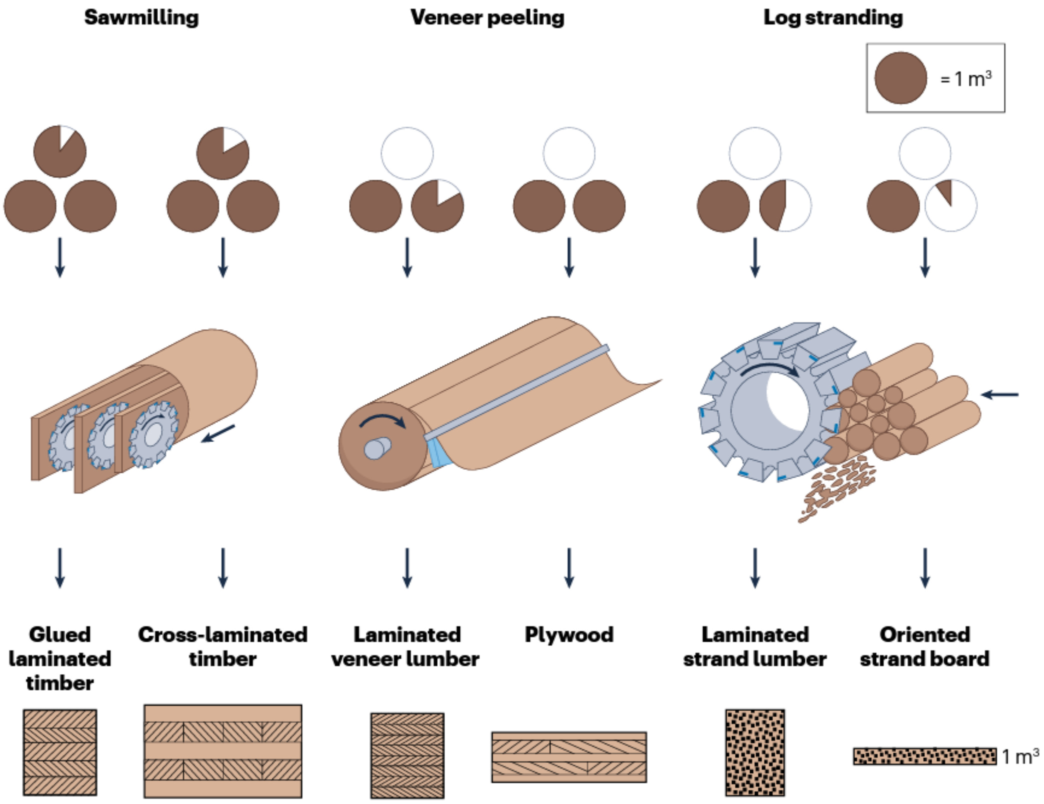


Fig. 5.3 Conversion of wood to MTP (Pramreiter et al., 2023)

#	Product	m3 needed round wood for 1m3 product	Conversion
1	Glue laminated timber*	2,8	35%
2	Cross laminated timber (CLT)*	2,7	37%
3	Threated timber**	1,6	63%
4	Laminated veneer lumber (LVL)*	1,7	59%
5	Plywood*	2	50%
6	Laminated strand lumber*	1,4	71%
7	Oriented strand board (OSB)*	1,2	83%
8	Fiberboard**	1,8	56%

*Table 5.2 Conversion of wood to MTP * (Pramreiter et al., 2023) ** (UN, 2011)*

5.1.3 Product - Timber

Fig. 5.4 Close-up of cross laminated timber (Stora Enso, n.d.)

The first product group is timber, consisting of products where solid timber boards are laminated, which are Glue laminated timber (Glulam) and Cross laminated timber (CLT). Glulam was already introduced in the early 1900s. Glulam typically comes in beams or columns and consists of softwood boards with thicknesses between 6 and 45 mm, which are aligned and glued together in the longitudinal direction. The boards are typically joined together with a finger-joint. CLT on the other hand was only introduced around the 1990s and is gaining popularity fast. In this product softwood boards are glued together in the perpendicular direction through which a structural panel could be manufactured. The benefit of perpendicular layering is that the product could withstand forces in two directions, which means a structural panel could be created. Thicknesses vary between 60 and 500 mm with a width up to 4.5 meters and a length of maximum 25 meters.

5.1.4 Product - Wood fibre

Fig. 5.5 Close-up of wood fibre insulation (Gutex, n.d.)

Next comes wood fibre. Wood fibre based products are classified according to density, typically softboard, medium density fibre board (MDF) and high density fibre board (HDF). The starting point of all these products is obviously wood fibre which is collected as saw loss from the processing of logs into timber products. This saw loss, which mostly come as chips, is refined into wood fibre which pocesses a natural binding element called lignin. Binding this wood fibre into solid boards could be done in a wet and a dry process. In the wet process, the lignin is bound by mixing the wood fibre with water after which it is pressed under high pressure in very high temperatures into boards. Softboard and HDF are in general manufactured with a wet processing. Alternatively a dry process could be applied, in which the wood fibres are bound by a synthetic formaldehyde based glue. Wood fibre based products have many application in high quality products. Softboard is relatively porous which means it has insulating properties. Companies like Steico and Gutex are specialized in wood fibre insulation and offer a wide variety of products. MDF and HDF are both mainly used as non-structural finishes and in the furniture industry. For all three products it should be mentioned that several variations are possible when certain additives are used in the manufacturing process, to make the products more water- or fireproof (Centrum hout, 2015).

5.1.5 **Product - Strands**

Fig. 5.6 Close-up of flax particle board (Unilin, n.d.)

The third product group are the engineered wood products made out of strands. The increased need for efficiency has lead in the late 20th century to an increased use of waste-material from the processing of wood products. Strands, chips and particles were increasingly utilized in newly designed engineered wood products. Currently the best known standardized wood panels are particle boards and oriented strand board (OSB). In both cases, small wood chips which are collected as sawdust, are glued together with a synthetic formaldehyde based glue, after an industrial hot-press creates the panels. Both the particle board and OSB are used as non-decorative sheeting material. Similar to fibreboards, additional properties (like fire- or water resistance) could be added to these products by using additives (Van der Lugt, 2020).

5.1.6 **Product - Veneer**

Fig. 5.7 Close-up of laminated veneer lumber (Metsawood, n.d.)

And finally, engineered wood made from veneers. Similar to the use of strands, the use of veneers arose from an increased need for efficiency. The process consists of multiple steps. After debarking, the logs are steamed and go through a rotary veneering which peels of large sheets of 2-4 mm. These veneers are dried and graded on their strength. Several products are manufactured with veneers, of which plywood is perhaps the most well-known product. Plywood was the first industrialized wood panel, already introduced in the 1930s. Later, new developments took place which has led to the introduction of new MTPs based on veneers such as laminated veneer lumber (LVL), parallel strand lumber (PSL) and laminated strand lumber (LSL). All these products are quickly gaining popularity, however, LVL truly stands out. The veneers used to construct LVL, which are with 6 mm slightly thicker than the ones used for plywood, are hot-pressed with a synthetic formaldehyde based glue. This continues process produces large panels up to 3 x 24 meters. LVL is praised for being very consistent, stable, stiff and strong. A general rule is that it has twice the strength of sawn timber of the same species (Van der Lugt, 2020).

5.1.7 End of life

In contrast to conventional building materials, mass timber stands out as a lightweight and easily manageable material, lending itself well to dry construction methods, which are ideal for flexible and demountable buildings. By designing demountable elements or modules for easy disassembly they can be efficiently extracted from structures at the end of their functional life. This approach holds particular relevance for sizable solid components like CLT and glulam which, when kept dry, can be reshaped and reused with a simple sanding process. This reusing of timber components has two advantages. On the one hand the embodied biogenic carbon is stored for a longer period. And on the other hand the forests will have a longer period to regenerate multiple times. After a second or third high-quality useful life, it becomes sensible to recycle timber components by chipping them for use in panel boards like particle boards, MDF, or OSB. In their fourth or fifth life, these elements can serve purposes in bio-energy production, biochar for soil improvement, or biochemistry, ultimately reaching their final destination. This approach contrasts with grey biomass, which directly uses newly harvested logs for energy production.

Currently, most LCA's and EPD's are still based on a scenario where timber is eventually incinerated for energy. However, the EU's environmental goals by 2050 suggest that incinerating existing timber constructions will likely be banned, especially since many timber constructions have functional lifespans exceeding 50 years. It is probable that after 2050, greater emphasis will be placed on reusing timber, and the current practice of incineration for energy production may become prohibited. When a mass timber EPD is based on a circular scenario, incorporating element reuse, the resulting global warming potential and carbon footprint are significantly lower than the already low impact (Van der Lugt et al., 2023).

5.2 FLAX

The first fiber crop which is researched in this paper is flax. Flax is an ancient crop with a fascinating history. The Egyptians were already making linen threads from flax 7000 years ago. In Europe, particularly in Flanders, flax cultivation has thrived for centuries. It was already introduced to the Netherlands in the 16th century (Alterra Wageningen UR, 2014). Today the Dutch flax industry is however rather small. What is the reason for this and what does the current processing of flax look like?

5.2.1 Resource

The coastal area in North-Western Europe, stretching roughly from Groningen to Caen in France appeared to be the ideal location to grow flax because of its rich soil and its temperate Northsea climate. For centuries people settled here to cultivate flax and produce linen. The Dutch flax industry has however been in a decreasing trend for several years now, mostly because of the use of synthetic materials in the clothing industry, through which the industry moved to Asian countries (Libeco, 2021).

A small revival is currently taking place due to new business models and new applications among which most of them are in the building industry. In 2022 farmers in The Netherlands cultivated flax on roughly 1945 hectares of which 39 was sown in the region of Zuid-Holland. The annual yield was nationally around 10 000 tonnes and in Zuid-Holland 149 (CBS, 2023). This yield was used in several products, like insulation or non-structural finishes. To give an idea of how much this yield it was checked how many top-ups could be build annually with the dominant application which is insulation material. The annual yield is given in tonnes, so to transfer this to volume, which is needed for the top-up, the content of short fibres was taken which is 37,5% (Wander & Zwanenpoel, 1999). Next, the density of flax insulation (Isovlas, n.d.) was used to calculate the total volume that could be reached with the current stock, which is 151 710 for The Netherlands. This means that in total 4 322 top-ups could be supplied with this flax insulation annually.

#	Region	Annual cultivation *(hectares)*	Annual yield *(tonnes)*	Conversion *(m3)*	Amount of Top-ups
1	Netherlands	1 945	10 114	151 710	4 322
2	Zuid-Holland	39	149	2.235	63

Table. 5.3 Flax cultivation (CBS, 2023)

Before being able to explain the different application of the flax plant has in the building industry it should be mentioned that flax consists of different parts. In the previous chapter the concept of parallel cascading was explained. Flax is actually the perfect example of where this concept is applicable. The flax plant namely consists of multiple parts, like the seeds, the shives and the fibres which can all be used for different purposes in the building industry (Grow2build, 2015).

Seed
The seeds of flax could be used to produce oil. This oil can serve as a base for ecological paints or for coatings of timber and other porous materials.

Shive
The stalk of the plant has a wooden-like material inside which is called the shive. With these shives particle boards could be made.

Fibre
The shive of the stalk is covered in a thin layer of fibres. The long fibres are separated from the short fibres. The long fibres are used for textile industry while the short fibres could be used for technical applications.

5.2.2 Product - insulation

Fig. 5.8 Close-up of flax insulation (Isovlas, n.d.)

Production
The first and most dominant application flax has as a building material is insulation. For the production of insulation materials, the shorter and stronger fibres are utilized to manufacture non-woven rolls. Non-woven implies that it isn't knitted or woven; instead, the fibres are bonded through friction, cohesion, or adhesion. In the case of flax insulation, the manufacturing process consists of three steps:

- Carding: This process aligns the fibres parallelly independently to create a consistent and durable web.
- Cross-lapping: Here, multiple layers are stacked to achieve the desired weight.
- Needling: Barbed needles interconnect the fibres in this step, forming a uniform and robust non-woven fabric.

Composition

- The short and stronger fibres of the flax plant
- A starch to enhance the strength
- A soda as a flame retardant
- Boric acid as a retardant for mould

Technical

#	Property	Amount	Unit
1	Density (ρ)	20-30	kg/m3
2	Thermal conductivity (λ)	0,038 - 0,040	w/mk
3	Thermal capacity (c)	1550 - 1600	j/kgk
4	Vapor diffusion resistance (μ)	1-2	
5	Airborne sound insulation	44	dB
6	Fire class	C	

Table. 5.4 Technical properties flax insulation (Isovlas, n.d.)

5.2.3 Product - biocomposite

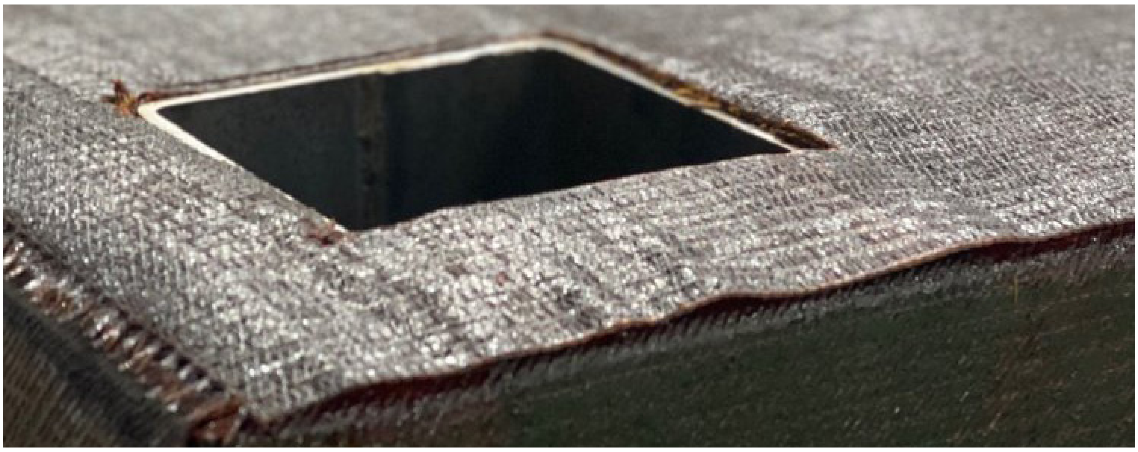


Fig. 5.9 Close-up of flax bio composite (duplicor, n.d.)

Production

The second application flax has is in bio composites. Bio composites typically consist of two main components: fibres and a matrix. The matrix could be fossil-based, like a polymer or cement, and bio-based like PLA which is extracted from corn or potato. For the production of bio composites the resin is shaped and reinforced with the flax fibres through which a stiff and lightweight material is created. A shortcoming of a bio composite is that it absorbs water after which it could deform.

Composition

- The short and stronger fibres of the flax plant
- A matrix (polymer, cement, resin)
- An accelerator and binder

Technical

Note: The technical properties depend on the properties of the specific product, in this case duplicor by Martens Keramiek (2022).

#	Property	Amount	Unit
1	Thickness	0,2 - 20	mm
2	Density (ρ)	1800	Kg/m3
3	Young's Modulus (E)	36000	N/mm2
4	Fire class	B	

Table. 5.5 Technical properties flax bio composite (Dupicor, 2022)

5.2.4 Product - particle board

Fig. 5.10 Close-up of flax particle board (Linex, n.d.)

Production

The third and final application of flax is that in particle boards. The shives of the flax plants could be used to create these non-structural panels. First, the shives are cut into the right sizes after which they are mixed with water and a resin, and compressed into firm and strong boards which have very similar properties as a particle board made from timber shives.

Composition

- Flax shives
- Water
- A binder (Formaldehyde based)
- A hardener

Technical

Note: The technical properties depend on the properties of the product, in this case Flaxboard by Linex (n.d.)

#	Property	Amount	Unit
1	Density (ρ)	350	w/mk
2	Thermal conductivity (λ)	0,07	Kg/m3
3	Fire class	D	
4	% biobased	70-80	

Table. 5.6 Technical properties flax particle board (Linex, n.d.)

5.3 HEMP

The second fibre crop which is researched in this paper is hemp. Hemp fibre refers to specific hemp plant varieties primarily cultivated for their fibre content. Dutch farmers in the southwestern region of the Netherlands, have cultivated hemp for centuries, mostly for the rope and sail industry. However, just like what happened with the flax industry, the emergence of more cheaper alternatives, such as sisal and jute, led to a decline in both the market and local production. Subsequently, the hemp fibre industry shifted predominantly to countries like Russia, Italy, and the United States. Currently the hemp industry in The Netherlands and Europe is experiencing a small revival because it is deemed a more sustainable solution for several application in the in construction sector (Biobasedgarden, 2018).

5.3.1 Resource

After the complete disappearance of the fibre hemp industry around 1940, it took almost 50 years before it was reintroduced by the founding of the company HempFlax in the eastern part of Groningen. The company quickly grew and expanded to Germany and Denmark as well. Following on Hempflax' success, yet another company in the same region was founded, DunAgro. As of today, these two companies still dominate the Dutch hemp fibre market. In 2021 they were cultivating roughly 1360 hectares which is 80% of the total Dutch hemp industry (1700 hectares). This is much less then in 2017 when it was more than 2000 hectares. This is partly due to the rather complicated process of harvesting (Grow2build, 2015).

It is said that the cultivation of hemp is relatively easy while harvesting it is much harder. During the growth phase, weeding is practically unnecessary because the crop is growing fast and compact in the field, through which diseases and pests don't stand a chance. Additionally, fibre hemp requires minimal nutrients to achieve a good yield with low fertilization. Furthermore, the extensive root system of this plant is known to improve soil quality.

Harvesting of this crop is on the other much harder. Fibre hemp is typically sown in April and May and can reach heights of up to 4 meters. Large harvesting machines are deployed from August onwards. The primary goal of the cultivation is to extract the fibres from the shive inside, which has yielded an average of 7 to 8 tons of shives per hectare in the Netherlands in recent years. These machines that can extract the fibres from the shive are complex and make the cultivation of fibre hemp economically less feasible. Still with the techniques available, it said that the cultivation of fibre hemp could rapidly grow if the demand will increase (Boerenbusiness, n.d.).
In the year 2022 a total of 1 684 hectares of hemp was cultivated in the Netherlands, and on 73 hectares in Zuid-Holland (CBS, 2023). This resulted in a total annual yield of 14 142 tonnes nationally, and of 512 in Zuid-Holland. Just like was done with the flax yield, this number was transferred to volume by taking the percentage of fibre content which is 30% (CAH Dronten, 2002) and multiply that by the density of hemp insulation (Hempflax, n.d.). Doing so, it was concluded that around 2 417 top-ups could be supplied with insulation material.

In the following subchapters the different applications of hemp fibre in products used in construction, were briefly explored.

#	Region	Annual cultivation *(hectares)*	Annual yield *(tonnes)*	Conversion *(m3)*	Amount of Top-ups
1	Netherlands	1 684	14 142	84 852	2 417
2	Zuid-Holland	73	512	3 072	87

Table. 5.7 Hemp cultivation (CBS, 2023)

5.3.2 Product - insulation

Fig. 5.11 Close-up of hemp insulation (Hempflax, n.d.)

Production

The first application is that in insulation. Similar to the flax fibres, insulation material is made with the fibres of the hemp plat. To do so, a non-woven fabric was created by following the following steps:

- Carding: This process aligns the fibres parallelly independently to create a consistent and durable web.
- Cross-lapping: Here, multiple layers are stacked to achieve the desired weight.
- Needling: Barbed needles interconnect the fibres in this step, forming a uniform and robust non-woven fabric.

Composition

- The short and stronger fibres of the hemp plant
- A starch to enhance the strength
- A soda as a flame retardant
- Boric acid as a retardant for mould

Technical

Note: The technical properties depend on the properties of the product, in this case Hempflax insulation (n.d.)

#	Property	Amount	Unit
1	Density (ρ)	30 - 36	kg/m3
2	Thermal conductivity (λ)	0,04 - 0,042	w/mk
3	Thermal capacity (c)	2100 - 2500	j/kgk
4	Vapor diffusion resistance (μ)	1-10	
5	Airborne sound insulation	44	dB
6	Fire class	D	

Table. 5.8 Technical properties of hemp insulation (Hempflax, n.d.)

5.3.3 Product - hempcrete

Fig. 5.12 Close-up of hempcrete (Isohemp, n.d.)

Production

The second application of hemp is found in hempcrete. This concrete-like product is in fact a mixture of hemp shives, limestone and water. This blend creates a natural, insulating, and breathable construction material. It has some load-bearing properties but should always be constructed with an additional structure like a timber frame. Hempcrete comes in block form, casted in-situ, or sprayed. The ratio of hemp shives to limestone varies depending on the application, manufacturer, and water content. A pozzolan is always added as a binding element.

Composition

- Hemp shives (80-85%)
- Limestone (10-15%)
- Water (5%)

Technical

Note: The technical properties depend on the properties of the product, in this case Isohemp (n.d.)

#	Property	Amount	Unit
1	Density (ρ)	340	kg/m3
2	Thermal conductivity (λ)	0,056	w/mk
3	Thermal capacity (c)	750 - 900	j/kgk
4	Vapor diffusion resistance (μ)	3,6 – 4,8	
5	Airborne sound insulation	52	dB
6	Fire class	B	

Table. 5.9 Technical properties of hempcrete (Isohemp, n.d.)

5.4 STRAW

The fourth biobased material which is researched in this paper is straw. For thousands of years, straw has been used as a building material in roofing or in clay-straw mixtures. However, the true history of 'straw construction' began with the invention of the straw bale press in the late 19th century in the USA. Settlers in the wood-scarce areas used straw bales as oversized bricks to construct houses, schools, and churches. Industrialization led to straw's decline in construction, but it was rediscovered with the energy crisis in the 1970s and the rise of environmental awareness. Today straw is considered a well-tested construction material with good building-physical properties (Vereniging Strobouw Nederland, 2017).

5.4.1 Resource

Straw is an interesting resource since it is in fact a residual of the grain industry. Since grains are globally among the most cultivated crops, it inherently means there vast amounts of straw available. In the Netherlands, six different types of grain was cultivated on at least 163 000 hectares, which means the total yield of straw was around 650 000 tonnes (RVO, 2021). This amount could potentially insulate roughly 65 000 homes annually, which is far more than the needed 12 500 top-ups.

Straw could be used in different applications in the construction sector. Traditionally load-bearing straw bales were used as walls to create entire buildings. In The Netherlands straw is used in combination with a timber frame in a so-called timber-straw panel.

