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Embracing Bio-Based Materials.

Exploring alternative ways of living in the countryside of the Netherlands.

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Master thesis

Embracing Bio-Based Materials – Exploring alternative ways of living in the countryside of the Netherlands

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"Instead of doing less damage to the environment, it is necessary to learn how we can participate <u>with</u> the environment, by using the health of ecological systems as a basis for design"

—Bill Reed

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Peculiar research between DIST and Kumiki

The thesis delves into the realm of "**Embracing bio-based materials: Exploring alternative ways of living in the countryside of the Netherlands"**, with assistance from Politecnico di Torino (DIST), conducted at the Amsterdam-based studio, Kumiki, this research aims to explore the selected topic in-depth. This research builds on the foundational work of Mees Wijnants, a team member at the studio since April 2023, who explored 'The Future of Countryside Living' in a master's thesis completed in 2021 at TU Delft.

Throughout the dedicated period for the thesis, I had the privilege of advancing my research under the guidance of Professor Andrea Bocco Guarneri from the Inter-University Department of Regional and Urban Studies and Planning and Architect Kevin Veenhuizen, founder and principal architect at Kumiki. During my stay in Amsterdam, spanning a year, in addition to the research I actively contributed to various projects at different stages of construction. I also engaged in discussions about my research with colleagues, the local community in Noordoostpolder, Building balance and local suppliers. Additionally, the studio had the opportunity to seek support from stimulating funds, which partially funded the research. This experience held significant value as it allowed me to align my design objectives, interests, and approach with the well-thought-out philosophies of Kumiki and as well as Professor Andrea Bocco's perspectives on appropriate Technology and low-tech architecture. The structure and execution were carefully planned and informed by the unique perspectives cultivated within the studio.

Abstract – EN

The Netherlands, a small, densely populated country with 54% of its surface area devoted to agriculture, has achieved high productivity through monoculture, homogeneity, and heavy inputs. However, this has come at the cost of soil degradation, biodiversity loss, emissions, and accelerated ecosystem decline. Additionally, the Netherlands is facing a housing crisis driven by limited construction, immigration, rising housing prices, and a lack of affordable options. Consequently, new construction in the coming years is inevitable to meet the growing demand. However, the production of building materials in the current Dutch built environment significantly contributes to anthropogenic greenhouse gas (GHG) emissions.

Given the urgent need to reduce GHG emissions and achieve net cooling impacts, this research proposes an alternative way of living in the Dutch countryside by integrating nature, agriculture, and housing. The case of Noordoostpolder, a municipality in Flevoland known for its fertile land, is explored.

This research is not just an academic exercise but a real-world demonstrative case study that arose from social and political demands. It was developed in collaboration with public and private entities. During the design and development of the building technology for the Kumiki Model House, various challenges emerged, necessitating a holistic approach that considered the landscape, farming, local development, land health, and lifestyle. Through connections facilitated by Building Balance, reasonably established and promising local biobased supply chains were investigated, including the associated building technologies and their implementation in construction. The study also examined the impact of cultivating fibre crops on soil structure, ecology, and biodiversity, while promoting the diversification of material use.

The Kumiki Model House aims to implement the theories of 'Vegetarian Architecture' and 'Vernacular Architecture of the 21st Century' by demonstrating the potential of regionally produced, locally available natural and fast-growing bio-based materials while employing exemplary construction techniques. The proposal also seeks to minimise high-tech components, utilising them only in unavoidable circumstances to enhance overall performance.

The multi-layered issues in Noordoostpolder are addressed through permaculture principles, emphasising regenerative living, self-reliance, and resource minimisation. This approach aims to create a more robust and sustainable agroecosystem, ensuring long-term agricultural viability.

Lastly, potential environmental savings from cradle to gate were illustrated using the Ökobaudat database. The use of fast-growing, locally sourced bio-based materials like straw, flax, paulownia, and willow, along with the limited use of robinia, Douglas fir, Norway spruce, and oak, allows the Kumiki Model House to store significant amounts of biogenic CO_2, making it carbon-negative.

Public access to the construction site of the Kumiki Model House and collaborative landscape restoration efforts will foster community development initiatives and raise awareness of urgent issues related to agricultural transition and ecology.

Abstract – IT

I Paesi Bassi, un piccolo paese densamente popolato con il 54% della sua superficie destinata all'agricoltura, hanno raggiunto un'elevata produttività attraverso la monocoltura, l'omogeneità e l'uso intensivo di input. Tuttavia, ciò è avvenuto a scapito del degrado del suolo, della perdita di biodiversità, delle emissioni e del declino accelerato degli ecosistemi. Inoltre, i Paesi Bassi stanno affrontando una crisi abitativa causata dalla limitata costruzione, dall'immigrazione, dall'aumento dei prezzi delle abitazioni e dalla mancanza di opzioni accessibili. Di conseguenza, la nuova costruzione nei prossimi anni è inevitabile per soddisfare la crescente domanda. Tuttavia, la produzione di materiali da costruzione nell'attuale ambiente costruito olandese contribuisce significativamente alle emissioni antropogeniche di gas serra (GHG).

Data l'urgenza di ridurre le emissioni di GHG e di ottenere impatti di raffreddamento netti, questa ricerca propone un modo alternativo di vivere nella campagna olandese integrando natura, agricoltura e abitazioni. Viene esplorato il caso di Noordoostpolder, un comune di Flevoland noto per la sua terra fertile.

Questa ricerca non è solo un esercizio accademico, ma un caso di studio dimostrativo del mondo reale nato da richieste sociali e politiche. È stato sviluppato in collaborazione con enti pubblici e privati. Durante la progettazione e lo sviluppo della tecnologia edilizia per la Kumiki Model House, sono emerse varie sfide, che hanno richiesto un approccio olistico che considerasse il paesaggio, l'agricoltura, lo sviluppo locale, la salute del territorio e lo stile di vita.

Attraverso le connessioni facilitate da Building Balance, sono state investigate catene di approvvigionamento locali biobased ragionevolmente consolidate e promettenti, comprese le tecnologie edilizie associate e la loro implementazione nella costruzione. Lo studio ha anche esaminato l'impatto della coltivazione di colture fibrose sulla struttura del suolo, sull'ecologia e sulla biodiversità, promuovendo la diversificazione dell'uso dei materiali.
La Kumiki Model House mira a implementare le teorie dell''Architettura Vegetariana' e dell''Architettura Vernacolare del 21° Secolo' dimostrando il potenziale dei materiali biobased prodotti regionalmente, disponibili localmente e a crescita rapida, utilizzando tecniche di costruzione esemplari. La proposta cerca anche di minimizzare i componenti ad alta tecnologia, utilizzandoli solo in circostanze inevitabili per migliorare le prestazioni complessive.

Le problematiche multilivello di Noordoostpolder vengono affrontate attraverso i principi della permacultura, enfatizzando la vita rigenerativa, l'autosufficienza e la minimizzazione delle risorse. Questo approccio mira a creare un agroecosistema più robusto e sostenibile, garantendo la viabilità agricola a lungo termine.

Infine, i potenziali risparmi ambientali dal cradle-to-gate sono stati illustrati utilizzando il database Ökobaudat. L'uso di materiali biobased a crescita rapida e di provenienza locale come paglia, lino, paulownia e salice, insieme all'uso limitato di robinia, abete di Douglas, abete rosso norvegese e quercia, consente alla Kumiki Model House di immagazzinare quantità significative di CO_2 biogenica, rendendola carbon-negative.

L'accesso pubblico al cantiere della Kumiki Model House e gli sforzi collaborativi di restauro del paesaggio favoriranno iniziative di sviluppo comunitario e aumenteranno la consapevolezza delle questioni urgenti legate alla transizione agricola e all'ecologia.

Comprehensive Background – Beyond Annual Agriculture

Malnutrition remains a significant problem, as is obesity. 800 million people are chronically hungry, while 2 billion people are deficient in essential micronutrients; Simultaneously, obesity is reaching epidemic proportions (FAO, 2023). The industrialised nations are suffering from diseases mainly caused not by the wrong sorts of food or by lack of food but by excessive food consumption mainly carbohydrates and animal-based proteins. The primary source of calories is mainly derived from "annual agriculture." The carbohydrates, proteins, and fats are produced using annual agricultural production methods to survive in the competitive market and to meet the demands of the increasing population. Human settlements have always been dependent on staple food crops derived from annual agriculture. The ease of storing and transporting staple foods (grains) facilitated the establishment of permanent settlements, which subsequently expanded into cities.