#	Region	Annual cultivation *(hectares)*	Annual yield *(tonnes)*	Conversion *(m3)*	Amount of Top-ups
1	Netherlands	163 000	600 000	-	155 844
2	Zuid-Holland	-	-	-	-

Table. 5.10 Availability of straw (RVO, 2021)

5.4.2 Product - timber-straw panel

Fig. 5.13 Close-up of a timber-straw panel (Ecococon, 2022)

Production

A timber-straw panel is nothing more than a prefab timber-frame wall filled with straw. In the case of the product Ecococon (2008), it is a load-bearing twin stud frame. The straw insulation is first pressed into the right shape by a multidirectional press. The benefit of this system is that the insulating material is just straw. There are no additives like formaldehyde resins or fire retardants needed. It is decided to combine the panels with other natural materials like limestone or loam. The fire-safety of the entire wall comes from these additional materials.

Composition

- Straw (89%)
- Timber (10%)
- Steel connections of the timber frame (1%)

Technical

Note: The technical properties depend on the properties of the product, in this case Ecococon(n.d.)

#	Property	Amount	Unit
1	Density (ρ)	115	kg/m3
2	Thermal conductivity (λ)	0,0645	w/mk
3	Phase shift	18	hour
4	Load-bearing capacity	60	kN/m
5	Fire class	E	

Table. 5.11 Technical properties of a timber-straw panel (Ecococon, n.d.)

5.5 MISCANTHUS

Miscanthus is an originally Asian genus of giant grasses that visually falls somewhere between reed and bamboo. It appears to possess all the qualities necessary for cultivation in various applications: it thrives in diverse conditions, it has a high growth potential, requires minimal care, and has the habit of storing its nutrients in the roots at the end of the growing season, so that these could be reused in the next season which means this crops needs nearly zero fertilization. Promising and high-value applications of miscanthus include for example fibres as a substitute for cotton in clothing, paper, livestock feed, packaging material. But also, as a raw material for bio plastics and bio composites (Baecke, 2019).

In Europe, miscanthus has been cultivated as an ornamental plant since 1930, originating from Japan. In the late 1960s, Denmark examined the yield potential of miscanthus for cellulose fibre production. Trials for bioenergy production began in 1983, after which the crop gained interest in Germany and the rest of Europe. Around the year 2018, approximately 5 500 hectares were already dedicated to miscanthus cultivation in France, and 4 600 hectares in Germany (Baecke, 2019). Around 2020 in Great Britain already 15 000 hectares were used for the cultivation of miscanthus (Trindada, n.d.).

Lately, miscanthus is often categorized as a super crop due to its growth potential, its ability to absorb CO2, and the high-quality products that could be made with it. However, in The Netherlands the market is relatively new, and there is still much to be done before cultivation and processing become economically feasible. Numbers of the current cultivation of miscanthus in The Netherlands are scarce. In 2014, Boosten & Oldenburg estimated, in order of Stichting Probos, that the acreage of miscanthus cultivation would grow up to 500 hectares in 2020. Whether this has been accomplished has not been checked.

5.5.1 Resource

Miscanthus has an effective lifespan of 15 to 20 years with an annual harvest. The plant is planted in spring and, in one season, grows to a height of 1-2 meters. In the first year, the yield is still relatively limited, so no harvesting takes place. From the second year onwards, the plant reaches a height of 3-3.5 meters, resulting in an average annual biomass harvest of about 20 tons. Miscanthus grows densely and tall, requiring minimal weed control. Furthermore, it has relatively low soil requirements, making it suitable for cultivation on unused land, such as a large piece of land under the flight path of Schiphol Airport, where about 60 hectares have been planted.

Due to its rapid growth and high yield, miscanthus is considered a viable alternative for biomass. It can be used for direct combustion or gasification to produce bioethanol. However it also has a lot of application in the construction sector. Miscanthus is a grass species with relatively thick fibres, thick enough to serve as an alternative to the shives that are used in particleboards (Baecke, 2019). There are currently two companies, Linex-pro-grass and Ecoboard Europe bv, that use miscanthus fibres in their particle boards. Additionally, it is also used as a filler in bio concrete (Xiriton) by Aqronic and in a bio-composite board by Vibers. There are ongoing experiments to use miscanthus as a filler for sandwich panels and in combination with lime and water, creating a product similar to hempcrete. However, these products are still in the development phase and are not included here.

#	Region	Annual cultivation *(hectares)*	Annual yield *(tonnes)*	Conversion *(m3)*	Amount of Top-ups
1	Netherlands	500	10 000	-	-
2	Zuid-Holland	-	-	-	-

Table. 5.12 Cultivation of miscanthus (Boosten & Oldenburg, 2014)

5.5.2 Product - particle board

Fig. 5.14 Close-up of particle board with miscanthus (Linex, n.d.)

Production

The first application miscanthus has is in particle boards. In 2009, the Dutch company Linex Pro-Grass bv, initiated a pilot project by contracting 20 hectares of miscanthus from five local farmers for the purpose of incorporating it into particleboard production. In this application, miscanthus fibres can function as a substitute for wood chips, much like flax shives, enabling the production of environmentally friendly sheet materials. These contracts with the farmers were established for a duration of 10 years. Currently, Linex Pro-Grass annually processes 2400 tons of miscanthus in their production. Product specifications for their particle board include that the miscanthus fibres should have a moisture content of less than 16% and a chip length of 5 mm. This shorter chip length facilitates better drying of the particle board (Snauwaert & Ghekiere, 2012).

In 2012 Arjan Berkhout from Linex-Pro-Grass explained that they were blending at least 15% miscanthus for the production of their lightweight panels. To achieve this, they require an equivalent of 150 hectares of miscanthus. The roughly 30 hectares available in the region were therefore insufficient. Linex therefor primarily sources most of its miscanthus from Germany. "From a certification standpoint, we could potentially increase the blend to 30%. This would mean that there needs to be 300 hectares of miscanthus. The closer these fields are to the factory, the better, as transportation is costly" (Dieleman, 2012).

Composition

- Flax shives
- Miscanthus shives
- Water
- A binder (Formaldehyde based)
- A hardener

5.5.3 Product - bio concrete (Xiriton)

Fig. 5.16 Close-up of bioconcrete (Xiriton, n.d.)

Production

Similar to the applications of hemp, miscanthus is used in so-called bio concretes of which Xiriton is currently a promising Dutch example. Standard concrete normally consists of cement, water and gravel. In the quest to reach a carbon neutral concrete, several companies have started to experiment with replacing this carbon intensive materials with more eco-friendly alternatives. Xiriton has done this by replacing the gravel by miscanthus shives, and replacing the cement by a pozzolan, a natural binder. The miscanthus shives obviously have a much lower density than gravel, resulting in a reduced strength of the material as well. On the other hand, the material does have a certain insulating capacity through these same shives. This lightweight bio-concrete could theoretically have many application in for example infrastructure and street furniture, but in the construction of housing as well where it could in certain case replace regular concrete.

Composition

- Miscanthus shives
- Water
- A pozzolan binder
- Additives (seashells)

5.6 CATTAIL

Fig. 5.17 Close-up of cattail (Bgdd, n.d.)

Resource

A crop which is currently still in a somewhat experimental phase, though very promising, is cattail. This native species could be cultivated on the wet peat soils in The Netherlands. Traditionally cattail was grown along creeks and rivers and harvested for nutrition. Since several years companies have started to see the potential of cattail in the light of biobased materials. This crop thrives, other than the other biobased resources named in this paper, in waterlogged conditions. It prefers water-saturated soil where the roots are always wet. Doing so, this crop will store a lot of carbon, and improve the quality of the water. Up to now, experience with cattail cultivation has mainly been gained from small-scale pilot fields. Efforts are currently underway to scale up production (Colbers et al., 2017).

Production

The plant of the cattail consists of a stem made from cellulose fibres forming hollow chambers. This property makes that the plant already naturally insulates well. Currently most companies that make insulation material from cattail use only this stem and shred it. This could then be used as blow-in insulation or be hot-pressed into sturdy insulation boards with. Colbers et al. (2017) however do mention that the thermal conductivity of these products is still relatively high, whit which they question the insulating properties of these products.

5.7 SEAWEED

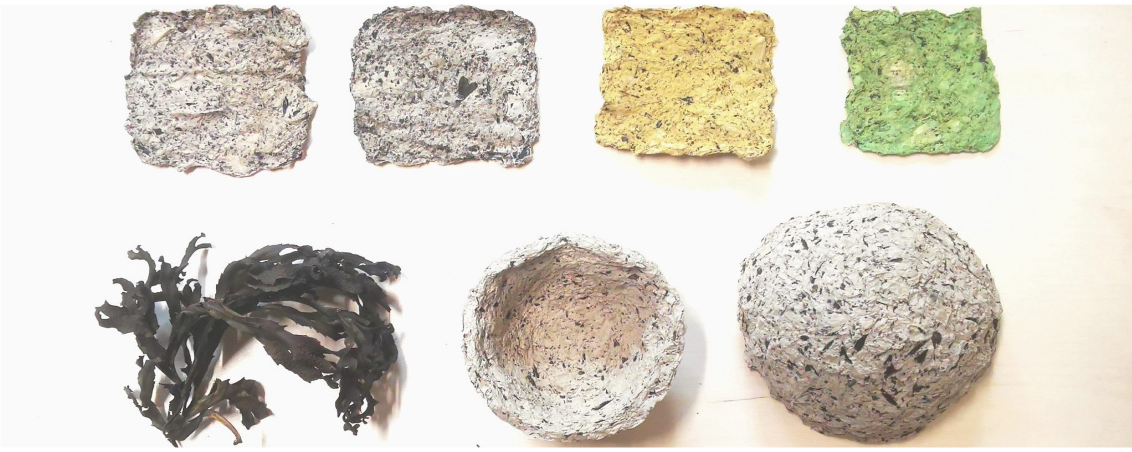


Fig. 5.18 Close-up of hempcrete (Blue Blocks, n.d.)

Production

Seaweed is a fast-growing crop which is grown in the sea. The most important benefit of this crop is that it does not require any scarce land, fresh water or harmful fertilizers, which are all three quite pressing problems in the Netherlands and the region of Zuid-Holland. There are currently a few companies in The Netherlands that experiment with locally sourced seaweed. BlueBlocks for example, sources different species that grow in the Dutch water like red, green and brown seaweed and also mixes them with other fibres like hemp or flax. This company has developed a technique to extract a binding agent into a bioplastic, and with the residual fibres they can make pressed boards which could serve as non-structural finishing. There is currently a lot of research conducted into these products, to perhaps start scaling-up the production in the near future (BlueBlocks, n.d.).

5.8 CONCLUSION

This chapter reviewed which biobased materials could currently be sourced in the Netherlands and in what quantities. A literature review showed that there are at least seven resources that either have a decent amount of supply or are promising because of its properties. In the table and figure below, the findings of this literature review with the availability of the material and its application, is displayed. The availability of timber is clearly not enough to supply the need of structural material for the 12 500 top-ups that should be built annually, even if all available timber in the Netherlands is utilized. The promising alternative for this lack of structural material is straw because of the enormous quantities of the available stock. Straw is a residual from the processing of grains and is therefore abundantly at hand. Pressed straw furthermore has a load-bearing capacity which is utilized in timber straw panels that only require a minimal amount of timber. With the four available fibre crops, flax, hemp miscanthus and cattail, both insulation material as non-structural finishes could be made. Quantifying the amount of non-structural finish material for the top-up is very complex was left out of this comparison. Flax and hemp together supply for around 6 700 top-ups which is, like timber, not enough.

It could therefore be concluded that the current supply of biobased materials is insufficient for the 12 500 top-ups that should be built annually. Both the need for structural material as for insulation material should be increased.

#	Resource	Annual cultivation *(hectares)*	Annual yield *(tonnes)*	Conversion *(m3)*	Amount of Top-ups
1	Wood	373 480	-	390 000	7 400
2	Flax	1 945	10 114	151 710	4 322
3	Hemp	1 684	14 142	84 852	2 417
4	Straw	163 000	600 000	-	155 844
5	Misanthus	500	10 000	-	-
6	Cattail	-	-	-	-
7	Seaweed	-	-	-	-

Table. 5.13 Available biobased materials in the Netherlands

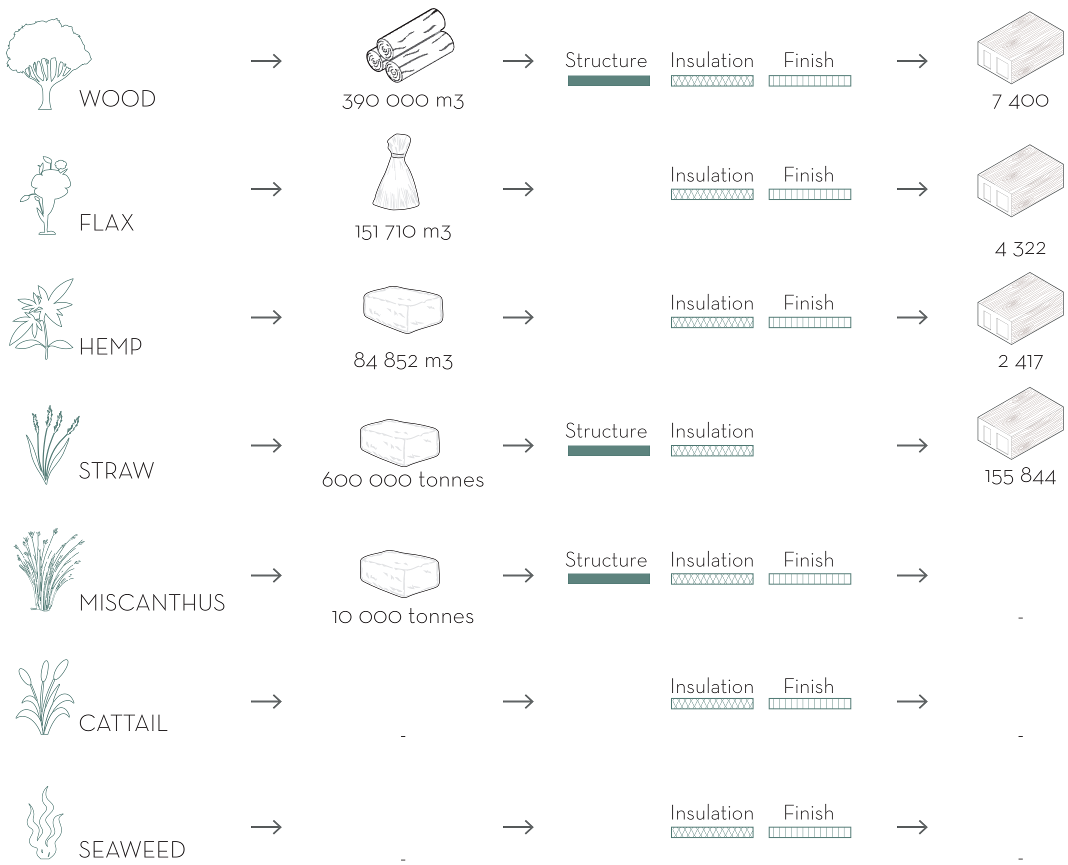


Fig. 5.19 Available biobased materials in the Netherlands

6. THE SCALE-UP

On November 8th, 2023 four ministries of the Dutch government together announced a stimulating fund for biobased building materials, of in total 200 million euros (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties et al., 2023). The goal of this fund is to enhance the production and use of biobased building materials in the Netherlands. Apparently, the market needs a boost. But until what extend is the Dutch landscape fit for scaling up, and will it not compete with for example food production or biodiversity?

This chapter will answer the following research question:

Can the production of biobased building materials be scaled-up to contribute to the construction of the 100 000 needed top-ups?

To answer this question multiple scales were covered. First of all, a national approach was given by mainly one document. With the announcement of the 200-million-euro fund of last November, a document was published that sets out a national approach to stimulate the production and use of biobased materials in the Netherlands. Next, a regional approach will be created by performing an analysis of the landscape of Zuid-Holland, which is then linked to the resources from the previous chapter. And lastly, each resource will be evaluated once more to check how the production could be scaled up.

6.1 THE NATIONAL APPROACH

The Netherlands is currently confronted with serious environmental challenges, particularly the need to preserve the biodiversity and address the impacts of climate change. Biobased building is seen as one of those solution that could tackle multiple of the national problems which is also noticed by the government. Multiple studies to the potential of biobased materials have been conducted. The most recent study the 'Nationale Aanpak Biobased Bouwen' (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties et al., 2023), describes a national strategy for biobased building. In this subchapter the most important findings of this report will briefly be summarized.

6.1.1 Environmental challenges

The pressing environmental challenges for which biobased materials could provide solutions are:

Nitrogen crisis

To protect the remaining Dutch nature reserves, it is necessary to limit nitrogen emissions across various sectors in the coming years. This fact has led to an immediate stop on the expansion of farms in the Netherlands, due to the vast amounts of ammonia and nitrogen emissions of livestock farming. The cultivation of fibre crops for biobased construction materials provides farmers with an alternative income source and can help in reducing nitrogen in agriculture. Particularly beneficial in areas where farmers need to expand, such as around Natura 2000 sites and specified water bodies, cultivating fibre crops allows for growth by partially transitioning from livestock farming to fibre cultivation. This shift requires less artificial fertilizer, leading to reduced nitrogen emissions and a more profitable model for farmers.

Biodiversity
In contrast to more intensive crops, fibre crops can boost the biodiversity because they often do not use pesticides, involve less annual soil cultivation, and use very little fertilizer. This leads to an increase in organic matter in the soil, which also attracts microorganisms and insects. Fibre crops can thus aid in developing nature on and around fields and restoring depleted agricultural lands. Some of them also serve as a food source for pollinators like bees and provide shelter for birds and small wildlife. But most of all, the biodiversity could be improved by creating a diverse landscape. So a combination of food production, small forests, fibre crops, water bodies and wild vegetation is highly desired.

Waterlogging and drought
The Netherlands is increasingly struggling with both waterlogging (due to excessive rainfall, rising groundwater levels, and soil subsidence) and drought (resulting from insufficient rainfall, groundwater extraction, and accelerated drainage). These phenomena are affecting both nature and agriculture, causing crop damage, loss of biodiversity, disruption of ecosystems, and water quality issues. Fibre crops can contribute to maintaining productivity in areas affected by waterlogging or drought, since these crops are in general more robust than other vulnerable crops used for food production. They could better withstand drought or excessive water.

6.1.2 Scenario 2030

The Dutch government is aiming to reach certain results by 2030. These results contain outputs (the direct results of the policy), outcomes (the consequences of these outcomes in the market), and the impact (the effect on society).

Outputs

- At least 25 functioning chains involving farmers/processors/builders.
- A minimum of 50 000 hectares of fibre cultivation per year (designated for construction).
- Processing capacity for at least 400 000 tons of fibres per year.
- At least 20 fully developed market-ready crop-product combinations.
- Minimum of 30 biobased construction concepts, with 30-45% biobased content.

Outcomes

- At least 30% of new residential buildings are constructed using 30% biobased materials.
- At least 30% of insulation for sustainability is implemented using biobased materials.
- At least 30% of the materials used in utility construction are biobased.

Impact

- A sustainable and resilient construction sector, as the annual CO_2 footprint of construction activities has been reduced by at least 1.6 million tons by 2030.
- A profitable business model for farmers, accelerating the transition of agriculture towards sustainability and more extensive practices.
- Improving soil and water quality, biodiversity, spatial quality, and reducing CO_2 emissions in the agricultural sector.
- The circular economy, replacing primary abiotic raw materials and mineral resources (excluding surface minerals like sand, gravel, and clay) with renewable resources and materials.

6.1.3 The importance of chains

The key action of the National Approach Biobased Construction is the establishment and scaling up of chains involving farmers, processors, and builders. By making long-term agreements between different parties in the chain, each party gains certainty, and the current impasse in the market will be broken. Providers of fibre crops no longer have to wait for demand because they have certainty that the fibres will be purchased. Builders have assurance regarding the supply of biobased materials, and processor will always have the necessary volume. The goal is to have multiple regional chains with at least 1 000 hectares of fibre crop cultivation, with the processing facilities organized nationally.

6.1.4 Forestry

Besides the approach to enhance the cultivation of fibre crops, there are also national policies on the forestry. Forestry has always been a loaded subject in the Netherlands. Felling trees evoke emotions, and the balance between biodiversity and financial benefit is a thin line. The total area of forestry has been decreasing since 2013 due to housing projects or for creating infrastructure (Schelhaas, 2021). At the same time there has been a longstanding ambition to expand the forestry, which apparently is complicated to bring to reality. The Dutch Government has translated their plans and ambitions into the Bossenstrategie (LNV & IPO, 2020). In this document, ambitious goals are set to increase the total area of forest by at least 10% by 2030, which means adding around 37 000 hectares of new forest with which the total area of forest in The Netherlands will roughly be 407 000 hectares. This expansion will be accomplished in the following ways:

3 400 hectares
Compensating for deforested areas to meet the objectives for Natura 2000 Areas

15 000 hectares
Expanding forests within the Nature Network Netherlands (NNN)

12 000 hectares
Expanding forests outside the Nature Network Netherlands (NNN), for example near densely populated regions or transitional zones.

7 000 hectares
Agroforestry, on for example on agricultural land.

This last means is specifically interesting in the light of this paper. Agroforestry is a form of agriculture in which there is a connection between the agricultural system and the natural system. In practice it means that trees and other woody crops are combined with the cultivation of agricultural crops or other farm land. It can take various forms such as strip cultivation, food forests and tree meadows. This last example comes the closest to a production forest, where trees are planted for their yield. This type of forests offer opportunities for fast growing wood species like poplar, willow and paulownia, which will be discussed later in this paper. Other benefits of agroforestry are for example the increased biodiversity, a more nutrient soil and the fact that more carbon is stored.

The measures that are currently implemented for forest expansion, revitalization of forests, and the increase of trees outside the forest, as described above, will contribute to a greater availability of wood in the long term. Through the revitalization of existing forests, local growth can double, allowing for increased wood harvesting without compromising biodiversity. Currently, around 50% of the annual growth is harvested, which is around 1.25 million cubic meter. This could be increased to 70% meaning that the harvest would be around 1.75 cubic meter (Compendium voor de leefomgeving, 2023).

6.2 THE REGIONAL APPROACH

Besides the national approach, an analysis of the actual landscape is desired. For this purpose, it was decided to conduct a brief research into the region of Zuid-Holland since the project location (which is described later in this paper) is located here.

The landscape of Zuid-Holland is a diverse one with peat, sand and clay soils scattered around over its area. Being a river delta, many rivers cross large cities like Rotterdam or The Hague. In this densely populated province with 3.5 million citizens, the city and nature are almost always intertwined. Zuid-Holland is also the province with by far the most greenhouse horticulture, and likewise hosts a lot of intensive agriculture. It should not come as a surprise that all these matters, are pressing hard on the landscape. Most of it is actually in a warning crisis. They are subsiding, salinizing, compacting, coursing, channelling al rainwater straight into the sea and emitting large amounts of GHGs. These areas should be transformed as soon as possible to become future proof (Boom landscape, 2020). In the previous subchapter it was concluded that the cultivation of fibre crops could offer various solutions but what crops should be grown where. To be able to allocate the biobased resources, three clusters were created based on the landscape of Zuid-Holland (Provincie Zuid-Holland, 2021). These three clusters are the peat soils, the clay soils and the sand soils. The ecology of all three clusters will briefly be summarized after which it could be explained what resources could grow in that area.