But, to cultivate annual plants, the natural perennial vegetative cover is removed, preparing the soil for planting. Annual plants' main strength and shortcoming is their single-season lifespan. While they grow quickly and produce seeds before dying, they require replanting each year, which disturbs the soil. Ploughing, planting, weeding, harvesting, and processing are annual tasks and have occurred every year since the dawn of civilisation. Tilling annually exposes the soil to the atmosphere. Tilled soil is highly susceptible to erosion by wind, causing the loss of organic matter and minerals due to oxidation, thereby reducing its fertility. Additionally, tilling dries out the soil, exacerbating drought conditions, and when left exposed, the soil is vulnerable to erosion by rainwater. Regular and frequent tilling will deplete fertile soil, leaving behind degraded land.

The use of fossil-fuelled equipment and chemical-based fertilisers to achieve high yields in a short period has accelerated ecosystem degradation at an unprecedented rate. Humanity is facing challenges such as ensuring global food security for a growing world population, climate change and biodiversity loss. The world population will continue to grow sharply until 2050, with estimates of 9.7 billion from the current 8 billion (UN, 2022). As global citizens increasingly experience prosperity, without any further interventions, it is speculated that more animal-based proteins and annual plants will be consumed (Fresco & Poppe, 2016), which will indirectly add pressure on the agricultural system. Agriculture, forestry and land use change accounts 19% of anthropogenic greenhouse gas emissions and the food system as a whole for 25% (Our World in Data, 2019). Agriculture and food production play an important role in mitigating these emissions. Biodiversity worldwide is under pressure. The Global Assessment Report of the Intergovernmental Platform for Biodiversity and Ecosystem Services states that the rapid decline of biodiversity poses an equivalent threat to humanity as global warming (IPBES, 2019). Human actions are predominantly held responsible for the loss of biodiversity.

The Oxford Dictionary defines a farm as, "an area of land and its buildings used for growing crops and rearing animals." We all rely on farm-produced staple foods which cannot be grown easily in the backyard or urban settings due to the requirement of larger extensions to harvest. Can agriculture be practised by avoiding frequent eradication and still producing enough food to cater for the needs? Can agriculture still be carried with the intention towards regenerative, small-scale, collective with. This thesis aims to investigate alternatives within the Country of the Netherlands, focusing specifically on the case of Noordoostpolder, a municipality in the Flevoland province renowned for possessing the most fertile land in the country.

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The Evolution and Challenges of Dutch Agriculture

Since the 1950s Dutch agriculture has been shaped by a predominant focus on modernisation, alternatively termed productivity or rationalism within the context of industrialism. Its primary motive was the production and merchandising of inexpensive (i.e. globally competitive) food produce of standardised quality (Commonly referred to as bulk products with relatively low-added value) by agro-industry. Within this framework, primary agriculture altered into providing cheap raw materials for agro-industrial uses. The growth in production (scale enlargement, specialisation, and intensification of land use) favoured as a strategy to maintain income parity at the farm level. The 'get big or get out' policy was extensively promoted and embraced as the sole feasible approach by agricultural households. It was reinforced by policy, research, and educational initiatives.

Meanwhile, the largest reclamation project was in its final phases. Although the reclamation of the Zuiderzee (shallow bay of the North Sea in the northwest of the Netherlands) was constructed to mitigate frequent storms, the government had plans for the land's use. On the 9th of September 1942, the Noordoostpolder was officially dry. The Noordoostpolder attracted many people because of its mineral-rich fertile marine clay soil. People who could showcase their skills of transforming 'the new land' into profitable agricultural businesses were allowed to settle there.

While Dutch agriculture has achieved notable success, the increasing volume and intensity of production have also led to a variety of problems. More plants meant lower prices. Fertility, which was originally meant to be procured from livestock raised on-farm, now was made available in the form of bags from the agri-chemical companies. In less than one lifetime, a family-led farming business went from being a self-contained ecological production system to a debt-ridden, input-dependent "agri-business" that relied heavily on government subsidies. Farming practices changed from being biologically diverse systems assisted by animal husbandry and crop rotation to technologically driven single-crop systems that were extensions of the chemical companies that manufactured the toxic brews to be spread on Dutch soil.

In the early 1970s, concerns emerged regarding the extensive reconstruction of the countryside solely for productive purposes.

Responding to these concerns, a pivotal national policy scheme was introduced in 1975, focusing on the preservation of nature and landscape within designated farmland areas known for their inherent natural and scenic qualities. This innovative approach propelled farmers to engage in nature and landscape conservation on their lands by offering incentives. Rather than advocating for the spatial segregation of agricultural and conservation areas, the strategy aimed to seamlessly integrate agricultural production with the preservation of natural habitats and scenic beauty. Over the years, these contrasting strategies of integration versus segregation have remained central to Dutch policy and research agendas, continually adapting to changing dynamics and evolving priorities.

Since the 1980s agriculture faced varied problems; produce quality, adulterations, environmental pollution, animal diseases, overall quality of life for animals, and others. Simultaneously, changes were observed in the society like the increasing demand in food production and in rural life. During this time, the focus on the subsidiary or non-productive role of agriculture was conceived through various terms such as agriculture with broader objectives, integrated agriculture, alternative agriculture, sustainable agriculture, and multiple land use. The concept of modernisation was constantly scrutinised for its mono-cultural, productivist perspective on agriculture and the countryside. This underlined an awareness that modernisation was beginning to clash with societal boundaries, prompting the recognition that agriculture needed a new "license to produce" from society (Frouws and Leroy 2003). The Netherlands also noticed a rise in nitrogen emissions from agriculture, transport, and industry. However, agriculture primarily contributed to these emissions due to the drastic growth in the livestock, the import of livestock feed, and the use of synthetic fertilizer. These factors lead to a nutrient surplus, thereby causing environmental damage.

Various measures were introduced in response to the aforementioned problems, including the implementation of production rights and quota systems, environmental initiatives, emission reduction techniques, nature and landscape conservation schemes, animal welfare standards, production rights, soil Protection Act, phosphate rights for dairy farmers to restrict increase in dairy cattle numbers, fertiliser act and food safety measures. However, these measures failed to fully address

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the issues and instead gave rise to new challenges for agriculture, including an escalating administrative burden, inflexibility, and rising costs (WUR- *Manure: A Valuable Resource*).

In 1996, for the first time the concept of 'Multifunctional agriculture' surfaced within a study held at Dutch Agricultural Research Institutes responding to a research agenda for MFA (Vereijken et al. 1997, Vereijken and Hermans 1998). In the past, similar perceptions and evolutions took place around the world, but there was a distinct approach by the Dutch. The Netherlands is a small, densely populated country where agriculture is one of the main occupations spread across 54% of the national surface area, producing high volume primarily due to massive inputs and major dependence on export markets (80%). So, there is a lot at stake and there are different types of stakes. However, problems due to pollution, the spatial arrangement of various functions, restoration of nature and landscape, as well as the future scale and importance of primary agriculture in the countryside and within the agro-industrial sector rule the current debate.

The contemporary approach conceives agriculture, both in terms of standardising and organisation, as a mono-functional activity that is influenced by global supplies and global competitiveness. Mono-functionality and growth are considered requisite to profitably scale the economy and simultaneously safeguard the competitiveness of the Dutch agro-industrial sector. The presence of multi-functionality agriculture is niche and practiced in regional areas without hampering the quantity of agricultural produce.

According to Vereijken and Agricola's theory, a vision is drafted for rural entrepreneurship to facilitate the economic development of the countryside, and it encompasses a wide range of ideas and approaches. The unique quality of this is its radical nature, it proposes a significant switch from traditional agricultural-based economies in the countryside to various non-agricultural business ventures and initiatives, such as small-scale manufacturing, tourism, technology start-ups, and service industries. This approach will lead to the extinction of agriculture as the agro-industrial supply chain will not be able to compete in the global market and powerful demand from corporate companies to claim this rural land for other purposes. (Vereijken and Agricola 2004).

Dutch policies have always supported diverse agendas, specifically against agriculture. Contemporary agriculture still holds its control, but the policies are embracing different approaches at the same time. "It wants to sit on the fence, run with the hare and hunt with the hounds". The approach to these issues is allocating activities in spatial planning and policy resulting in mono-functional farming areas in the favourable land and other activities concentrated in the less favourable areas.