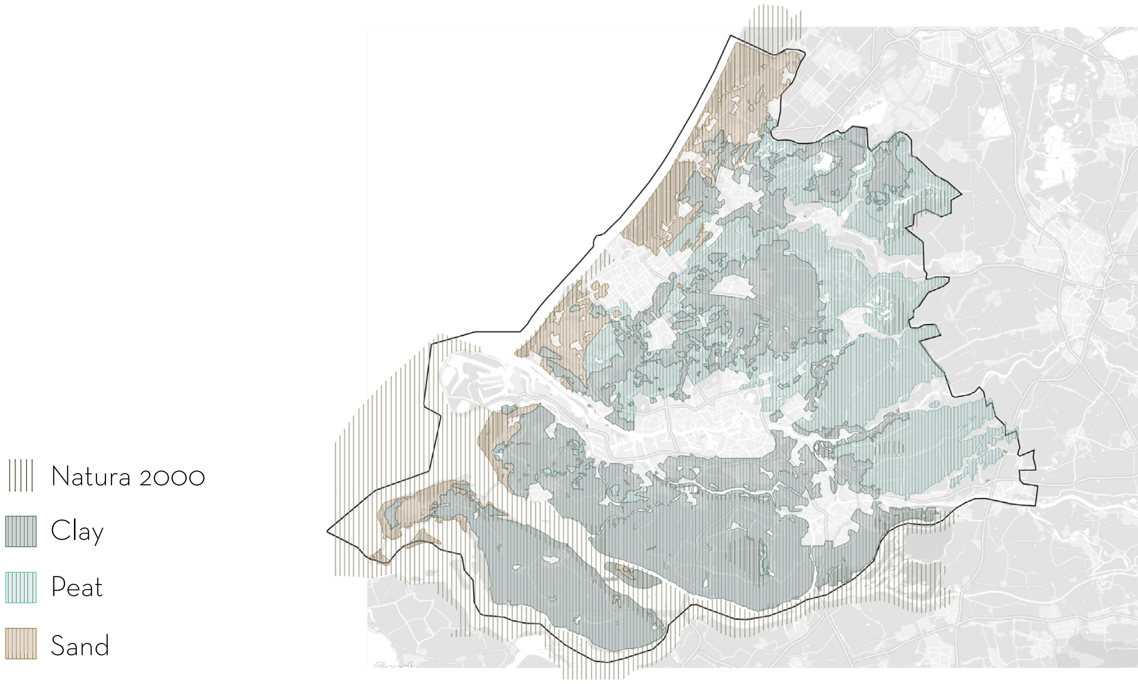


Fig. 6.1 Soil map Zuid Holland (Provincie Zuid-Holland, n.d.)

6.2.1 Peat region

The first landscape is the peat landscape. Approximately 25% of the Zuid-Holland province consists of peat soil (Provincie Zuid-Holland, n.d.). Peat is formed when organic material such as plant residues is compressed over a very long period in wet conditions where there is a minimum amount of oxygen available. This type of soil sequesters a lot of CO_2, since it consists of dead organic material (Geologie van Nederland, n.d.-c). There are in this landscape several problems occuring that need to be tackled.

Problem

There are mainly two problems occurring in the peat landscapes. In the province of Zuid-Holland there is a difference between the so-called 'lower peat' and the 'higher peat'. The lower peat is located below sea-level which means it needs to be kept dry by controlling the groundwater level. This results in dried peat which reacts with oxygen and oxidizes. In this process the sequestered CO_2 is released in the atmosphere. The amount of released CO_2 could seriously add up. In the Netherlands almost 2% of the total CO_2 exhaust is caused by peat oxidation. Another problem in the peat landscape in Zuid-Holland is soil subsidence. Overall, the ground sinking on an average of 0.5 to 1 centimetre per year, which is significant. Countering this is not easy but there are definitely some opportunities (Provincie Zuid-Holland, n.d.).

Opportunities

In order to mitigate subsidence and oxidation in peat landscapes, the reintroduction of water bodies is essential. The landscape needs to regain its diversity, incorporating swamps, meadows, and reed beds. The objective is to establish a productive environment fostering rich biodiversity. A crucial strategy involves water retention in buffer zones surrounding natural areas. Transforming wetlands into productive sponges through the cultivation of fiber crops, such as hemp and cattail, is proposed to counter the current trend of ecological degradation. This semi-wet landscape provides an ideal habitat for thriving vegetation. To ensure biodiversity, it is recommended to plant trees, such as paulownia or birch, along the fields (Boom landscape, 2020).

Fig. 6.2 Visualization of the peat region

6.2.2 Clayregion

A clay landscape is formed when suspended sediment particles in seawater settle at the seabed. This natural process is still taking place in the Wadden region in the north of the Netherlands and certain areas in Zeeland. Thousands of years ago, the sea also covered more inland parts of the country which is in fact still below sea level, contributing to the prevalence of marine clay soil in the lower western areas. Over time, however, the ancient marine clay has lost its salinity due to rainfall, as the soil has been cleansed (Geologie van Nederland, n.d.-b). The clay landscape is found in areas below sea level throughout the country, and at least 30% of Zuid-Holland, situated below sea level, as well (Provincie Zuid-Holland, n.d.).

Problem

Despite the fact that the soil itself no longer contains salt, there is still a significant degree of salinization occurring in Zuid-Holland. This is primarily due to intensive agriculture and livestock farming combined with longer periods of drought. Controlling groundwater levels through deep polder areas allows seawater to infiltrate in the landscape, leading to an increasing shortage of fresh water in the entire region. Furthermore, the soil is also being significantly depleted due to current agricultural practices. Overfertilization and monotone agriculture are affecting the soil quality. Additionally, the use of heavy machinery and an increasing shortage of biological nutrients are causing soil compaction. To minimize the damage, the landscape needs to become more adaptable to climate change and be able to adjust to changing conditions (Boom landscape, 2020).

Opportunities

To address the primary issue of salinization in the clay landscape, more freshwater is required. Currently, the Dutch landscape is designed to quickly drain all water to the sea to prevent flooding. However, it is currently advisable for farmers to retain freshwater along the edges of their fields in creeks. Along these creeks willow and cattail could grow, and through the straight agricultural fields where flax could be cultivated, small stamps of poplar could grow.

Fig. 6.3 Visualization of the clay region

6.2.3 Sand region

The province of Zuid-Holland has a coastline and consequently a dune landscape with a sand soil. Dunes and beaches are formed by the sea currents in combination with an inland wind. Sand is brought in from the sea and is blown onto the land. In the Netherlands, dune landscapes are generally highly protected. In Zuid-Holland a significant area of the dune landscape is a Natura 2000 area. Moving further inland, on the sand soils, intensive agriculture such as bulb cultivation and greenhouse horticulture takes place (Geologie van Nederland, n.d.-a).

Problem

In the sand landscape of Zuid-Holland, several environmental challenges are occuring, with the foremost concern being the excessive presence of nitrogen in the air. Intensive agricultural practices on non-calcareous soils contribute to soil and water pollution through the extensive use of fertilizers and pesticides. The resultant ammonia, a byproduct, enters the groundwater channels, eventually reaching the sea. Through the cycle of evaporation, precipitation, and subsequent rainfall, nitrogen is reintroduced inland, posing a threat to the already fragile ecosystems. At the same time, traffic and urban areas cause even more nitrogen. This leads to an ecological monoculture of plants that do well with nitrogen. Swift intervention is required to stop this process (Boom landscape, 2020).

Opportunities

Mitigating the nitrogen crisis in this region involves transitioning current agricultural practices towards sustainability and implementing the establishment of dry forests. Forest ecosystems possess the capacity to absorb significant amounts of nitrogen, thereby fostering the biodiversity in the area. These forests can take the form of dry forests, suitable for sandy soils, or semi-wet forests. Specifically nearby the dunes, it is recommended to create dune valleys integrated with wet seep areas. Planting dune grass on higher dunes is advised, as it can effectively absorb a substantial portion of the nitrogen. The sea plays a pivotal role in this approach as well. Encouraging the growth of seagrass is imperative, given that these underwater fields serve as storage for nitrogen and CO_2. In summary, the sand landscape can benefit from the cultivation of production forests featuring oak, beech, birch, and poplar, while the sea offers an opportunity to expand the growth of seagrass.(Boom landscape, 2020).

Fig. 6.4 Visualization of the sand region

6.3 THE RESOURCE APPROACH

Now that it is clear what the Dutch landscape, and specifically the region of Zuid-Holland, has to offer in terms of biobased materials, a final look at the seven given resources was taken to check whether they have a potential to be scaled up. For wood, an analysis was performed to several fast-growing species in the hope that the annual yield could be scaled up. And for the other resources a SWOT-analysis will explain what this potential is.

6.3.1 **Wood**

In the previous chapter it was concluded that the availability of wood in the Netherlands is limited. According to Bas Lerink (2023), annually only 1900 houses could be built with Dutch wood. In the 'Bossenstrategie' the goal is set to increase the annual yield of the Dutch forest slightly, but this is still limited and it is not a certainty yet whether this is actually going to happen. Therefore it is recommended by Pablo van der Lugt to look at alternative wood species than the ones that are currently used in the industry. Traditionally mostly coniferous wood was used for construction because of its straight logs. Rising temperatures (due to climate change) are however causing a shift in the balance between coniferous and deciduous trees in the Dutch forest since deciduous trees grow better in warmer climates. Using deciduous wood in high quality MTPs, would make the available supply of wood already increase significantly. It is pointed out that there are several promising fast growing species which could be cultivated on agricultural land or in production forests. Examples of fast growing species are bamboo (3-5 years), paulownia (8-10 years), poplar (15 years) and willow (15 years). In this subchapter these four fast-growing species, as well as the two most harvested ones, pine and oak, will be briefly highlighted.

The first species, bamboo, is actually not a tree but a grass. It is a fast-growing giant grass species with the stem "hardening" after a few years. The stems were primarily used locally in the regions Asia, Africa and South and Central America. In Europe industrialized bamboo has been available since the mid-1990s, because its properties are comparable to tropical hardwood. Initially it was mostly used in Europe for floorboards and interior sheeting. Since several years however, this material has been praised for its high carbon storage and of course its ability to regrow really fast, making it a very good solution for the biobased economy (Van der Lugt, 2017).

The second species is the Paulownia tree (also known as kiri tree), one of the fastest growing trees in the world. This tree is capable of growing mature in 8 to 10 years, producing impressive amounts of wood. It is possible to harvest multiple times without replanting the tree. Paulownia naturally grows in China but it could withstand nearly any climate. Across Europe there are currently several location where this tree is grown on a large scale in production forests, producing for example firewood. Recently however, companies have also started to see the potential of this tree in high-quality construction products (Van Dijk et al., 2021.).

The third tree is the poplar tree, a fast growing native species in the Netherlands which is ready for felling within 15 years. This tree is quite a familiar one in the Dutch landscapes in planted forests, along roads, creeks and farm land, and in production forests. In these production forests, wood has been harvested for a long time and used as firewood or for infrastructure in the railways or mining (Al, 2016).

Next comes the willow tree. This species naturally thrives on fields bordering rivers or creeks in the Netherlands and has notably been extensively cultivated for energy production. Similar to the poplar, the willow is suitable for harvesting within a 15-year timeframe. Ongoing experiments are currently exploring large-scale cultivation of willow on degraded lands and in floodplains (Boosten & Oldenburg, 2011).

Constituting 36% of Dutch forests, the pine tree holds the distinction of being the most prevalent tree species in the country and is also a significant contributor to the timber industry (Oldenburg, 2019). Its straight logs find application in various structural roles within the construction sector. However, the softwood nature of pine makes it less ideal for cladding or finishing applications.

Oak, encompassing approximately 17% of Dutch forests, ranks second in terms of quantity (Oldenburg, 2019). Renowned for its hardwood properties, oak wood is well-suited for cladding and finishing applications.

Besides increasing the total supply of wood, it is currently also deemed necessary by many to make more efficiently use of the available wood, since even if the set goals to increase the yield are met, it will still by far not be enough to sufficiently supply the Dutch construction sector. To do so Van der Lugt, et al. (2023) point out three paths to increase the efficiency of the forestry and timber industry:

The first action would be to increase the construction timber out of the sawlogs, for the use of high-end building products. The processing of the logs always causes a certain amount loss, which could obviously be minimized. This loss is explained in a conversions factor and is averagely in Europe around 50%. Increasing the efficiency is for example done in the manufacturing process of LVL. Veneer is created by peeling the log, making optimal use of it, with nearly zero loss. These veneers are glued to sheets which have high and uniform technical performances.

The second means is to make more efficiently use of timber in structural systems. In general Van der Lugt et al., point out that hybrid structures are desirable. This could be reached on a building level, an element level and a product level. On a building level it is necessary to be critical to where to use CLT or Glulam. CLT is often praised for its structural properties and for the fact that it stores carbon (Van der lugt, 2020), but it also uses a lot of resources and still has a certain environmental impact. A timber stud frame could often be used as well and uses a lot less wood. On the element level the authors mention the use of for example cassette flooring elements instead of solid CLT floors. On the product level, timber I-studs made from solid timber combined with OSB, and CLT with hollow cores filled with wood fibre, are named to be promising alternatives.

The last means of increasing the efficiency of timber in construction sector is by making more use of circular timber. Design for disassembly is important when it comes to circularity, and this could be reached by making use of dry connection to improve the demountability. A casted concrete top-floor on a CLT-slab would does certainly not improve the demountability. And lastly, reclaimed timber from urban mining is in some cases suited to be re-used making use of sequential cascading, even for structural purposes.

6.3.2 Flax

Needs

Flax is grown as part of a rotation scheme of 7 years which implies it could only be cultivated on a land once every 7 years, because flax is vulnerable for several diseases. It should therefor always be combined with other crops. Flax could grow on moisture retentive soils and requires only low amounts of nitrogen. In The Netherlands that means it can grow on for example clay or loam (Van Den Oever et al., 2023).

Strengths

- The Dutch climate, with its moisture retentive soils and temperate North-Sea climate are very well suited for growing fibre flax.
- Fibre flax has been cultivated for centuries in The Netherlands and has a longstanding tradition
- Several products could be made with the fibres, the shives and the linseed. This is economically beneficial since the farmer is not dependent on one market.

Weakness

- Fibre flax is relatively expensive to produce.
  It will have to compete with cereal and grass seed, since the profits are rather similar. These crops are grown on a much larger scale in The Netherlands.

  The flax production is currently relatively low in The Netherlands compared to for example Belgium or France.

- The composite industry is also much further in France and Belgium. These companies have access to a lot of flax in the region, so the knowledge stays there.

- The flax cultivation is currently still dependent on the export to China for the textile industry.

Opportunities

- Flax has a smaller environmental impact than resources like cotton or synthetic fibres.
- Since The Netherlands is currently facing a nitrogen crisis, flax could be a good alternative in a rotation scheme. Like mentioned before it needs low amounts of nitrogen in the soil. The emissions to the air will therefore also be limited.
- The fibres of hemp are perfectly fit for composites which is a growing market in The Netherlands, and the technologies are improving.

Threats

- History shows that the cultivation in The Netherlands will not increase when the prices go up, where this was the case in France and Belgium.

Conclusion

In general, it can be concluded that farmers on the peat and clay soils in the Southwest of the country need to be convinced to start cultivating flax as a rotation crop on their existing agricultural land, since it has serious environmental benefits. The government should try to enhance this process since history shows that these farmers are hesitant.

6.3.3 Hemp

Needs

Hemp could grow very well on peat and sand soil and is just like flax a rotation crop since the plant is genetically not related to other crops that are now cultivated. Its roots go very deep through which it will enhance the quality of the soil (Van Den Oever et al., 2023).

Strengths

- Hemp has a relative high yield and needs low maintenance.
- The plant will improve the structure of the soil due to its long roots.
- The climate in The Netherlands is suited for growing fibre hemp.
- Fibre hemp has a long history in the North-East of The Netherlands.
- Several products could be made with the fibres and the shives. This provides more resiliency for farmers since they do not depend on just one market.

Weakness

- In North-Western Europe hemp will only be mature in October. However, this is too late to let the plants properly dry. In The Netherlands hemp is therefore mown in in August, when its thus not mature yet.
- The low density of the hemp shives limits the transportation distance.
- The Netherlands has a relative low fibre hemp production compared to for example France.
- Currently only two companies are processing fibre hemp in The Netherlands.

  The composite industry in France and Germany are quite advanced. However, they are mostly using regional hemp so the industry and with that the knowledge remains in these countries.

Opportunities

- There are currently industrial developments going on to improve the retting of the hemp plant. This technique is called green decortication.
- Just like flax, hemp could also help fighting the nitrogen crisis. If implemented in a rotation scheme.

- This crop can take up nutrients from deeper soil layers and thus requires less nitrogen, and with that also emits less nitrogen in the air.
- The composite is industry is rapidly developing. Hemp fibres offer a good alternative for the glass fibres that are now often used.

Threats

- The market of fibre hemp will most likely not grow by itself in The Netherlands. So if there are no regulations adopted it will remain as it is right now.

Conclusion

In general, it can be concluded that farmers on the peat and sandy soils in The Netherlands need to be convinced to start cultivating hemp as a rotation crop on their existing agricultural land, since it has serious environmental benefits. The government should try to enhance this process since history shows that these farmers are hesitant.

6.3.4 Straw

Needs

As mentioned before, straw is a residual of cereal cultivation. It is therefore abundantly present in The Netherlands and throughout Europe (Van Den Oever et al., 2023).

Strengths

- Straw is abundantly available throughout Europe.
- Straw has a lot of applications.
- It could also be used as a soil fertilizer as it has a lot of nutrients.

Weakness

- Currently more than half of the available straw is left on field and ploughed under the soil.
- There is currently a lot of straw imported from other European countries.

Opportunity

- The Netherlands is easily able to meet its domestic demands if not half of the straw is ploughed under the soil.
- Straw is a relative hydrophobic material, which means it is very dry. It is therefore very well suited for the production of panels and boards.
- Currently straw is used a lot for animal bedding. However, other residual streams could be used for this as well like verge grass. In this way the availability for the construction sector will increase.

Threats

- When too much straw is harvested, the amount of carbon stored in the soil might decrease.

Conclusion

It can be concluded that straw has a great potential due to its widespread availability. The responsibility for scaling-up the use of straw, lies with the construction sector which needs to understand and see this great potential.

6.3.5 Miscanthus

Needs

Miscanthus is a crop which grows for several years. It is therefore unfit to be implemented in a rotation scheme. The crop is praised for the fact that it can grow on almost any soil as long as it's not flooded for longer periods. Depleted or low-quality soils, riverbanks, ground water protection areas, agricultural land or just unused land are all very fit for miscanthus. It is for example already grown on unused land around airports because geese don't like the crop because it grows so densely (Van Den Oever et al., 2023).

Strengths

The crop can grow on unfertile soils, or land which unsuited for agriculture.

It requires limited input (water and nutrients).

It also requires minimal labour for the production and harvesting.

It grows very fast and captures a lot of CO2.

It has an extensive root system through which it also stores a lot of CO2 in the soil.

The soil quality will improve by cultivating miscanthus.

Although the crop is non-native, it does provide shelter for a lot of species which will help improving the biodiversity.

Weakness

The production of Miscanthus is currently very limited in The Netherlands. This also makes the processing of it expensive because it is not a bulk product yet.

The plants will take about 3 years before it can be harvested.

When the plants are grown on former industrial sites, which is already done, the harvested crop may be polluted.

It is a permanent crop so it cannot be used in a rotation with other crops.

Opportunities

Miscanthus is truly gaining awareness and popularity.

There are also some companies and startups now that experiment with Miscanthus. This way there is a growing number of processing facilities in The Netherlands.

It cannot be used in a rotation scheme, but it might be interesting for farmers to cultivate some miscanthus since it has a very low nitrogen emission. This will help compensating the emission of the entire farm.

Threat

Climate change is a serious threat since wet circumstances are not ideal for growing Miscanthus. With more heavy rainfall and floodings this could become a problem.

Conclusion

In general, it can be concluded that the government should stimulate farmers to incorporate miscanthus in their business. In fact, any farmer could use some of its land for miscanthus because it is so easy to grow it. Furthermore could the provinces and municipalities start cultivating it on land that they own. For example along roads, next to airports or just unused land.

6.3.6 Cattail

Needs

The crop cattail is a native water plant which grows well along rivers and creeks all over the Netherlands (Holland Houtland, 2021).

Strength

The plant naturally already grows in large quantities in the Dutch landscape.

Cattail helps against subsidence and improves the quality of the water and the biodiversity. It could be harvested every year.

Weakness

There are currently only a few companies that make a business of cattail. Therefore, even though there is enough material, the application of cattail in actual products is very limited.

Opportunity

The peatlands are currently exhausting a lot of greenhouse gasses. Furthermore, there is a lot of subsidence in these regions. To help tackle these problems, the government wants to make these areas more 'wet'. Introducing more water in this region, means there is also more land where cattail can grow and flourish (Van Den Oever et al., 2023).

Threat

For cultivating cattail, quite a lot of land is needed.

6.3.7 Seaweed

Needs

Seaweed is a collection name of algae, grasses and weeds attached to the bottom of the sea. It can grow in salty seawater from the North Sea as well as in the brackish water of the Dutch delta (Holland Houtland, 2021).

Weakness

- In the Netherlands the focus of seaweed cultivation lies with food production. Using seaweed for construction purposes is relatively new and in an experimental phase.

Opportunity

- The opportunities are endless since it does not compete with any other crop cultivated on land.

6.4 CONCLUSION

This chapter seeks to formulate an answer on the following research question, '*can the production of biobased building materials be scaled-up to contribute to the construction of the 100 000 needed top-ups*'. A comprehensive literature study revealed that all biobased resources except wood could significantly be scaled up. Questions are often raised whether the production of biobased materials does not compete with for example food production or biodiversity in terms of land-use. These concerns were taken away by formulating a realistic approach on a national scale and a regional scale, taking into account these environmental challenges. It was concluded that there are three pressing challenges, a nitrogen crisis, decreasing biodiversity and water-related concerns, to which the cultivation of biobased materials actually provides solutions. First of all, all biobased resources absorb substantial amounts of nitrogen which is therefor a reasonable alternative for livestock farming. Secondly, biobased resources require less fertilizer and often less nutrients than food production, which will boost the biodiversity. And lastly, especially fibre crops are more robust and could grow on either very wet or very dry lands, where crops for food production grow under more specific conditions. Growing fibre crops will therefore be easier in a land which is struggling with water management.

Additionally, for each of the seven given resources, it was reasoned whether there is a potential for scaling-up. Both flax and hemp are very interesting since they are rotation crops, which means that farmers continue their daily practice of food production and grow flax or hemp on their fields every 5 or 7 years. Doing so, the quality of the soil will improve. Straw is a residual of the production of grains and is abundantly available in the Netherlands. Miscanthus has minimal requirements to grow and has a relatively high annual yield. It could theoretically grow on any unused land in the Netherlands. Cattail is promising since it grows on wetlands which will become more and more visible in the Dutch landscape. And finally of seaweed it is mentioned that it grows in the sea which means it theoretically has an endless potential.

The only resource which has a very limited potential for scaling-up is wood. The Netherlands only has a small area of forest, and the annual yield is limited and actually decreasing. Even if the goal to slightly increase this yield by 10% is met, the availability of timber in the construction sector will still not be enough to supply the 100 000 needed top-ups. Measurements to increase the efficiency of forestry and timber products are therefore extremely important. Increasing the output of sawlogs or applying wood in different systems like an I-joist will help limit the need for wood. It is also recommended to start cultivating fast-growing species like paulownia and poplar on agricultural land.

The strong believe is that all these measurements are very feasible, and do not have to compete with other vital needs in the small country the Netherlands is.

7. THE BENEFIT

Even though it was concluded that the production of biobased materials could significantly be scaled up in the Netherlands, it is still the question whether this is desirable in terms of environmental impact. There is an ongoing debate whether the Dutch forestry should be exploited further or whether it might be better to simply import all wood from sustainably managed forests in northeastern Europe in countries with a much larger industry. In this chapter the pros and cons of local biobased materials in the Netherlands will be highlighted.

In this chapter the following research question will be answered:

> *Does using locally sourced biobased building materials reduce the environmental costs compared to the current material choices?*

Answering this research question will follow two steps. First, a theoretical framework of the existing literature on local biobased materials was set out. In total four comparative studies were consulted and the main conclusions were summarized. Additionally for the purpose of this research and for optimising the existing design for the top-up of Smits Vastgoedzorg, eight LCA's were studied and summarized as well. This data could be compared with the theoretical framework to be able to prove whether the embodied emissions are actually reduced with the proposed adjustments.

7.1 COMPARING LCA

Before diving into the literature, a few words have to be spent on LCAs. The standardized method for LCAs is explained in the EN 15804, 2013 and was showcased in figure 7.1. This method outlines a framework divided into five stages and several modules. Generally, suppliers of materials order an external company to conduct an LCA and collect the data in EPDs. These documentations are publicly available on the supplier's website or in databases. A general remark that should be made before diving into the literature review is that EPD's are interpretable. The analyses are obviously performed by professionals, and the results are quite extensive. When materials are compared, decisions should be made on what to compare. In certain databases it was for example decided to only look at the module A (product and construction stage), to compare the GWP. In other words, a comparison is almost never complete. Furthermore, conducting an EPD is relatively expensive. Larger companies have the means to have updated and recent EPD's for all their products while novel small-scale companies do not have these means. This is especially problematic for start-ups that work with biobased materials. Proving the reduced environmental impact could be very difficult. For this reason, comparative studies conducted by academics, comparing large amounts of data, are extremely important.

Assumption

One important assumptions was made as well. Commonly used categories for quantifying the environmental impact in LCAs are the GWP, ozone depletion and eutrophication. For this research it was decided to only compare the GWP.

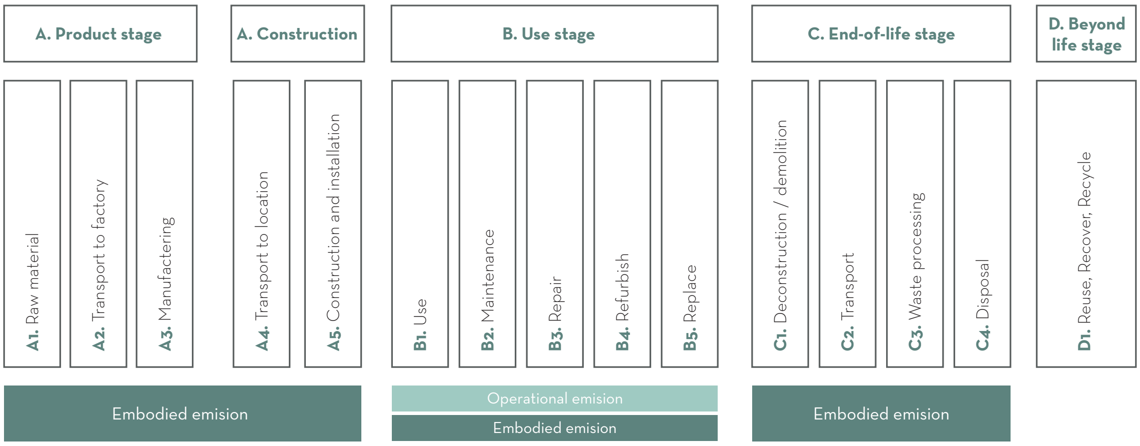


Fig. 7.1 Schematic representation of Life Cycle Assessment (EN 15804, 2013)

7.2 LITERATURE REVIEW

Mouton et al. (2023) conducted a state-of-the-art literature review, looking at the environmental performances of timber, straw and hemp-based construction materials, by comparing the LCAs of these materials with the LCAs of conventional materials. The study considered various building elements such as external wall, internal wall and flat roof. The researchers found a significant variation in the GWP compared to the conventional materials. Biobased products showed mixed results with some performing better than the conventional materials and some worse. Straw-based elements generally showed lower GWPs where hemp-based products showed unexpectedly a high GWP. The researchers were also able to identify environmental 'hotspots', the modules in the LCA that have the strongest impact. The majority of the GWP is caused by modules A1-A3, occurring in the production stage. Apart from this, the transport to site (A4), the replacement (B4), and the disposal (C4) are named as important modules with high impact.

Schulte et al. (2021) evaluated the environmental performances of various insulation materials including wood fibre, hemp fibre, flax fibre and miscanthus as biobased options and EPS and stone wool as non-renewable options. The analysis is based on central European conditions with fixed thermal properties and transportation. The results indicate that wood fibre and miscanthus insulation materials are the most environmentally friendly, while miscanthus insulation and EPS are the most cost-effective over their life cycle. An analysis of the entire life cycle of the bio-based insulations highlights that the cultivation of feedstock primarily contributes to the GWP, while manufacturing and installation are economic hotspots.

Pittau et al. (2018) investigate in their paper the potential of storing carbon in building components using different biobased products. The study considers various construction technologies and materials, each with different lifespans and amounts of biomass. The goal is to show how the choice of building components and materials can impact the reduction of the GWP. The functional unit for comparison is defined as 1 m2 of wall with specific thermal properties and a 60-year lifespan. For this research five wall structures were considered (fig. 7.2); I-joist frame with pressed straw, hempcrete blocks, timber frame with glass wool and concrete with EPS. The most important conclusion drawn from this research is that fast-growing biobased materials like straw and hemp offer an excellent opportunity to reduce the GWP of buildings because these crops unlike wood products have short rotation periods with a relative high carbon storage. Timber does not always lead to climate neutrality due the long time required for the forest to regrow.

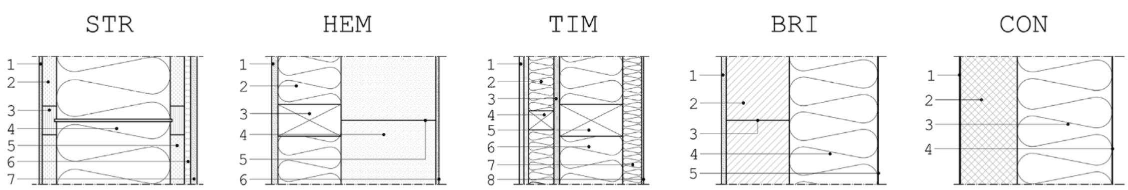


Fig. 7.2 The composed wall structures (Pittau et al., 2018)

Peñaloza et al. (2016) conducted a study to three building designs: one with a concrete structure (0% biobased), one with a CLT structure (50% biobased), and another one with increased bio-based materials (69% biobased). The study showed that increasing the biobased material consistently reduced the environmental impact of the building. The concrete structure accounted for 481 kg CO_2 eq/m2, the CLT structure for 281 kg CO_2 eq/m2 and the increased biobased scenario for 268 kg CO_2 eq/m2. "An outcome in almost every studied scenario setup is that increasing the biobased material content of the building results in a reduced climate impact. Further reductions could be reached if the impacts from transport are reduced." So the researchers concluded that increasing the number of biobased materials, also increased the amount of transport which is displayed in the graph below.

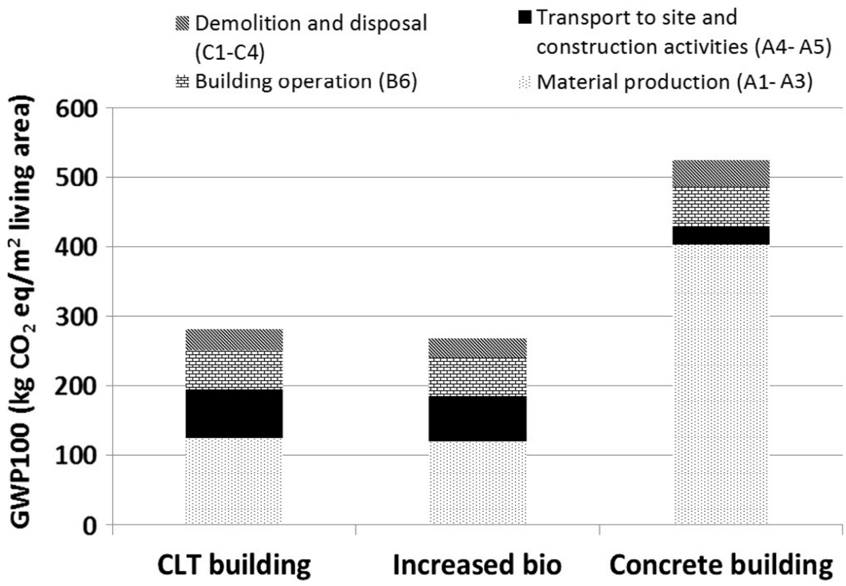


Fig. 7.3 The GWP of three different building designs (Peñaloza et al., 2016)

In general, it can be concluded that biobased materials show a limiting effect on the GWP. However, this could vary among the different modules. So-called trade-offs will always appear. Mouton et al. (2023) state that additional finishing or supporting layers might negatively affect the GWP of biobased constructions, where Peñaloza et al. (2016) conclude that the increased biobased design causes more GHG emissions because of the increased transport. Dr. Elizabeth Migoni Alejandre (personal communication, November 16, 2023), LCA specialist from the TU Delft, confirms this phenomenon. She describes that the embodied emissions for cultivating different materials could vary per region. It could therefore be the case that sourcing timber in the Netherlands would cause less emissions for transporting the materials, where the emissions for processing the trees would increase. The same goes for example for bamboo, which is currently almost solely imported from China. Cultivating this in The Netherlands would make sense when you try to limit the emissions for transport. However, the Dutch landscape is much less suited for this type of cultivation and might therefor need a lot more energy than when this crop is grown in China where it is so abundantly available. These trade-offs between modules in the LCA play a significant role when answering the final sub question of this research. However actually measuring these trade-offs is extremely complex and, in some way, out of the scope of this research.

7.3 THE IMPACT OF CARBON STORAGE

It has been mentioned in chapter three and four that a major advantage of biobased materials is the storage of carbon. During the production of biomass, CO_2 is captured and by photosynthesis converted to carbon and stored in the material. When the material breaks down again by for example combustion or incineration, this CO_2 emits into the atmosphere again. This absorption and emission of CO_2 in biomass is referred to as biogenic.

The EN 15084 has standardized the way that this biogenic carbon should be calculated. For biobased materials this means that the absorption of CO_2 during the production stage (Module A) is valued, and that the CO_2 emissions when the material is combusted or incinerated is equally devalued in the end-of-life stage (Module D). The balance over the entire life cycle results consequently in zero. For fossil-based products like plastics it means that no CO_2 is absorbed by the production (Module A), where there is still CO_2 emissions by combustion or incineration in the end-of-life stage (Module D), meaning there is a contribution to global warming. So biobased products balance out in terms of CO_2 emissions, where fossil-based materials have a negative impact, meaning that with the current standardized rules the impact of carbon storage is already visible.

However, questions are raised whether biobased should not have a positive biogenic carbon result. The environmental impact of CO_2 storage and emission is now linked to the end-of-life scenario, however it is currently ambiguous what the impact is of different end-of-life scenarios, since in LCAs one end-of-life scenario is chosen. It comes without saying that reusing will heavily impact the LCA, since the carbon is stored for a longer period, all while new biomass is growing and storing even more carbon (Stichting Nationale Milieudatabase, n.d.).

SGS search has conducted a research in 2021 to find alternatives to the current quantification method. The conclusions however were that the CO_2 net-zero impact of biobased materials, compared to the negative impact of fossil-based products, is currently sufficient, and that discounting an additional benefit for biomass would be double. "The calculated value of this captured biogenic carbon in GWP-biogenic may and cannot be offset with the results of an LCA" (Kanselaar et al., 2022).

To conclude, for this study the biogenic carbon was left out of the comparison. However, it should be stressed that there is on ongoing debate whether stored carbon should play a more important role in the regulations.

7.4 THE IMPACT OF TRANSPORT

To be able to check whether using locally sourced resources reduces the environmental impact of the top-up, it is necessary to first explain how the environmental impact of transportation is modelled. To do so again the EN 15804, 2013 (fig 7.2) was used. This framework, outlining the LCA of buildings, specifically addresses transport in the modules A2, A4 and C2, respectively the transportation of the source plant to the factory, transportation of the manufacturer to the construction site and the transportation of the building site to recycling facility. There are multiple factors that still make the calculation for transport deviate a lot. Transport costs for one single case could be calculated after it took place, but taking averages for a longer period means predictions should be made. This information gap underscores the need for specific methods to be able to incorporate transport data into the LCA. Various approaches exist in the literature, considering factors like transport distances, means of transport and the mass of the goods. (Soust-Verdaguer et al., 2022).
Transport modelling for an LCA typically involves three steps (Ecochain, n.d.):

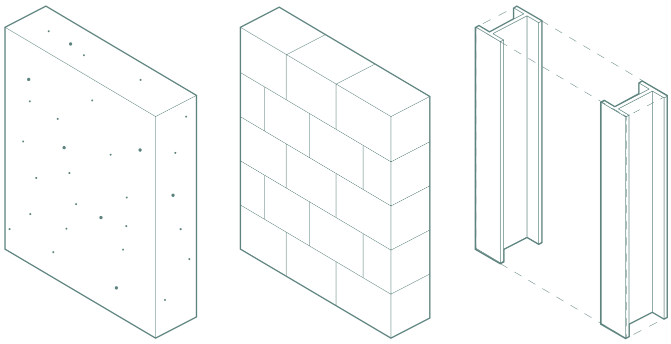
1. Choosing the transportation method.
There are several transportation methods of raw materials and products like a lorry, a truck, an airplane, freight railway, a barge or an ocean ship. These methods have different environmental impacts.

2. The distance travelled.
Transportation takes place between different points for example supplier and factory, the manufacturer and consumer, installation site and recycling facility. The distances between these points are calculated in kilometres.

3. The mass of the goods that are transported.
The mass of all products in the building is calculated in tonnes.

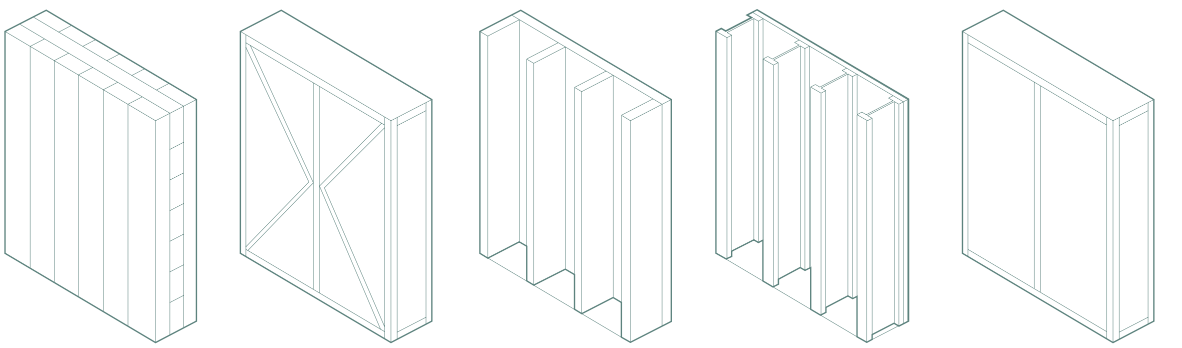
EPDs are the only accurate resource of information about transportation. In every EPD the used transport distance per functional unit, and the transport means is given. Since this chapter tries to check whether sourcing biobased materials locally would actually make a difference examples had to be chosen. It was decided to compare a set of load-bearing structures, since these components usually contain the most weight, and consequently cause the most emissions during transport. In total three conventional structures and five biobased alternatives, displayed in the figure below, were considered. The functional unit was 1m2, with a thickness of 250mm.

Conventional load-bearing structures



1. Concrete 2. Lime sandstone 3. Steel

Biobased load-bearing structures



1. CLT slab 2. Timber-straw 3. LVL-rib panel 4. I-joist panel 5. Hempcrete

EPD's usually distinguish a GWP-fossil, the global warming potential due to the exhaust of fossil fuels during the production and construction, a GWP-biogenic, the amount of biogenic carbon captured in the material, the GWP-luluc, which indicates the indirect global warming potential due to land-use change, and finally the GWP-total, which is the sum of all three. As was mentioned before may the GWP-biogenic not be offset with the results of an LCA (Kanselaar et al., 2022). For this comparison it was decided to solely compare the GWP-fossil, indicating all GHGs released during the production and construction stage. The GWP-biogenic will confuse this comparison, since it is a negative number in these stages because it stores carbon and will only become a positive number when this carbon is released by for example disposal.

In the table and graph below the found data is summarized. Two conclusions could be drawn from this. First of all, it could be concluded that the amount of biobased material influences the GWP. Hempcrete still has a significant GWP which might be due to the substantial amount of abiotic material in this product. Secondly, the impact of transportation of CLT and the timber-straw panel is slightly higher than the other products. The other biobased products have similar transport impact as the other products.

#	Material	Company	**A1 - A3** (product)	**A4** (transport)	**A5** (construction)
1	Concrete (in situ)	Fedbeton	37,00	5,20	0,39
2	Lime sandstone	Kalkzandsteenplatform	25,81	6,13	0,32
3	Steel structure	SNS	33,60	0,60	1,20
4	CLT slab	KLH	21,33	11,38	3,25
5	Timber-straw panel	Ecococon	14,50	13,00	1,23
6	LVL rib panel	Stora Enso	21,80	4,30	0.64
7	I-joist panel	Metsa Wood	14,53	0,43	6,35
8	Hempcrete	Isohemp	31,96	1,47	3,26

Table. 7.1 The GWP-fossil of load-bearing structures

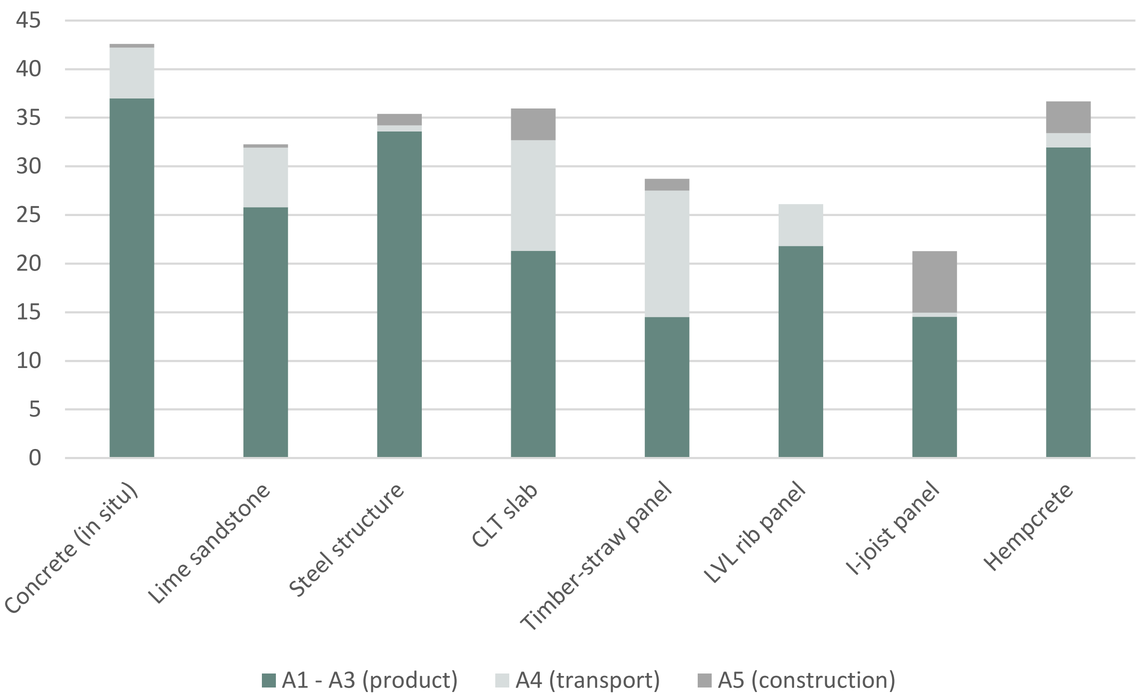


Fig 7.4 The GWP-fossil of load-bearing structures

To better understand the emissions for transport, a closer look was taken to the EPDs (fig 7.5). As mentioned before, the module A2 covers the transport from the source location to the factory and the module A4 the transport from the factory to the construction site. A major drawback, in the light of this research, is that most EPDs combine the module A1-A3, which means it cannot be checked what the effect of the source location is. The distance used in A4 for, for example steel is now 150km, but the actual iron ore is sourced all over the world (Tata steel, n.d.).

In the case of the timber-straw panel another lesson could be learned. Currently the Lithuanian company Ecococon is a large supplier of timber-straw panels throughout Europe, using straw from Lithuania. This while it was concluded in a previous chapter that the availability of straw in the Netherlands is widespread. One explanation of the increased transport impact of biobased materials in general could be that it often involves novel products that might have a factory in one single country.

#	Material	Company	Location	Distance (km)	Means of transport	A4 transport
1	Concrete (in situ)	Fedbeton	-	17	Truck	0,39
2	Lime sandstone	Kalkzandsteenplatform	-	-	-	0,32
3	Steel structure	SNS	-	150	Truck	13,7
4	CLT slab	KLH	Wiesenau (GE)	582	Truck	13,7
5	Timber-straw panel	Ecococon	Kybartia (Li)	1526	-	13
6	LVL rib panel	Stora Enso	Ybbs (Au)	634	Lorry	4,3
7	I-joist panel	Metsa Wood	King's Lynn (UK)	-	-	0,4
8	Hempcrete	Isohemp	Fernelmont (BE)	100	Truck	2,1

Fig. 7.5 The impact of transport

7.5 CONCLUSION

The research question, '*does using locally sourced biobased building materials reduce the embodied emissions compared to the conventional material choices*', was answered in this chapter by conducting a literature review and a data analysis on a selection of EPDs. In the literature review four representative studies were discussed of which all four were conducted in Northwestern Europe. In general, the drawn conclusions indicate that biobased materials perform better in terms of GWP than conventional materials. However, different hotspots were allocated. The modules A1-A3 were mostly named as hotspots were a substantial amount of the GWP originated, however the transport costs A4 are named as well. It was concluded as well that certain trade-offs take place between modules when the materialisation changes. It is therefore very complicated to state that sourcing a material in The Netherlands, per definition has a lower GWP. The only certainty will be that the module A4 (transport) will decrease, however the energy needed to source the material here might increase, or the indirect impact of the land-use change might be higher.

Next, a data analysis was conducted on a selection of EPDs. It was decided to compare three conventional and five biobased load-bearing structures. Through this data it indeed became clear that biobased materials account for a lower GWP than conventional materials. Furthermore, CLT and the timber-straw panel showed a significantly higher transport impact which could be explained by the fact that there are only a few factories located in Europe which increases the average transport distance. Whether this is true for other biobased resources needs to be covered in further research.

CASE-STUDY

8. THE DESIGN

During the period July – December, the student participated in an internship at Smits Vastgoedzorg, a constructing company located in Rotterdam specialized in renovation. During this period a design was made for a 1:1 mock-up which would serve as presentation model for clients. This design for one single top-up was used in this chapter as a reference. Calculations were conducted, theories were tested, and adjustments were made to fully apply the learned lessons from this research.

This chapter will answer the following research question:

How can locally sourced biobased materials help inform the design for the top-up Smits?

This question will be answered by participation in the design for the top-up. The student entered this design process when a sketch design was already finished. The desire was however to, on the one hand become aware of novel and feasible biobased alternatives for the current design, and on the other hand reason by data why these alternatives are more beneficial in terms of environmental impact. The student therefore used the previous built-up knowledge about biobased materials to create multiple scenarios for 2023 as for 2030. To test these their environmental impact, the Nationale Milieudatabase (2023) was used.

8.1 THE CURRENT DESIGN

The starting point of this chapter is the existing sketch design for a top-up, by a consortium consisting of Smits Vastgoedzorg, Nieuwe Architecten and IOB ingenieurs. In this chapter this design will be decomposed and displayed. With the help of professionals, a status quo of the performances of the design was set-up, after which the learned lessons could be applied in a following subchapter.

8.1.1 Structure

The first step is to create the 'foundation' of the top-up. Openings are created in the existing roof insulation in which large timber beams were placed. These beams will level the flooring elements of the top-up.

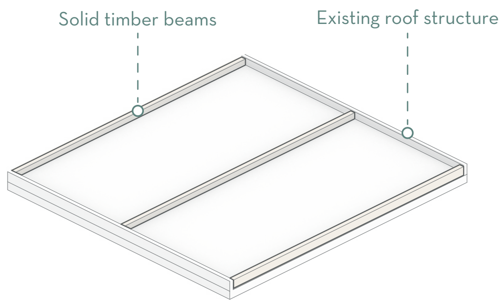


Fig. 8.1 Foundation of the top-up

The next step is to place a 3D module composed of timber stud frames. This element will be completely constructed in the factory and transported as a module to the building site. Being a 3D element, it will take care of the stability of the entire top-up. This is beneficial because now the other elements could be 2D prefabricated which area more easily transported.

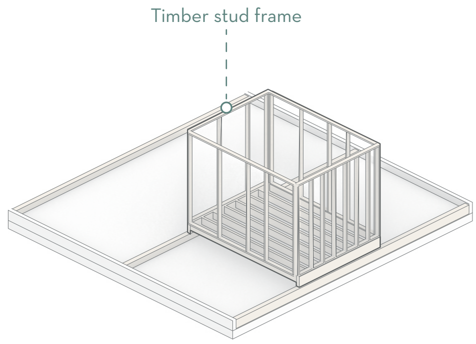


Fig. 8.2 3d element

Thirdly, the flooring elements are placed. These elements are 2D prefab elements composed of solid timber beams. The sizes of the elements could differ per case, since they need to align with the grid sizes of the existing structure of the flat. It should be noticed that all elements consist of header joists on the edges, and floor joists on the inside. In the current design these were both constructed of solid timber. The elements are filled with glass wool insulation and covered with fermacell fire-proof sheeting.

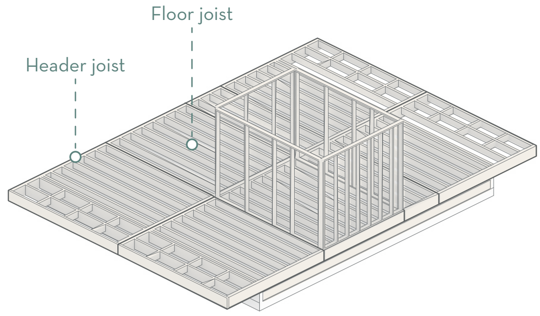


Fig. 8.3 2d floor elements

The next step is to bring in the vertical 2D elements which are in fact very similar to the flooring elements, so composed of solid timber studs, filled with glass wool and covered with fermacell. On the centre grid line of the top-up there will not be placed a timber stud frame, instead columns will be applied. This is done to keep the floor plan of the appartement as open as possible.

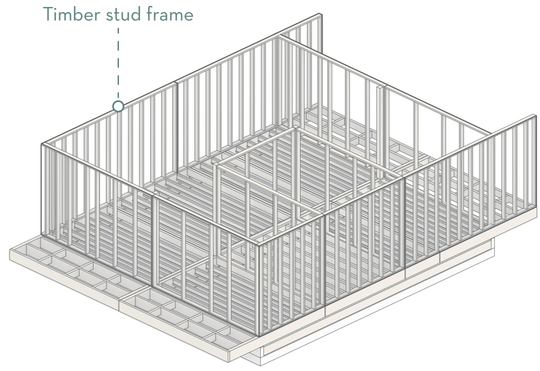


Fig. 8.4 2d wall elements

The last step will be to place the roofing elements. These elements are very similar to the flooring elements. They are composed of solid timber beams which will remain open and visible after completion. On top of the structure an insulation layer is placed consisting of PIR insulation boards.

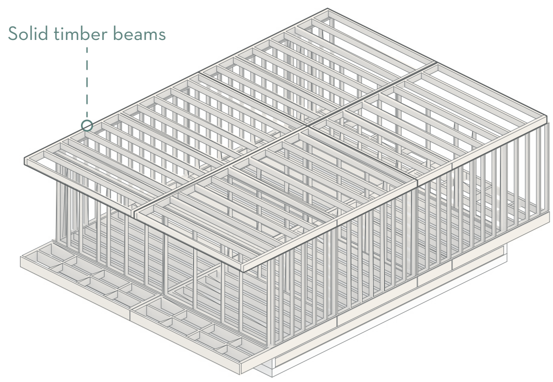


Fig. 8.5 2d roof elements

8.1.2

Skin

With mostly a timber frame as a structure the remaining skin of the top-up was constructed. The materialisation of the floor, the facade and the roof were displayed in the two axonometric details below.

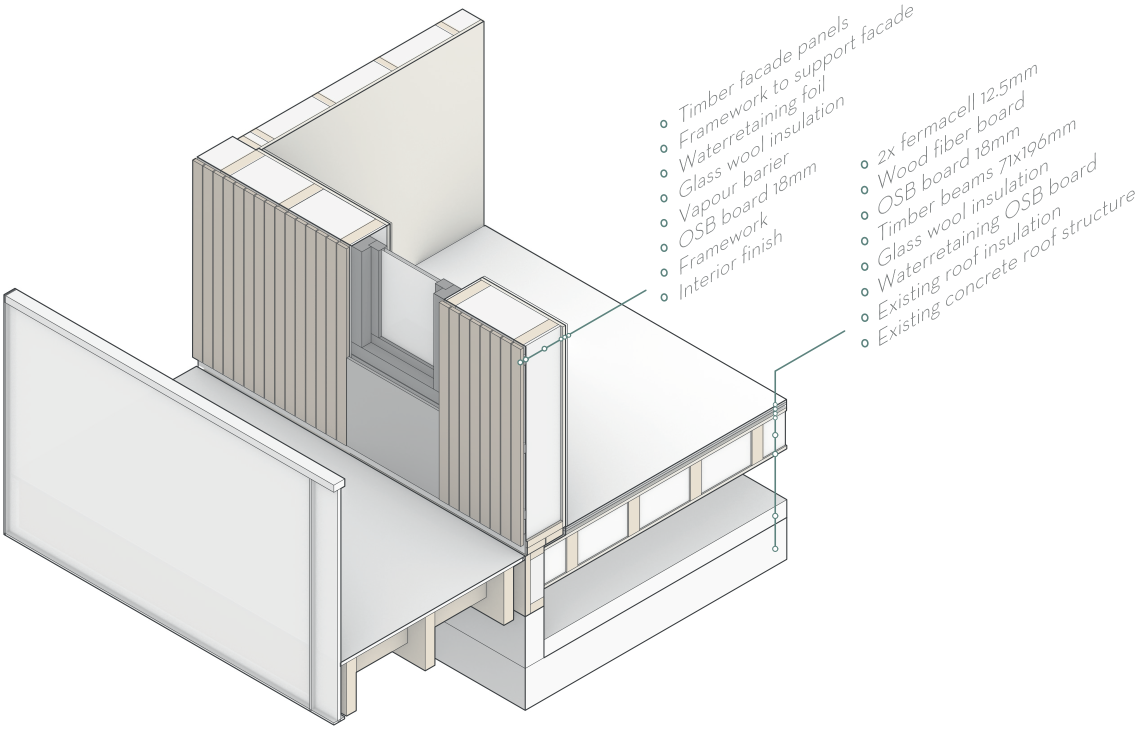


Fig. 8.6 Floor and wall composition of the top-up

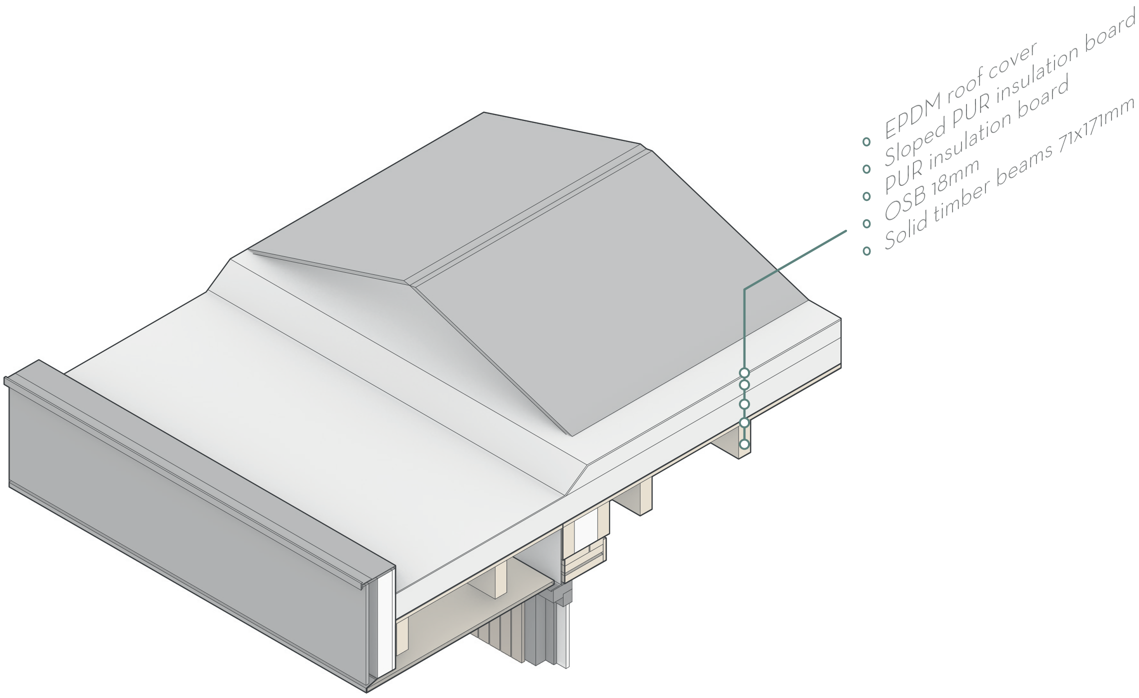


Fig. 8.7 Roof and wall composition of the top-up

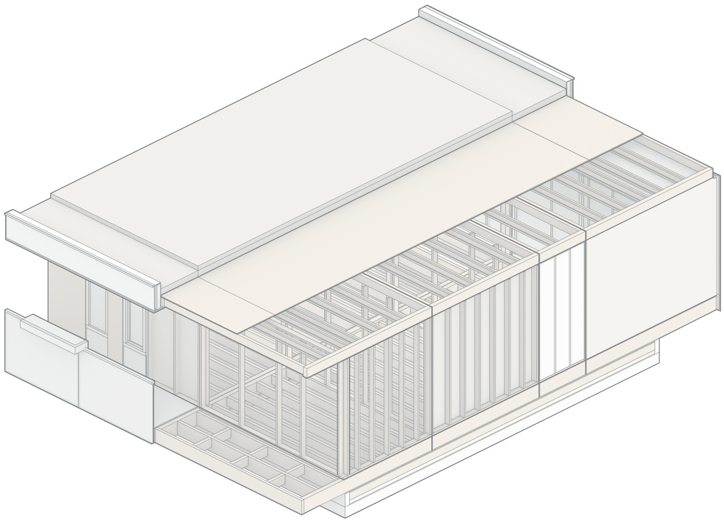


Fig. 8.8 Design of the top-up

In the graph above, the proposed design for the top-up by Smits Vastgoedzorg was displayed, showing all the components of the design. To be able to compute the GWP of this design, the volumes, amounts and quantities should firstly be defined. This was done by looking at the floor elements, the wall elements and the roof elements. The given numbers in the table below will be used in further calculations where needed.

Totals

#	Material	Quantity	Unit
1	Total amount wood	18,2	m^3
2	Total volume insulation	35,1	m^3

Wall

#	Material	Quantity	Unit
1	Total area of the wall	125,74	m^2
2	Total length of studs	329,3	m
3	Total length columns	10,52	m
4	Total volume insulation	7,6	m^3

Floor

#	Material	Quantity	Unit
1	Total area of the floor	88,1	m^2
2	Total length of header joist	82	m
3	Total length floor joist	95	m
4	Total volume insulation	10,3	m^3

Roof

#	Material	Quantity	Unit
1	Total area of the roof	86,1	m^2
2	Total length of header joist	82	m
3	Total length floor joist	91	m
4	Total volume insulation	12,2	m^3

Table 8.1 Quantities of the top-up

8.2 SCENARIOS 2023

With this status quo as a starting point, adjustments were implemented in line with the two goals which were formulated in the previous chapter:

- *Maximize the amount of biobased materials in the design.*
- *Minimize the amount of scarce biobased materials in the design.*

Simultaneously there is the underlying goal of this paper, which will be explored further in the next chapter, and that is:

- *Minimize the global warming potential.*

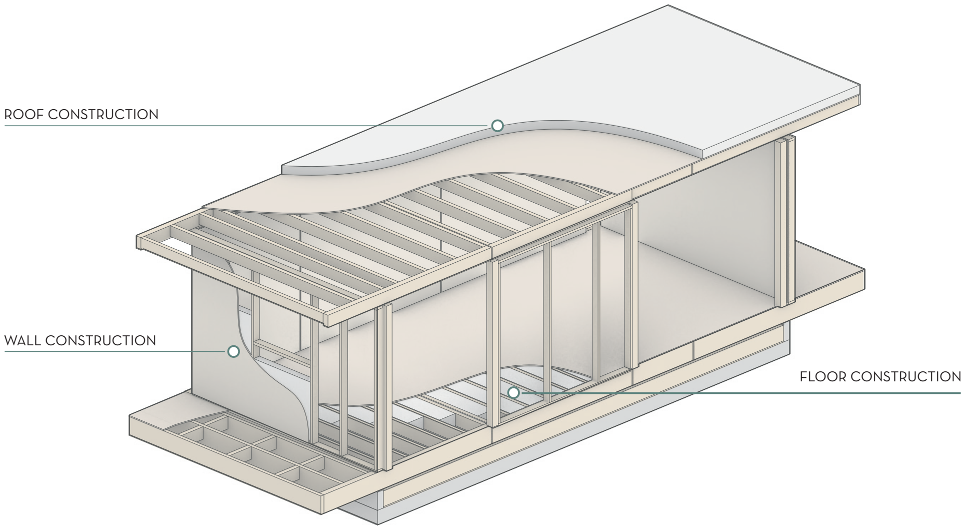


Fig 8.9 Quantities of the top-up

In the graph above a section of the existing design of the top-up by Smits Vastgoedzorg was displayed. In this section all the components are visible, including a part of the 3d element in the middle of the top-up to take care of the stability, as the glulam columns on the centre grid line. With this graph it is explained that there will be scenarios worked out for the the floor, the wall and the roof construction.

Assumptions

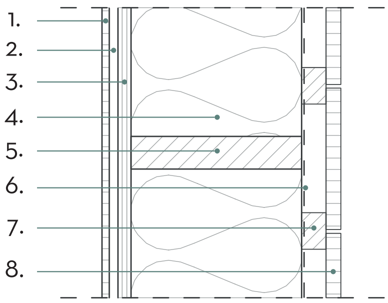
To compare certain structures a few assumptions were made beforehand:

- 1 m2
- Rc wall: 6
- Rc roof: 6
- All structures are load-bearing
- Lifespan of at least 60 years

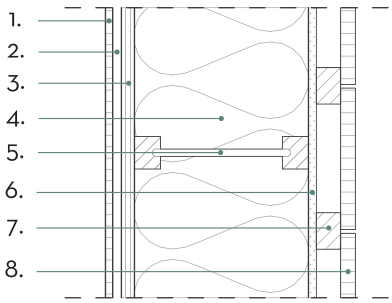
8.2.1 Wall construction

For the wall construction, the literature and the built-up knowledge about biobased building, was used to compose four wall constructions. The four designs are the current one consisting of a timber stud frame with glasswool as insulation and plaster as internal finish, a timber stud frame composed of I-studs filled with flaxwool and MDF board as interior finish, a timber-straw panel with pressed straw inside of light timber frame with clay as interior finish, and finally a CLT-panel with wood fibre insulation. Of all the four designs the GWP was calculated as well as the carbon storage.

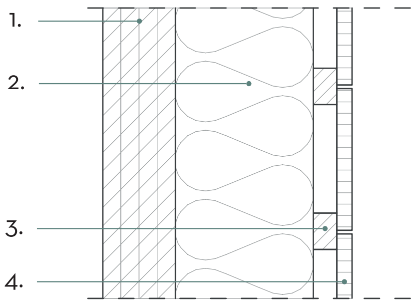
1. Timber frame - glasswool



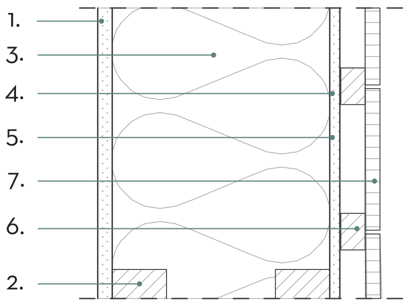
2. I-joist - flaxwool



3. CLT - wood fibre



4. Timber-straw panel



1. Timber frame - glasswool

The first design is the current one consisting of a timber stud frame with filled with glass wool insulation. The stiffness of the wall will come from an OSB board on the interior side the wall. This panel will be covered with a plaster board as an interior finish. The material with the highest impact is the glass wool.

#	Material	Thickness *mm*	GWP/unit *Kg CO2 -eq*	Unit	Stored carbon *Kg carbon*	% biobased
1	Loam plaster	10	1,49	m2	0,00	0
2	Planed spruce	10	-	-	-	100
3	OSB board	18	1,2	m2	16,23	93
4	Glass wool	240	3,85	m2	0,00	0
5	Planed spruce	240	0,9	m1	6,32	100
6	Recycled pvc foil	-	1,78	m2	0,00	0
7	Planed spruce	33	0,5	m1	0,78	100
8	European Pine (uncoated)	15	1,65	m2	17,70	100
9	**Total**	**-**	**11,37**		**41,01**	

Table 8.2 Design alternative 1: timber frame - glasswool

2. I-joist - flaxwool

One proposed alternative wall composition is constructed of I-joists filled with flax wool insulation. The I-joist has a distinctive 'I' shape with top and bottom flanges made from high-tension materials like LVL or graded solid timber, while the vertical web is typically constructed from structural plywood or OSB (Wood solutions, n.d.). In between the joists an insulation layer of flax wool was placed. As a water barrier, multiplex by Gutex (n.d.) could be used. A very small amount (1,5%) of paraffine was added to make this wood fibre board water-resistant. The perhaps disappointing truth for this design is that the GWP is more than double the GWP of the design with mineral glass wool. This is due to the fact that currently nearly every biobased insulation, just like flax, has a fire class D or E, which means that a fireproof board like a gypsum fibre board needs to be added.

#	Material	Thickness *mm*	GWP/unit *Kg CO2*	Unit	Stored carbon *Kg CO2*	% biobased
1	MDF board	10	1,26		11,34	100
2	Gypsum fiber board	18	11,17		0,00	0
3	OSB board	18	1,2		16,23	93
4	Flax wool insulation	240	1,33		17,50	88
5	I-joist	240	3,59		1,84	93
6	Woodfiber multiplex	15	5,08		3,48	100
7	Planed Spruce	33	0,3		0,78	100
8	Dutch Pine (coated)	15	2,48		17,70	100
9	**Total**	**-**	**26,41**		**68,85**	**-**

Table 8.3 Design alternative 2: I-joist - flax wool

3. CLT - wood fibre

The third design consists of a CLT panel as structure. On the exterior face of this structure, wood fibre boards are placed. This design has a similar GWP as the current design, however it stores more than three times the amount of carbon. This should definitely be taken into account. In the light of this paper however, this alternative is less likely to be applied since a lot of wood is required to build one top-up. Scaling up to a decent amount of top-ups made from CLT with Dutch wood will most likely be extremely hard.

#	Material	Thickness *mm*	GWP/unit *Kg CO2-eq*	Unit	Stored carbon *Kg carbon*	% biobased
1	CLT panel	100	6,98	m2	86,92	62
2	Wood fiber boards	200	2,88	m2	34,76	82
3	Planed spruce	33	0,3	m1	0,78	100
4	European Pine (uncoated)	15	1,65		17,70	100
5	**Total**	**33**	**11,81**		**140,15**	**-**

Table 8.4 Design alternative 3: CLT - wood fibre

4. Timber straw panel

The final design is one composed of a timber-straw panel. This is a prefab element which in the Netherlands is currently supplied by Ecococon (2022). Pressed straw is known as a structural material, and therefore a very limited amount of timber is needed in this prefab element. A disadvantage of this wall construction is that pressed straw has a lambda value(λ) of 0.05 w/mk, which means the thickness of the element should be 300mm to reach an RC-value of 6. The NMD provides data for an entire prefab panel by Ecococon. The GWP of this panel is significantly higher than the other options. To reason this, the EPD of Ecococon (2022) was consulted. The total GWP of 28,59 was divided as follows. A1 – A3 (production stage) account for 14.3 kg CO_2, A4 (transport) accounts for 13.6 kg CO_2 and A5 (construction) accounts for 1.23 kg CO_2. So almost half of the embodied emissions are due to transport. Ecococon is namely a Lithuanian company and also produces their product in that country. In their EPD they take into account a travel distance to the Netherlands of 1526km. Thus, it can be stated that using locally sourced straw will cut the embodied emissions by almost half.

#	Material	Thickness *mm*	GWP/unit *Kg CO2-eq*	Unit	Stored carbon *Kg carbon*	% biobased
0	**Timber-Straw-Panel**	**400**	**28,59**	**m2**	**96**	**52**
1	Wood fiber board	10	-	-	-	-
2	Timber framework	10	-	-	-	-
3	Pressed straw panel	300	-	-	-	-
4	Multiplex	10	-	-	-	-
5	Recycled pvc foil	-	1,78	m2	0	0
6	Planed spruce	33	0,3	m1	0,78	100
7	European Pine (uncoated)	15	1,65	m2	17,70	100
8	**Total**	**33**	**32,32**		**114,47**	**-**

Table 8.5 Design alternative 4: Timber-straw panel

Comparing the four wall constructions creates an interesting and perhaps surprising image. The current design is performing very well in terms of GWP. In general, it can be concluded that the biggest weakness of biobased insulation is its fire class. If the additional fire-proofing layer was left out, alternative 2 (I-joist – flaxwool) would outperform the current design. The timber-straw panel neither performs very well in terms of GWP as previous explained. The CLT panel does perform well since it requires less additional layers. However, this alternative seems undesirable in terms of timber use. Carbon storage could make a difference in this comparison.

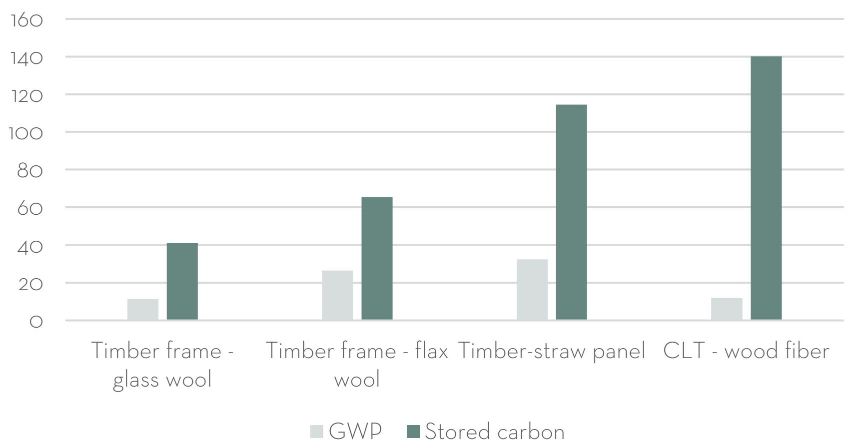
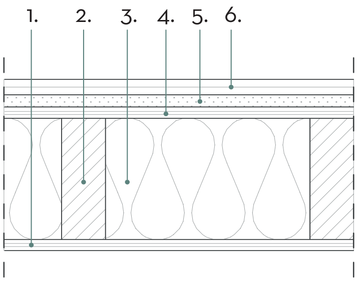


Fig 8.10 Comparison wall constructions

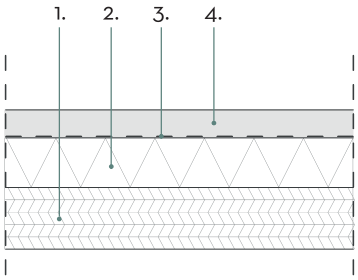
8.2.2 Floor construction

For the floor construction three designs were explored. One is the proposed design by Smits Vastgoedzorg, a timber frame with glass wool. The first alternative is a CLT panel with wood fibre insulation and the other alternative design is composed of I-joist, LVL beams and flax wool. For all layers the GWP and the carbon storage was calculated.

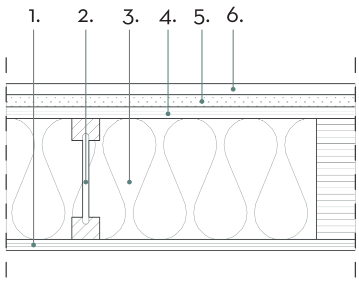
1. Timber frame - glasswool



2. CLT - wood fibre



3. I-joist - LVL - Flaxwool



1. Timber frame - glasswool

The proposed design consists of a timber frame of planed timber beams with size 71x196mm. In between these beams a glass wool insulation was placed. On both sides of this element there is on OSB board. On top of the floor a layer of wood fibre is topped off with two layers of fireproof gypsum fibre board.

#	Material	Thickness	GWP/unit *Kg CO2-eq*	Unit	Stored carbon *Kg carbon*	% biobased
1	OSB board	18	1,2	m2	16,23	93
2	Planed spruce	196	0,9	m1	6,32	100
3	Glass wool insulation	196	3,24	m2	0,00	0
4	OSB board	18	1,2	m2	16,23	93
5	Wood fiber insulation	20	2,88	m2	3,48	82
6	Gypsum fiber board	18	11,17	m2	0,00	0
7	**Total**	**-**	**20,59**		**19,70**	

Table 8.6 Design alternative 1: Timber frame - glasswool

2. CLT - wood fibre

The first alternative design is composed of CLT panel with on top of it a wood fibre insulation board. To meet acoustical performances, a layer of screed is often applied in this type of structures (INBO, 2022). This layer however drastically increases the total GWP. Biobased alternatives with for example a floating floor finish should be considered.

#	Material	Thickness *mm*	GWP/unit *Kg CO2-eq*	Unit	Stored carbon *Kg carbon*	% biobased
1	CLT panel	100	6,98	m2	86,92	62
2	Wood fiber boards	100	2,88	m2	34,76	82
3	Dampopen PE foil	-	1,6	m2	0,00	0
4	Screed	50	16,75	m2	0,00	0
5	**Total**	**-**	**28,21**		**121,68**	

Table 8.7 Design alternative 2: CLT panel - wood fibre

3. I-joist - LVL - Flaxwool

The final design is one constructed of LVL edge beams combined with I-joists. In between these beams a layer of flax wool was placed. In this alternative it was chosen to apply fireproof OSB board. This biobased alternative could reach a fire class B which was sufficient in this case.

#	Material	Thickness	GWP/unit Kg CO_2	Unit	Stored carbon Kg CO_2	% biobased
1	OSB board	18	1,2	m2	16,23	93
2	I-joist	196	3,59	m1	1,84	93
3	LVL beam	196	5,2	m1	5,70	
4	Flax wool insulation	196	1,33	m2	17,50	88
5	OSB board	18	1,2	m2	16,23	93
6	Wood fiber	20	2,88	m2	3,48	82
7	Fire retardant OSB	18	4,4	m2	16,23	93
8	**Total**	-	**19,8**		**77,19**	

Table 8.8 Design alternative 2: CLT panel - wood fibre

In the graph below the three floor constructions are compared. The GWP of all three are quite similar, especially if the screed in the second alternative (CLT floor – wood fibre) is replaced by a biobased alternative.

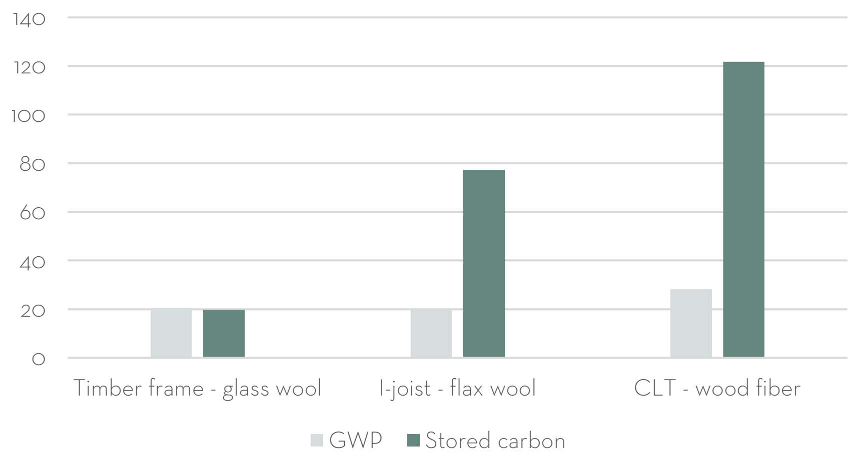
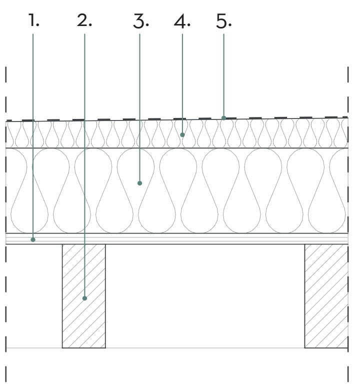
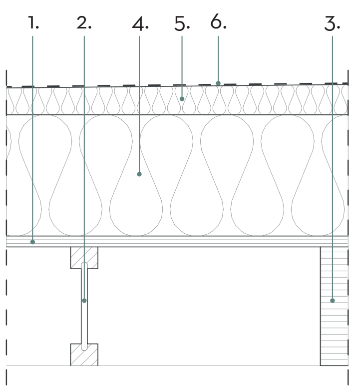


Fig 8.11 Comparison floor constructions

8.2.3 Roof construction

Lastly two designs were compared for the flat roof construction. The first one is the current design composed of a timber frame combined with PUR insulation. The alternative biobased design consists of LVL edge beams combined with I-joists. On top of this structure lays a wood fibre board insulation.





1. Timber frame - PUR

The current design consists of a timber frame with on top of this a PUR insulation board, and EPDM foil as a water barrier. Both the PUR as the EPDM has a really substantial GWP which definitely make this design undesirable.

#	Material	Thickness	GWP/unit Kg CO2	Unit	Stored carbon Kg CO2	% biobased
1	OSB board	18	1,2	m2	16,23	93
2	Planed spruce	171	0,93	m1	6,32	100
3	PUR insulation	140	30,7	m2	0	0
4	Sloped PUR insulation	50	10,2	m2	0	0
5	EPDM foil	-	7,54	m2	0	0
6	**Total**	**-**	**50,57**		**22,54**	

Table 8.9 Design alternative 1: Timber frame - PUR

2. I-joist - wood fibre

The alternative design is composed of LVL edge beams combined with I-joists, with on top of that wood fibre boards as insulation and a lead alternative as water barrier. This alternative design has a significant lower GWP than the current one.

#	Material	Thickness	GWP/unit Kg CO2	Unit	Stored carbon Kg CO2	% biobased
1	OSB board	18	1,2	m2	16,23	93
2	I-joist	171	3,59	m1	1,84	93
3	LVL beam	171	5,2	m1	5,70	98
4	Wood fiber insulation	200	11,97	m2	34,76	88
5	Sloped wood fiber insulation	50	2,85	m2	17,38	-
6	Lead alternative	-	6,23	m2	0,00	0
7	**Total**	**-**	**31,04**		**75,90**	**-**

Table 8.10 Design alternative 2: I-joist - wood fibre

As was expected, the biobased alternative with I-joists and wood fibre performs better in terms of GWP. It furthermore also stores more carbon which make this alternative the preferred design.

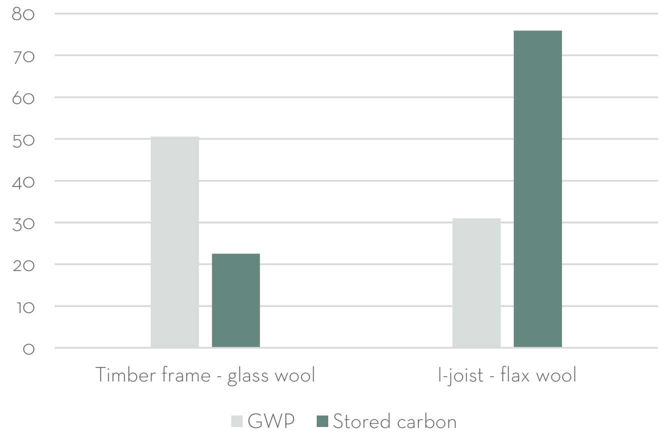


Fig 8.12 Comparison roof constructions

8.3 SCENARIOS 2030

The goal of this paper is to find whether it is possible to build the 100 000 required top-ups with local biobased materials. As part of answering this question, a strategy for transforming the landscape of the region Zuid-Holland was proposed in the previous chapter. If these would eventually be implemented, the supply of local biobased materials would obviously drastically increase. However, it is still a matter of several years before these transitions have actually fully taken place. Therefore, in this subchapter a hypothetical scenario for 2030 was worked out. To do so, the potential for the landscape in the region was linked to the requirements of the bio-based crops. In that way a clear image of what materials could be sourced where is created. All the materials could be sourced within 50km reach from the project location, which drastically reduces the carbon emissions for transport.

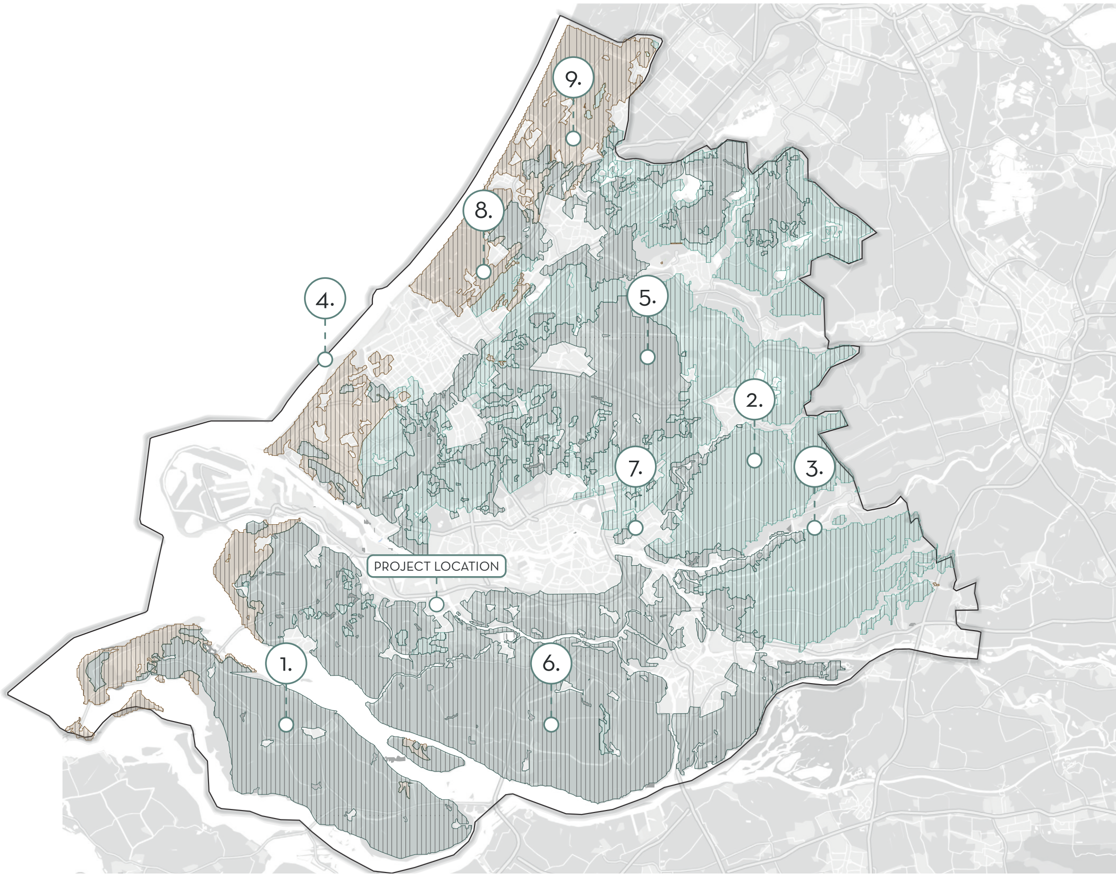
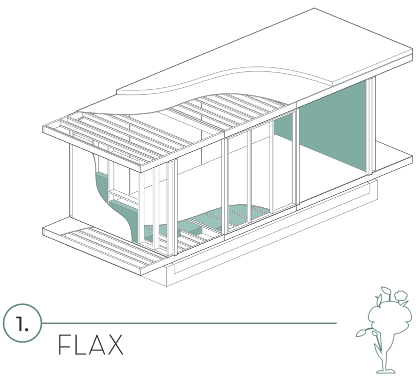
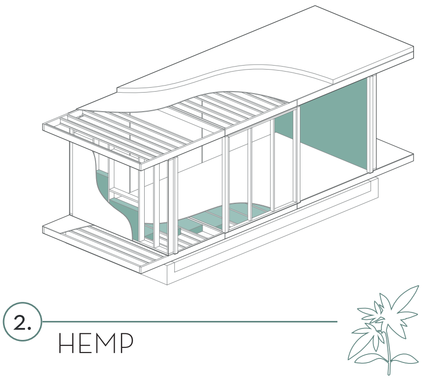


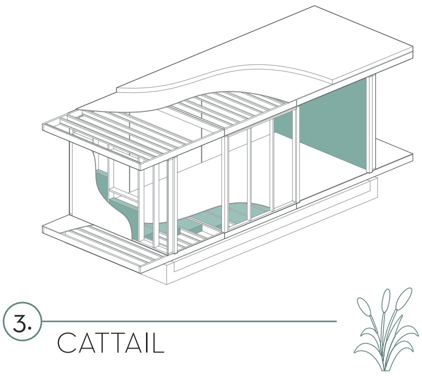
Fig 8.13 Map scenario 2030



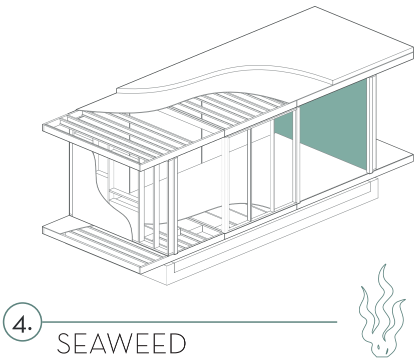
As was concluded in a preceding chapter, flax is found to thrive in the moistures clay soil prevalent in the south-east region of Zuid-Holland, where cultivation is already underway. It is recommended that more farms in this region incorporate flax into their rotation schemes to ensure a consistent supply. This flax can be utilized in the production of insulation materials and non-structural finishes, such as particle boards or bio composites.



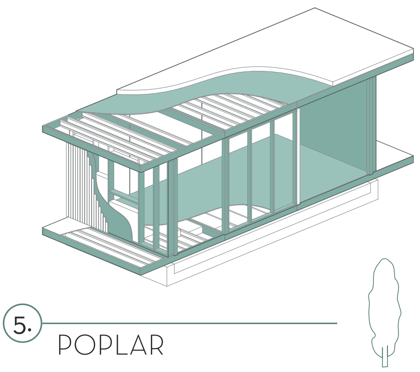
Presently, hemp cultivation is predominantly concentrated on peat soils situated in the north-east region of Zuid-Holland, where a considerable amount of farmland is found. It is recommended that farmers in this region consider incorporating hemp into their crop rotation schemes to establish a reliable supply. The fibres extracted from hemp can be utilized for manufacturing insulation materials or bio composites, while the shives can be employed in the production of particle boards.



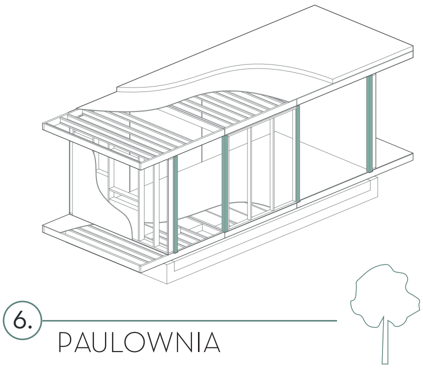
Historically in the peat region in Zuid-Holland there has been a lot of so called paludiculture farming, meaning these lands were semi flooded to grow crops like reed and cattail. Alongside the rivers and creeks that flow through the province, these crops have been grown for centuries (Weterhof, 2021). This fact is even more promising since these blue elements will be increased since it reduces the amount of GHG emissions. With cattail, blow-in insulation for the flooring or wall elements could be produced, as well as sturdy insulating boards, similar to wood fibre boards, for the wall or the roof.



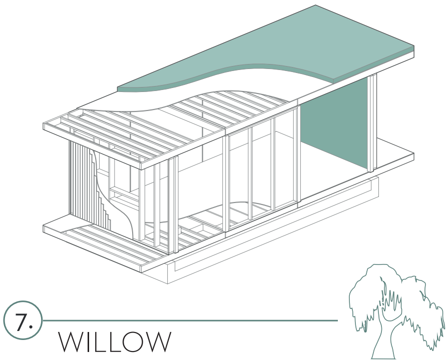
Because of its connection to the sea, Zuid-Holland is able to grow vast amounts of seaweed. Currently a farm of 600 hectares is located in the Oosterschelde and a similar project was run in the North Sea at Scheveningen (The seaweed company. (n.d.). The Rotterdam based company BlueBlocks (2023) is using seaweed to (among other products) produce non-structural panels which could be used for interior finishes.



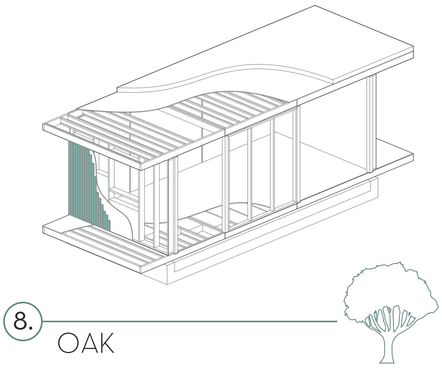
The poplar tree is currently widespread in the Dutch landscape, with optimal cultivation suggested in the clay region of Zuid-Holland, given its preference for moist soil conditions. Traditionally, the lower density of poplar has led to its frequent use in oriented strand board (OSB) applications (Van Dam & Van Den Oever, 2019). However, due to its rapid growth potential, companies are increasingly exploring the possibilities of utilizing poplar for higher-quality products such as LVL or even Glulam (Van Acker et al., 2016).



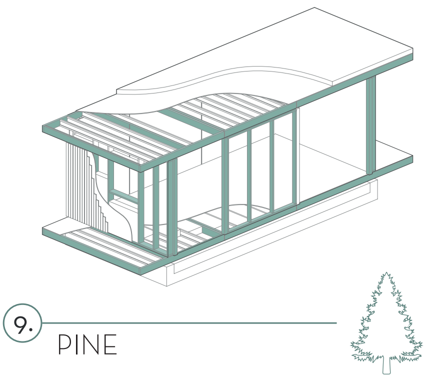
For the paulownia tree there is currently little experience in The Netherlands. However, it is mentioned that the tree needs a moistures soil, which means the sand grounds in the coastal regions will not do well. The wood of the paulownia is lightweight and very strong (Van Dijk et al., 2021), and is already applied in CLT. It could therefore well be used for the Glulam columns.



The willow tree, traditionally found along creeks and rivers, has also been intentionally cultivated on expansive fields interspersed with numerous creeks. This tree thrives in moist soil conditions and is suitable for cultivation in both peat and clay regions (Boosten & Jansen, 2014). According to Van Acker et al. (2016), the willow tree is utilized in the production of fiberboards, including MDF, HDF, and insulating boards.

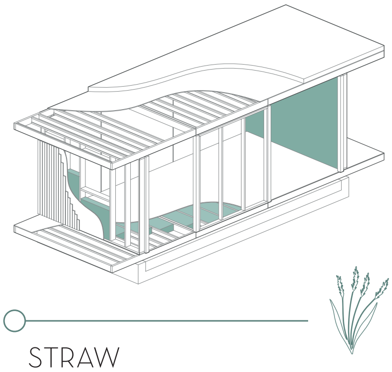


The oak tree is well-suited to thrive in the somewhat nutrient-deficient sandy soils of the dune landscape in Zuid-Holland. In the elevated dune areas, where the soil tends to be less moist, the establishment of a dry dune forest is proposed, fostering the growth of oak trees. Oak, being a hardwood, is commonly used in cladding applications, showcasing its potential for use without requiring additional treatment (Boom landscape, 2020).



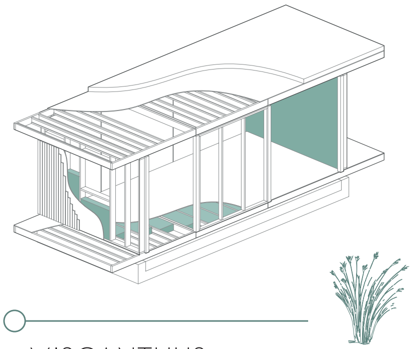
Similar to the oak, the pine tree can flourish in a dry dune forest characterized by lower soil moisture and nutrient levels. The straight logs of the pine tree make it a valuable resource for manufacturing various building products, such as LVL beams and studs, as well as Glulam columns. (Boom landscape, 2020).

Apart from the provided materials that were allocated in the region of Zuid-Holland there are two resource that were not allocated since they do not have specific requirements, namely straw, which is in fact a residual from grain production, and miscanthus which could grow anywhere.



STRAW

Straw is a byproduct of grain production, a process occurring across various soil types in the Netherlands. Although it is noted that the yield is higher on clay soils, it's important to acknowledge that peat soils are also utilized for cultivating cereals. Straw finds diverse applications in construction products, including being pressed into timber-straw panels (Ecococon, n.d.) or used as blow-in insulation (Strobouwer, n.d.) in structures such as timber-stud frames.



MISCANTHUS

Miscanthus is praised for its capability to thrive on virtually any soil. Neglected or depleted lands, such as those along highways or near airports, could be used to start growing this "wonder crop." The fibres of miscanthus could like any other fibre crop be used for insulation material, and the shives for particle boards (Linex, n.d.) or bio-concrete (Xiriton, n.d.). Bio-concrete still has a relatively high mass, which make it less suitable for topping-up.

Design

Next, it was visually displayed in the new design for the top-up what materials were applied and where these were sourced (if allocated).

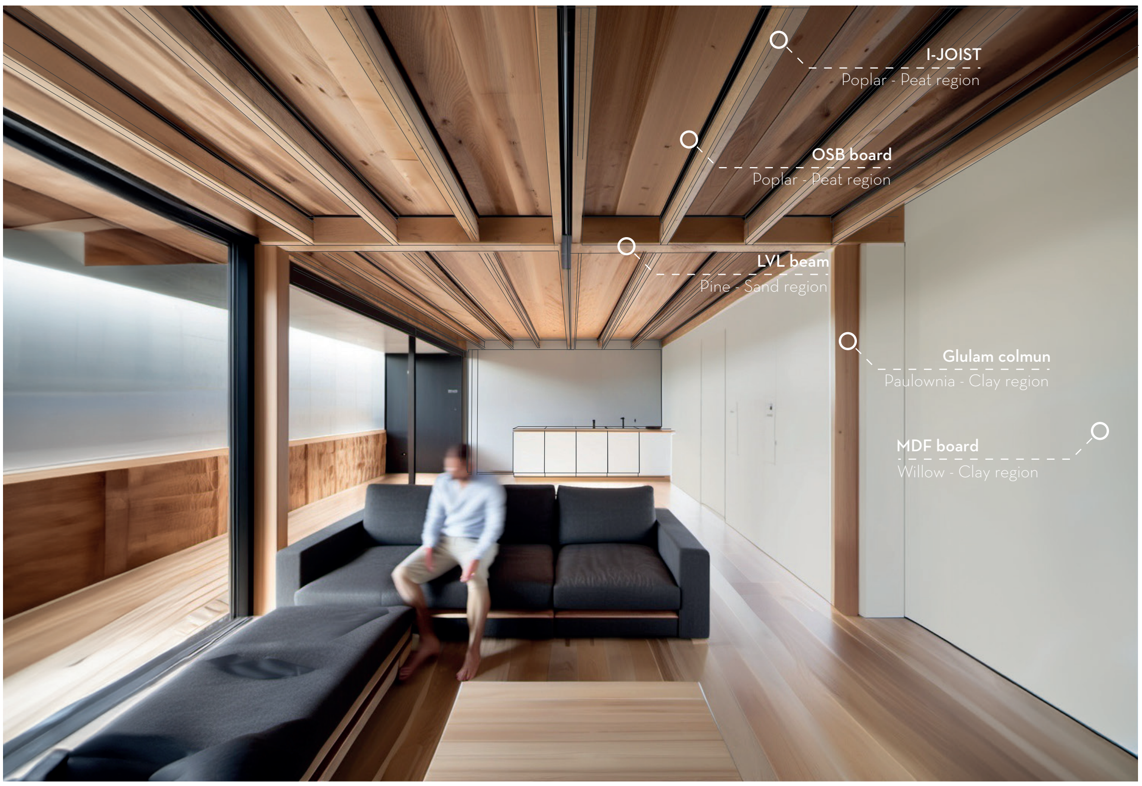


Fig 8.14 Interior visualisation

Fig 8.15 Section visualisation

Fig 8.16 Section visualisation

8.4 Paris Proof 2030

As a final check, this subchapter reviews whether the adjustments made to designs will actually help in reaching Paris Proof housing by 2030. In chapter 3.3.4 of this paper, the maximum embodied carbon emissions for housing was adopted from a research conducted by the Dutch Green Building Council (DGBC). In the figure below this data was summarized once more. Comparing this data with, the data found for the design for the top-up, raises the question whether a top-up should be considered 'new construction' or 'renovation'. Since there is at this moment not a right answer to this, and regulations do not specify this, the design will be compared with both.

Paris Proof		embodied carbon kg CO2-eq. per m2			
#	Type of building	2021	2030	2040	2050
1	Housing (new construction)	200	126	75	45
2	Housing (Renovation)	100	63	38	23

Fig 8.17 Paris Proof housing (DGBC, 2022)

Assumptions

To offer a comprehensive overview, certain assumptions were necessary. First of all, the three 'best practice' constructions were selected for examination, encompassing the floor, walls, and the roof. It must be mentioned that in some cases the chosen alternative did not perform the best in terms of GWP. However, it was reasoned that in the light of this paper it is not likely to choose CLT instead of an I-joist framing since CLT requires a lot of timber which is a scarce biobased good in the Netherlands. Additionally, there are more elements in a building than just floors, exterior walls and a roof. To complete the overview, additional data was added on the interior walls, the window frames and the glazing. This data was collected with help of the NMD. And finally, it should be stressed that this is still not a complete building and that there are still elements that are not incorporated yet, like for example installations. However this was deemed out of scope for this paper. This calculation gives a first insight in the performances of the design for the top-up.

#	Element	Description	Area [m2]	GWP/m2	GWP
1	Total area floor	An I-joist frame with LVL edge beams and flax wool insulation as an infill. The top-floor is covered with fireproof OSB board.	88,1	19,8	1744,38
2	Total area wall exterior closed	An I-joist frame with flax wool insulation as an infill. The facade consists of Dutch pine, and the interior wall finish is MDF board.	101,1	26,41	2670,05
3	Total area wall exterior open	For the sake of simplicity all window frames are constructed with European pine. Data collected from the NMD	24,2	3,66	88,57
4	Total area glass	Insulated glazing by 'Vakgroep Glas' of 'Bouwend Nederland'. Currently a realistic low-carbon alternative in the Netherlands. There are companies that pretend to have less than 10kg CO2 as GWP, but these are not in the NMD yet.	54,2	20,7	1121,94
5	Total area wall interior	The interior walls are FAAY panels, a Dutch company that makes sandwich panels of gypsum boards with flax wool insulation.	60,7	18,6	1129,02
6	Total area roof	An I-joist frame with LVL edge beams. On top of this lie wood fibre insulation boards. The water barrier consist of a lead alternative.	86,1	31,04	2672,54
7	**Total GWP**				**9426,5**
8	**GWP/m2**				**107**

Fig 8.18 GWP for the top-up

It was concluded that the total GWP of the top-up is 9 426 kg CO2 which comes down to 107 kg CO2/m2. Comparing this with the boundaries for Paris Proof housing, it can be concluded that this amount perfectly falls within the margin of 'new construction' in 2030 which is 126 kg CO2/m2. It is on the other hand more than the boundaries for 'renovation' which is 63 kg CO2/m2. It should be specified in the future whether a top-up should meet the requirements for renovation or for new construction.

8.5 CONCLUSION

In this chapter the research question, '*how can locally sourced biobased materials help inform the design for the top-up Smits vastgoedzorg'*, was answered by designing and testing multiple alternatives for a scenario in 2023 and 2030. A status quo was created which was based on a current design for a top-up by Smits Vastgoedzorg. The goal for each alternative is eventually to increase the amount of biobased content in the design and evaluate whether this reduces the GWP. The results showed that the current design is already performing well in terms of GWP. One explanation for this could be that biobased insulation practically always have a fire class D or E, which means additional layers should be included. These additional layers often show a relatively high GWP. In the roof construction, switching to biobased insulation did actually make a significant difference, due to the high impact of PUR insulation, which was now replaced by wood-fibre. Furthermore, it was concluded that all biobased alternatives show a higher carbon storage which is in fact inherent to biobased materials. This temporarily stored carbon is highly dependent on the end-of-life scenario, and current regulations state that this could not be incorporated.

For the scenario 2030, it was first visibly displayed on map where materials could be sourced. In total, nine resources were allocated. Of each resource it was explained where in the top-up the material could be applied. It should be mentioned that these allocations are based on research, however still highly hypothetical. However, in the case this strategy will be implemented, materials for the top-up could all be sourced within 50km reach.

As a final conclusion it was found that with the adjustments to design, a total of 107 kg CO2/m2 was reached. This falls within the margin for Paris Proof housing in 2030, for 'new construction'. If the requirements of 'renovation' should be met, this amount will eventually have to

IV CONCLUSION

9. DISCUSSION

This study followed several steps to answer the main research question, how can locally sourced biobased building materials be used in constructing top-ups in The Netherlands. A narrative was created, which was used as chapters, each answering a research question. In this section a discussion on the drawn conclusions was given. For each research question, the main findings were summarized, after which a reflection on the used data and method was provided.

The potential of biobased topping-up was found and confirmed. The performed literature review showed that renovation and topping-up cause a substantial lower GWP since it makes use of existing structures. Adding on this, several reasons were provided why these top-ups should be built with biobased materials. Apart from the generic benefits, which were summarized as well, there are several properties of these materials that are specifically useful when topping-up. It was found, by comparing the generic properties of the materials, that biobased structures are more lightweight than conventional structures. Furthermore, biobased structures show a high potential for prefabrication (Amer & Attia, 2018) in the form of for example CLT-slabs, a timber-stud frame or a timber-straw panel. Biobased insulation also performs well in terms of thermal properties due to its thermal capacity (Visser et al., 2015), creating a phase shift through which in summer heat will transfer at a slower pace though the material (Biobeest, 2022). Finally, biobased materials have the ability to absorb moisture through which a damp-open construction could be constructed (Visser et al., 2015).

In this chapter, it was found that the current amount of literature on the specific topic of biobased topping-up was very limited while policy makers did highlight it as part of the transition towards the biobased economy (Van Der Steen & Rotmans, 2022). The benefits of biobased topping-up were not specifically given in one document and had to be formulated with the help of several sources and pre-knowledge of the student on this topic. Some benefits were relatively easy to prove, like the weight reduction, where others were more complex to prove like the level of prefabrication. However, in general the conclusion that biobased topping-up is a means towards reaching Paris-proof housing by 2030, seems justified.

After confirming the potential of biobased topping-up, the available **resources** to build the required 100 000 top-ups had to be found. A set of seven promising resources, wood, flax, hemp, straw, miscanthus, cattail and seaweed, was set-up with the help of several documents of which the Inspiratieboek biobased en natuurinclusief bouwen (College van Rijksadviseurs, 2023) appeared to be leading since it is the national guideline for biobased building. With the numbers provided by the Kerngegevens bos en hout (2022), it was concluded that there is currently not enough timber to provide structural material for 12 500 top-ups annually. Flax and hemp similarly could provide insulation material for only 6 700 top-ups annually (CBS, 2022). The only resource that is currently abundantly available is straw, with a potential to construct more than 150 000 top-ups annually (RVO, 2022). However this material is currently barely implemented in the Dutch building sector (Vereniging Strobouw Nederland, 2017). Miscanthus, cattail and seaweed are all still in an experimental phase and similarly barely applied in practice. It could therefore be concluded that the cultivation and production of biobased materials should be scaled up to be able to build 100 000 biobased top-ups by 2030.

The most important data in this chapter is the available stock of biobased material in The Netherlands. Unfortunately, this data was not found for cattail and seaweed and for miscanthus a rough estimation was used (Boosten & Oldenburg, 2014). It could furthermore in most cases also not be specified for what purposes this stock is used which is a major drawback for this research. It should therefore be stressed that the total amount of top-ups that could be built with the material is a very rough estimation, and could still vary a lot. The only certainty in this chapter is that the current supply of local biobased materials is too little to build the 100 000 needed top-ups and should therefore be scaled-up.

To **scale-up** the cultivation and production of the given seven resources a literature review was conducted to formulate a national potential, a regional potential and a resource potential. The national potential was provided by one single document de nationale aanpak biobased bouwen (2023). On a national scale, the cultivation of biobased materials could provide solutions for the nitrogen crisis, the decreasing biodiversity and water-related concerns. For the region of Zuid-Holland, the landscape was decomposed with help of maps published by the Provincie Zuid-Holland. Three cluster of landscapes were pointed out, a peat landscape, a clay landscape and a sand landscape. For each a strategy was developed, mostly with the help of a research conducted by the office Boom landscape (2020). Lastly the potential for each resource was further explored. It was concluded that most resources do not compete with food production or biodiversity. Flax and hemp are rotation crops, straw is a residual, miscanthus has minimal requirements and can grow on any soil (Van Den Oever et al., 2023), cattail grows along the increasingly more present creeks and rivers, and seaweed does not grow on scarce land (Holland Houtland, 2021).

In this chapter, it was found that several studies have already done a similar analysis on a national scale and on a regional scale, showcasing the current interest in this topic. Using these studies, made it possible to give a holistic overview of the pressing problems in the region, however the chapter does lack a certain in depth explanation of the allocation of the resources. It was deemed that this is out of scope of this paper. To find the potential of the resources a literature review was conducted for which scientific resources were used, resulting in the most important conclusion, which is that the cultivation of these resources, except for wood, could significantly be scaled-up by 2030.

The final step in this narrative would be to check whether this strategy, which enhances the use of local biobased material, is actually **beneficial**, looking at the environmental impact. A comprehensive literature study revealed that biobased materials perform better in terms of GWP. The effect of the locally sourcing of the materials was more complex to prove, since so called trade-offs could take place between modules. When materials are sourced locally, the emissions through transport will decrease, however the energy needed to produce the material might increase. It is very complicated to predict these effects. A data analysis on a selection of EPDs showed that CLT and the timber-straw panel did show an increased impact of the module A4 (transport). A generic explanation for this could be that the facilities to manufacture biobased materials are still rather limited throughout Europe, through which The Netherlands is now importing timber-straw panels from Lithuania (Ecococon, n.d.) while there is enough straw available here as well.

In this chapter the theoretical framework was created by comparing four representative studies (conducted in Northwestern Europe). This framework provides a holistic idea of the environmental impact of biobased materials, and the impact of transport, however the only accurate resource on this topic has been the EPDs, providing actual on these materials. A major drawback of most EPDs is that the modules A1-A3 are combined, making it impossible to distinguish the transport from the source location to the factory. This could have been studied by using an LCA software like SimaPro in which the conditions could be changed manually, however this was deemed to be out of scope for this research.

In the case study, the actual **designs** were tested by creating multiple alternatives for the flooring, the walls and the roof in two scenarios, one for the year 2023 and one for 2030. The goal in both scenarios was to increase the biobased content and to improve the GWP. In the scenario for 2023, it was concluded that the current design with timber framing and glass wool is performing relatively good. This was mostly due to the fact that biobased insulation materials always have a fire class D or E which means additional layers had to be added, often causing a higher GWP. The biobased alternatives do however show a higher carbon storage, which could have a significant impact on the GWP. However, following the current regulations on this topic, this carbon storage was currently left out of the comparison of GWP. In the scenario for 2030 more resources will be available in the region which was displayed in a map. All resources for the top-up could with this strategy be sourced within 50km from the project location.

The believe is that the data used in the scenario for 2023 creates an accurate idea of the impact of different constructions. However, the used method is open for discussion. Comparing alternative designs means that decisions on what to compare need to be made. Either all insulation materials, structural material and finishes are compared, or entire wall, floor and roof constructions, or variations on both. The fact that it was now chosen to compare four entire constructions which were set-up with pre-knowledge implies that the best alternative of these four could be found, but that this alternative might not be the most optimal. It could still be that the optimal solution would be to combine elements of different constructions. Furthermore, the scenario for 2030 is highly hypothetical, and it should always be considered that sourcing location is not the same as the manufacturing location. In the national strategy for biobased building it was mentioned that manufacturing locations should be organized nationally, which immediately means that the sourcing location has a lesser impact. The factory could simply still be in the other part of the country. However, the conclusions that a nearly completely biobased top-up with locally sourced material will be possible in 2030 seems legitimate.

Societal and scientific context

The topic of biobased topping-up frequently appeared to be of high academic and societal relevance. The national government is currently trying to boost both biobased building as topping-up, and have started several projects to accomplish this. On March 20th, 2023, a document was released in which the national potential of 100 000 top-ups by 2030 was proclaimed, and on November 8th, 2023, the government launched a stimulating fund guided by a national strategy to enhance the production and use of biobased materials. Furthermore, biobased topping-up is part of the transition the province of Zuid-Holland wants to set in motion, however this specific topic still lacks a scientific basis.

Many studies have already been done into biobased materials and the environmental benefits of it. Similarly, a few studies have been performed to research the benefits of topping-up. And there have also been several projects carried out to enhance the use of locally sourced biobased materials in The Netherlands. These projects also conducted an analysis on the landscape and tried to scale-up the production of biobased materials to be able to supply a certain amount of houses to build. In this paper, all these resources were used to come the novelty of this research which is the combination of these topics. Linking biobased materials with topping-up is barely done before, and the recently published ambition to build 100 000 top-ups offered the amazing goal of providing all these top-ups with locally sourced biobased material. With this combination, many scales could be covered. From a national scale to a building and material scale. Doing so, this paper hopefully provides a needed addition to the current available literature.

Recommendations further research

This paper provides an holistic overview of biobased topping-up in the Netherlands, covering the national scale, the regional scale, and the material scale, eventually culminating in a design. It could be stated this research set-up is spread too thin, making it hard to draw conclusions. The narrative is clear, however there is plenty of room for additional research to validate the drawn conclusions. Several limitations in this paper could be identified.

The regional strategy to scale-up the production of biobased materials is inherently only applicable to the region of Zuid-Holland. This strategy is not extrapolatable to the rest of the country since different landscapes are present there. Further research should include the remaining parts of The Netherlands, to create a more detailed idea whether building 100 000 biobased top-ups is reasonable.

It furthermore appeared to be complex to quantify and prove the benefit of stored carbon that biobased materials usually have. It was, in the light of practicality and comparability, decided to make use of the Nationale Milieudatabase, and follow the current regulations to quantify the GWP. It should however again be mentioned that this method is questionable and currently insufficiently taking into account the amount of stored carbon. Current research on this method is conducted by Wageningen University and will be finished this year.

Lastly, surprising little research has been conducted to the impact of sourcing location and transportation of materials. This means that it was very complex to provide evidence for the learned lessons in this paper. A literature review, and a comparison of eight load-bearing structures was conducted. However, to be able to accurately prove the posed hypothesis, much more data is needed which was slightly out of scope for this research. A comparative study with the help of an LCA tool like SimaPro should be conducted to compare many different scenarios, and check what the impact of these scenarios is.

10. CONCLUSION

This study evaluated the potential of applying locally sourced biobased materials in the construction of top-ups in the Netherlands. In the hypothesis it was stated that it will be possible to construct the 100 000 required top-ups, by 2030, with biobased materials sourced in The Netherlands, and that doing so the embodied emissions will decrease. It was found that constructing lightweight top-ups will have a limiting effect on emission in the first place since existing structures are used. Through an extensive literature review it was then explained that constructing a top-up with biobased materials has several benefits. Biobased structures are in general lightweight, a level of prefabrication is possible through which the construction time on sight is limited, and there are several building physical benefits like the ability of construction a damp-open construction and the thermal capacity of biobased insulation.

It was however concluded that it is currently not possible to construct all 100 000 required top-ups with biobased materials. A comprehensive literature study and data analysis showed that with the seven most present or promising resources in The Netherlands, wood, flax, hemp, straw, miscanthus, cattail and seaweed, showed that currently less than 10 000 top-ups could be constructed annually where 12 500 are needed to build 100 000 top-ups by 2030. This fact called for a strategy to scale-up the current cultivation and production of biobased materials in The Netherlands.

On a national scale, only a general framework was created with the help of the current national guidelines on biobased materials. However, for the region of Zuid-Holland, the landscape was thoroughly analysed to be able to allocate potential area where biobased resources could be cultivated. A finite number on amounts of newly sourced materials was not found, but the conclusion that by 2030 the cultivation and production of biobased materials in the region of Zuid-Holland could significantly be scaled-up, seems justified.

In the hypothesis it was also stated that implementing locally sourced biobased materials in the design for the top-up would lead to a reduction of the GWP. A literature review and data comparison revealed that biobased materials do lead to a reduction GWP, however the statement that sourcing the material locally would also lead to a reduction appeared more complex to prove. The fact that the current impact (due to transport) of some biobased products is relatively high compared to conventional products, lead to the statement that the limited manufacturing facilities is the reason for this. The certainties of a larger demand, will lead to more facilities, and a further reduction of transport from source to factory and from factory to construction site, which will inherently result in a reduction of the GWP.

In conclusion it is justified to state that under certain provided circumstances, it is possible to construct 100 000 top-ups by 2030 with biobased material sourced in The Netherlands, and that this will lead to reduction of the embodied emissions.

11. REFLECTION

In this final chapter a reflection on the used approach and method of this research was provided. Being part of a graduation project of the master track Building technology of the master program MSc Architecture, Urbanism, and Building Sciences, this paper finds itself in a broader academic context. Biobased materials are currently of great scientific interest and represented in different faculties in the TU Delft like Industrial Design and Architecture. However, in my experience it is slightly underrepresented field of research in the Building Technology track, where I think this topic is the perfect match between architecture and engineering, what this track in the end is all about. This thesis combines the chairs Circular building design and Nature-inclusive design. Within these chairs and in general the Building Technology track, I hope to have added a feasible and practical application in The Netherlands of research conducted in a mostly international environment.

The introduction of this paper points out a handful of the most pressing environmental and social challenges of the coming few years. Answering to these major problems, required a journey through many different scales across many different topics which is more than often not the brightest thing to do for a master thesis. This became clear when proposing the 'graduation plan' during the P2, accompanied with the research method. It was very unclear what the eventual goal of this project would be. Would it become a strategy to enhance the cultivation and use of biobased materials in The Netherlands, or would it be a design where the use of biobased materials would be optimised. This combination of supply and demand was however the narrative I was almost desperately aiming for, since the strong believe was that these two are connected and appeared to be impossible to let go of. The reason why I was eventually allowed to continue this narrative, perhaps came when I started my internship at Smits Vastgoedzorg for which I am very thankful to both my main mentor Andy who made that happen, as for my mentor Christian from Smits. From the P3 onwards there was now an existing design for a top-up which could be evaluated and adjusted. This project now followed the research method of a literature review, in which the research questions were answered, and a case study, in which the learned lessons would be applied. In my experience taking this hurdle was a pivotal point in this project and the communication with my two mentors went a lot smoother from this point. Towards my P4, I was constantly receiving feedback from my mentors about my research, and similarly from the people I collaborated with at Smits about the practical implications of my research. Besides receiving feedback, the more frequent communication with my mentors proved to be very helpful for yet another reason. Having to explain myself forced me to constantly sharpen the narrative I proposed. Whenever the story would be vague or ambiguous the feedback would the same. This definitely kept me from wandering off, since I do have the tendency to lose myself in exploring perhaps less relatable topics, making my research even broader.

Additionally, I really enjoyed my position as graduation student since I was able to simply ask around to other involved people as well. I have been in touch with Pablo van der Lugt (TU Delft), Arjan van Timmeren (TU Delft), Elizabeth Migoni Alejandre (TU Delft), Daan van Rooijen (NHL Stenden), Joke Duformont (AMS Institute), Norbert Schotte (Building Balance) and many more.

The interplay between research and practice appeared to be vary valuable to me. However, it does leave me questioning what the added value is for both science as for Smits. This research has spread out rather thin, resulting in a strong desire to continue the research. Especially the topic of LCAs is a complex and challenging field of research and deserve a proper understanding The interplay between research and practice appeared to be very valuable to me. However it does leave me at times questioning what the added value is for science as well as for Smits. This research has spread out rather thin, so it does leave me with a feeling of wanting to continue the research. Especially LCAs are complex matter and deserve a proper understanding, especially now since biobased materials are broadly entering the market and it should be understood well how these materials perform. Simultaneously my added value to the design of Smits has also been limited, since most design decisions I would take were not implemented for several reasons, of which economical price was the most frequent heard. Due to these limitations, this project truly feels as just a start. I would very much like continue my research into LCAs and

BIBLIOGRAPHY

Acroniq. (n.d.). *Xiriton*. https://acroniq.nl/

Al, E. (2016). Populierenteelt anno 2016. *Vakblad Natuur Bos Landschap*.

Amer, M., & Attia, S. (2018). Timber construction methods for roof stacking : Classification and compare-tive analysis. *WCTE 2018-World Conference on Timber Engineering*.

ASN Bank & Climate Cleanup. (2021). *Construction stored carbon: A financial metric for carbon storage in the built environment*.

Baecke, F. (2019). *Teelthandleiding Miscanthus Giganteus (Olifantsgras)*. Growing a green future.

Bia-beton. (n.d.). *Hennepblokken*. https://www.bia-beton.nl/specials/hennepblokken/45

Biobasedgarden. (2018, February 5). *Vezelhennep*. Retrieved October 5, 2023, from https://www.biobas-edgarden.nl/gewassenoverzicht/vezelhennep/

Biobeest. (2022, June 30). *Te heet in huis*. www.biobeest.nl. Retrieved from https://www.biobeest.shop/blogs/nieuws/te-heet-in-huis/

BlueBlocks. (n.d.). *Biobased materials, circular solutions*. Retrieved November 3, 2023, from https://www.blueblocks.nl

BlueBlocks. (2023). *SeaWood materials*. Retrieved November 6, 2023, from https://www.blueblocks.nl/portfolio/seawood/

Boerenbusiness. (n.d.). *Waarom groeit teelt van vezelhennep niet explosief? - analyse Vezelhennep*. https://www.boerenbusiness.nl/akkerbouw/artikel/10897956/waarom-groeit-teelt-van-vezelhennep-ni-et-explosief

Boom landscape. (2020). *Biobased (ver-)bouwen Zuid-Holland: Ontwerpend onderzoek*. College van Rijksadviseurs.

Boosten, M., & Jansen, P. (2014). Wilgenplantages in Nederland: stand van zaken. *Bos Berichten, 7*.

Boosten, M., & Oldenburg, J. (2011). *Kansen voor de aanleg van wilgenplantages in Nederland*. Probos.

Boosten, M., & Oldenburg, J. (2014). *Biomassapotentieel NBLH-sector in 2020 en 2050*. Stichting Probos.

CAH Dronten. (2002). *Teelthandleiding vezelhennep*.

CBS. (n.d.). *Graanoogst Nederland 2022-2023* [Dataset]. RVO.

CBS. (2023). *Akkerbouwgewassen, productie naar regio* [Dataset].

Centrum hout. (n.d.). *Houtsoort: Populieren*. Houtinfo. Retrieved October 22, 2023, from https://www.houtinfo.nl/node/172

Centrum hout. (2015). Houtachtige plaatmaterialen. https://www.houtinfo.nl

Colbers, B., Cornelis, S., Geraets, E., Gutiérrez-Valdés, N., Tran, L. M., Moreno-Giménez, E., & Ramírez-Ga-ona, M. (2017). A feasibility study on the usage of cattail (Typha spp.) for the production of insulation materials and bio-adhesives (Vol. 71). Wageningen: Wageningen University and Research Centre.

College van Rijksadviseurs. (2023). *Inspiratieboek biobased en natuurinclusief bouwen*.

Copper8, Metabolic, NIBE, Alba Concepts. (2023). *Woningbouw binnen planetaire grenzen: mate-riaalvraag, CO_2-uitstoot & milieu-impact van de Nederlandse woningbouw*

Compendium voor de leefomgeving. (2023, February 13). *Ontwikkeling van het Nederlandse bos, 2001-2021*. CLO. Retrieved November 1, 2023, from https://www.clo.nl/indicatoren/nl0069-ontwikkeling-nederlandse-bos

De Visser, C. L. M., van Wijk, C. A. P., & van der Voort, M. P. J. (2015). *Health, comfort, energy use and sustainability issues related to the use of biobased building materials: to what extent are the effects supported by science and data?: what are next steps to take? (No. 641). Applied Plant Research of Wageningen UR, Business Unit arable farming, multifunctional agriculture and field production of vegetables.*

Dieleman, P. (2012). Miscanthus is bruikbaar als groene grondstof. *Boerenbond*.

Dutch Green Building Council. (2020, December 9). *Toewerken naar echt CO_2-neutraal renoveren om Parijse klimaatdoelen te halen*. https://www.dgbc.nl/nieuws/toewerken-naar-echt-co-neutraal-renoveren-om-parijse-klimaatdoelen-te-halen-5995

Dutch Green Building Council & Metabolic. (2023). *Routekaarten voor een duurzame bouw: Haalbaarheid CO2-reductie strategie bouwmaterialen industry*.

Ecochain. (n.d.). *How do you model transport? Step 1 - Calculating ton kilometer*. Retrieved November 11, 2023, from https://helpcenter.ecochain.com/how-to-model-transport-step1

EcoCocon. (2022). *The panel*. Retrieved November 2, 2023, from https://ecococon.eu/nl/paneel

European Committee for Standardization (CEN). (2013). EN 15804: Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products. European Committee for Standardization (CEN)

Geologie van Nederland. (n.d.-a). *Duinlandschap*. Geologie Van Nederland. Retrieved October 10, 2023, from https://www.geologievannederland.nl/landschap/landschappen/duiinlandschap

Geologie van Nederland. (n.d.-b). *Veenlandscap*. Geologie Van Nederland. Retrieved October 10, 2023, from https://www.geologievannederland.nl/landschap/landschappen/veenlandschap

Geologie van Nederland. (n.d.-c). *Zeekleilandschap*. Geologie Van Nederland. Retrieved October 10, 2023, from https://www.geologievannederland.nl/landschap/landschappen/zeekleilandschap

Grow2build. (2015). *Bouwen met vlas en hennep*.

Gürsel, I. V., Elbersen, B., Meesters, K., & Van Leeuwen, M. (2022). Defining circular economy principles for biobased products. *Sustainability*, *14*(19), 12780. https://doi.org/10.3390/su141912780

Gutex. (n.d.). *Gutex thermoroom*. www.gutex-benelux.nl. https://gutex-benelux.eu/assortiment/producten/produkt/gutex-thermoroom/

Hengelos Weekblad. (2022, July 14). *Oogstdagen bij Wendezoele*. hengelosweekblad.nl/. https://www.hengelosweekblad.nl/nieuws/algemeen/97487/oogstdagen-bij-wendezoele

Het bewuste stel. (2020, October 28). *Wanden: waar dienen ze eigenlijk voor!? Deel 2*. www.hetbewustestel.nl. https://hetbewustestel.nl/tiny-house-wanden-deel-2/

Holland Houtland. (2021). *Bedrijvengids biobased bouwen 2021: Partners, voorbeelden en oplossingen*.

INBO. (2022). *Cross Laminated Timber: Handleiding voor architecten en bouwkundigen* (2.2).
Interprovinciaal overleg. (2020). *Bos voor de toekomst, Uitwerking ambities en doelen landelijke Bossenstrategie en beleidsagenda 2030*. Ministerie van Landbouw, Natuur en Voedselkwaliteit.
IPCC. (2021). Sixth Assessment Report. In *IPCC*.

IPO & LNV. (2020). Bos voor de toekomst. Uitwerking ambities en doelen landelijke Bossenstrategie en beleidsagenda 2030. Den Haag, Interprovinciaal Overleg & Ministerie van Landbouw, Natuur en Voedselkwaliteit.

Isovlas. (n.d.). *Gezond bouwen zit in onze vezels*. https://www.isovlas.nl/bouwisolatie/

Isovlas. (2023, February 14). *Bouwisolatie - Isovlas*. https://www.isovlas.nl/bouwisolatie/

Kanselaar, J., Van Ewijk, H., & Casper, B. (2022). *Voorstel berekeningsmethodiek om koolstofvastlegging in biobased bouwmaterialen te kunnen realiseren: Onderzoeksrapport*. SGS Search.

Lerink, B. (2023). Produceren we in Nederland genoeg hout om voortaan alle huizen van hout te bouwen? *KlimaatHelpdesk*. https://www.klimaathelpdesk.org/answers/produceren-we-in-nl-genoeg-hout-om-voortaan-alle-huizen-van-hout-te-bouwen

LETI. (2020). *LETI Embodied Carbon Primer: Supplementary guidance to the Climate Emergency Design Guide*.

Linex. (n.d.). *Flaxboard*. https://linex.nl/en/products/flaxboard/

Linnen vakmanschap, van vezel tot weefsel. (2021, September 14). Libeco. https://www.libeco.com/nl/over-linnen

Martens Keramiek. (n.d.). *Duplicor*. Duplicor.nl. https://www.duplicor.nl/nl/

Metsä wood. (n.d.). *Berken multiplex*. Metsä Wood.
https://www.metsagroup.com/nl/metsawood/producten-en-diensten/producten/berken-multiplex/

Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, Ministerie van Infrastructuur en Waterstaat, Ministerie van Landbouw, Natuur en Voedselkwaliteit, & Ministerie van Economische Zaken en Klimaat. (2023). Nationale aanpak biobased bouwen: Van boerenland tot bouwmateriaal. In *Rijksoverheid*.

Ministerie van Infrastructuur en Waterstaat. (2023, May 4). *Omslag naar circulaire economie versnellen*. Circulaire Economie | Rijksoverheid.nl.
https://www.rijksoverheid.nl/onderwerpen/circulaire-economie/omslag-naar-circulaire-economie-versnellen

Mouton, L., Allacker, K., & Röck, M. (2023). Bio-based building material solutions for environmental benefits over conventional construction products – Life cycle assessment of regenerative design strategies (1/2). *Energy and Buildings*, *282*, 112767. https://doi.org/10.1016/j.enbuild.2022.112767

Nibe & DGBC. (2021). *Paris Proof Embodied Carbon: Achtergrond rapport*.

Oldenburg, J. (2019). *Stand van zaken bos in Nederland: Factsheet ten behoeve van de werkbijeenkomsten Bossenstrategie op 20 en 22 november 2019*. Probos.

Olifantsgras - Miscanthus. (n.d.). WUR. https://www.wur.nl/nl/dossiers/dossier/olifantsgras-miscanthus.htm

Peñaloza, D., Erlandsson, M., & Falk, A. (2016). Exploring the climate impact effects of increased use of bio-based materials in buildings. *Construction and Building Materials*, *125*, 219–226. https://doi.org/10.1016/j.conbuildmat.2016.08.041

Pittau, F., Krause, F., Lumia, G., & Habert, G. (2018). Fast-growing bio-based materials as an opportunity for storing carbon in exterior walls. *Building and Environment*, *129*, 117–129. https://doi.org/10.1016/j.buildenv.2017.12.006

Pramreiter, M., Nenning, T., Malzl, L., & Konnerth, J. (2023). A plea for the efficient use of wood in construction. *Nature Reviews Materials*, *8*(4), 217–218. https://doi.org/10.1038/s41578-023-00534-4

Probos. (n.d.). *Kerngegevens bos en hout in Nederland*. Houtverbruik, Bos En Hout Cijfers. https://www.bosenhoutcijfers.nl/de-houtmarkt/houtverbruik/

Probos & Centrum hout. (2023). *Waar komt ons bouwhout vandaan?* RvO.

Provincie Zuid-Holland. (n.d.). *Bodemdaling*. Staat Van Zuid-Holland. Retrieved October 10, 2023, from https://staatvan.zuid-holland.nl/portfolio_page/bodemdaling/

Provincie Zuid-Holland. (2021). Bodemkaar 2021 [Dataset]. In *Provincie Zuid-Holland, Bodematlas*. https://atlas.zuid-holland.nl/GeoWeb56/index.html?viewer=Bodematlas

Rijksoverheid. (n.d.). *Biobased economy: biomassa als grondstof*. https://www.rijksoverheid.nl/onderwerpen/duurzame-economie/biobased-economy

Rijskoverheid. (2022). *Aanpak bouw van 900.000 woningen tot en met 2030*. Rijksoverheid. https://www.rijksoverheid.nl/onderwerpen/volkshuisvesting/nieuwe-woningen

Rijksoverheid. (2021). *Omzien naar elkaar, vooruitkijken naar de toekomst*, Coalitieakkoord 2021-2025.

RVO. (2022). *Areaal en oogstgegevens volgens CBS* [Dataset].
Schelhaas, D. M. (2021, December 3). Weer minder bos in Nederland, trend aan het ombuigen. *WUR*. https://www.wur.nl/nl/onderzoek-resultaten/onderzoeksinstituten/environmental-research/show-wenr/weer-minder-bos-in-nederland-trend-aan-het-ombuigen.htm

Schik, W., Meijer, K., Verkerk, D., Paardekooper, D., Grim, L., & Peek, T. (2022). *De urgente belofte van biobased bouwen*. RVO.

Schulte, M., Lewandowski, I., Pude, R., & Wagner, M. (2021). Comparative life cycle assessment of bio-based insulation materials: Environmental and economic performances. *Gcb Bioenergy*, *13*(6), 979–998. https://doi.org/10.1111/gcbb.12825

Snauwaert, E., & Ghekiere, G. (2012). *Groene grondstoffen, Miscanthus*. Inagro.

Sobota, M., Driessen, I., & Holländer, M. (2022). *Carbon based design, onderzoek naar de milieu-impact van woningbouw*. Rijksdienst voor Ondernemend Nederland.

Soust-Verdaguer, B., Hoxha, E., Llatas, C., & Passer, A. (2022). How Transport Modelling affects the building Life Cycle Assessment (LCA) results: A Case Study Analysis. *IOP Conference Series*, *1078*(1), 012096. https://doi.org/10.1088/1755-1315/1078/1/012096

Stec groep. (2023). De potentie van splitsen en optoppen. Ministerie van Binnenlandse Zaken en Koninkrijksrelaties.

Stichting Nationale Milieudatabase. (n.d.). *CO2 opname in de bepaling van de milieuprestatie van bouwproducten*. NMD. https://milieudatabase.nl/nl/actueel/nieuws/co2-opname-in-de-bepaling-van-de-milieuprestatie-van-bouwproducten/

Stora Enso. (n.d.). *Cross-laminated timber*. www.storaenso.com/. https://www.storaenso.com/en/products/mass-timber-construction/building-products/clt

Strobouwer. (n.d.). Isoleren met stro: Duurzaam en circulair, gezond en behaaglijk.

Tata steel. (n.d.). *Van ijzererts naar eindproduct in vogelvlucht*. Tatasteelnederland.nl. https://www.tatasteelnederland.com/Hoe-maken-we-staal/Het-proces-van-staal-maken

The Ellen MacArthur Foundation. (2013). *Towards the circular economy : Economic and business rationale for an accelerated transition*.

The seaweed company. (n.d.). *Zeewierboerderij Oosterschelde*. Your Well. Retrieved November 6, 2023, from https://www.yourwell.nl/zeewierboerderij-oosterschelde/

Trindada, L. (n.d.). *'Supergewas' Miscanthus blijkt inderdaad vol potentie*. WUR. https://www.wur.nl/nl/artikel/supergewas-miscanthus-blijkt-inderdaad-vol-potentie.htm

UN. (2011). FAO: The European Forest Sector Outlook Study II. 2010–2030. United Nations, United Nations Economic Commission for Europe, Food and Agriculture Organization of the United Nations, Geneva.

Unilin. (n.d.). *Recyclage van hout*. https://www.unilin.com/nl/recyclage-van-hout

Universität Hohenheim. (n.d.). *Olifantengras als biobrandstof kan CO2-uitstoot drastisch doen verminderen*. innovationorigins.com/. https://innovationorigins.com/nl/selected/olifantengras-als-biobrandstof-kan-co2-uitstoot-drastisch-doen-verminderen/

Van Acker, J., Defoirdt, N., & Van Den Bulcke, J. (2016). *Enhanced potential of poplar and willow for engineered wood products*. UGent woodlab.
Van Dam, J. A., & Van Den Oever, M. (2012). *Catalogus biobased bouwmaterialen 2019 : Het groene en circulaire bouwen*. https://doi.org/10.18174/461687

Van Den Oever, M., Gürsel, I. V., Elbersen, W., Kranendonk, R., Michels, R., & Smits, M. (2023). *Regional supply of herbaceous biomass for local circular bio-based industries in the Netherlands*. https://doi.org/10.18174/630159

Van Der Lugt, P. (2023, June 8). *Forerstry and wood availability*. Houtbouw #8: Boom(ing) Business, Amsterdam, Netherlands.

Van der Lugt, P., Luque Martin, I., & Dufourmont, J. (2023). *Discussing timber myths*. AMS institute.

Van der Lugt, P. (2020). Tomorrow's Timber: Towards the next building revolution. MaterialDistrict.

Van Der Steen, L., & Rotmans, J. (2022). *Beknopte transitieagenda: naar doorbraken in Zuid-Holland*.

Van Dijk, S., Kremers, J., Boosten, M., & Jonker, J. (2021). *Paulowniateelt in Nederland*. Probos.

Vereniging Strobouw Nederland. (2017). *Bouwen met stro: Stro als ecologisch isolatiemateriaal*. De Bij.

Wander, J. G. N., & Zwanenpoel, S. (1999). Teelt van vezelvlas. *Praktijkonderzoek Voor De Akkerbouw En De Vollegrondsgroenteteelt*, *85*.

Weiss, M., Haufe, J., Carus, M., Brandão, M., Bringezu, S., Hermann, B., & Patel, M. K. (2012). A review of the environmental impacts of biobased materials. *Journal of Industrial Ecology*, *16*, S169–S181. https://doi.org/10.1111/j.1530-9290.2012.00468.x

Weterhof, R. (2021). *Factsheet natte teelten*. Nationaal kennisprogramma bodemdaling.

Wood solutions. (n.d.). *I-Beams*. Wood Solutions. Retrieved November 2, 2023, from https://www.woodsolutions.com.au/wood-species/wood-products/i-beams