Fig 1 – The Netherlands' glowing greenhouses raise questions about the future of the planet as the demand for food continues to soar with the increasing global population, Source – Tom Hegen. https://www.dezeen.com/2020/03/09/netherlands-greenhouse-series-aerial-photography-tom-hegen/

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Fig 2 – The Netherlands' glowing greenhouses raise questions about the future of the planet as the demand for food continues to soar with the increasing global population, Source – Tom Hegen. https://www.dezeen.com/2020/03/09/netherlands-greenhouse-series-aerial-photography-tom-hegen/

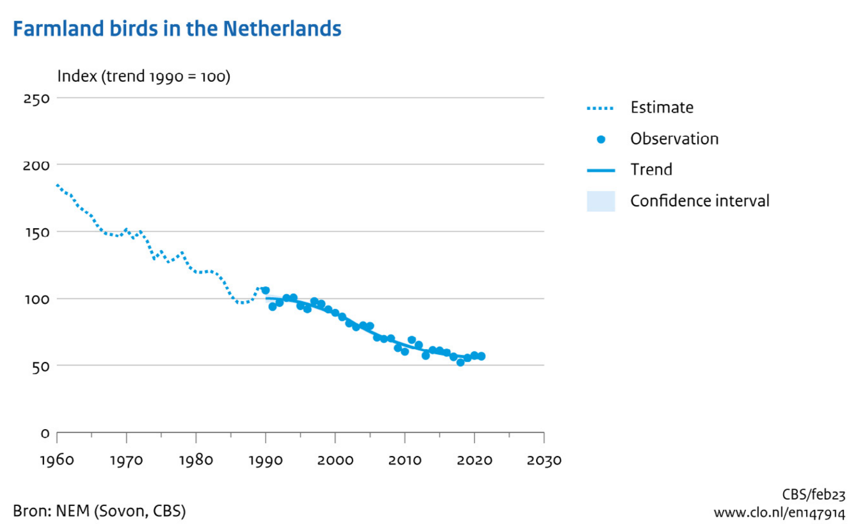


Fig 3 – Decline of farmland birds in the Netherlands, 2023, Source – NEM (Sovon,CBS). www.clo.nl/en147914

Fig 4 – Land use in the Netherlands, 2024, Source – Milos Popovic. https://milospopovic.net/

Theoretical Framework

Reviving Dutch Woodlands: The Shift from Industrial Use to Ecological Stewardship

The term "hol" traces back to "holt" (wood) (Gloerich, 2020). Biodiversity varies based on forest types, the surface area of the forest, the age of the growth place, the surface of the forest, fragmentation, and forest type. Forests are multifaceted ecosystems which provide numerous benefits to human societies. Wood has been used for the construction of buildings, furniture making, paper production, and as a source of energy. After the invention of leisure in the last centuries, forests have also offered an environment for recreational activities.

Until around 1000 AD, the Netherlands was extensively covered by dense primary forests. Over the period, forest management practices evolved, and forests were increasingly exploited. From the late Middle Ages, as the population burgeoned, pressure on forests escalated. Large swathes of forests on sandy soils were cleared to make way for extensive pasturelands. Due to the invention of chemical fertilisers, and the exploitation of fossil fuels the functions of wood were taken over, and the *potstal* system lost its purpose (Den Ouden et al., 2010). Simultaneously, in the low-lying peatlands, marsh forests of the 12th century were rapidly cleared to make room for arable farming and peat meadow cultivation (De Vries, W., & Peterse, A. S. 2008).

By the late 19th century, only 50,000 hectares of forest remained from the original 1 to 2 million hectares (Den Ouden et al., 2010). However, the beginning of industrialisation sparked renewed demand for timber: wood was essential for shoring up mining tunnels. The Dutch Heathland Corporation (KNHM) collaborated with Staatsbosbeheer (state forest service) and invested in the reforestation of large areas which is noticed in the evenly aged tree plantations.

Foot note – The "potstal" is a traditional Dutch agricultural practice used to create manure for farming. This method involves keeping livestock, such as cattle or sheep, in stables during the winter months. The animals are fed, and their bedding, often made of straw, absorbs their excrement. Over time, the bedding and manure mix and accumulate, forming a nutrient-rich compost. (Leestekens van het Landschap)

From the 1950s, new forest was created especially in response to the rapid urbanisation of the country. Uniformity in the type of species, age, and rigid planning or structuring restricted biodiversity and nutrients in the soil. The economic importance of these plantations has now declined, and current management is more focused on natural and recreational values, and on the use of trees as wind barriers, or as a buffer to industrial areas or highways.

As per the latest Dutch National Inventory, the forested area in the Netherlands has grown to about 363,801 ha which amounts to about 11% of the Dutch land area. (Wageningen Environmental Research, 2021)

Forest area

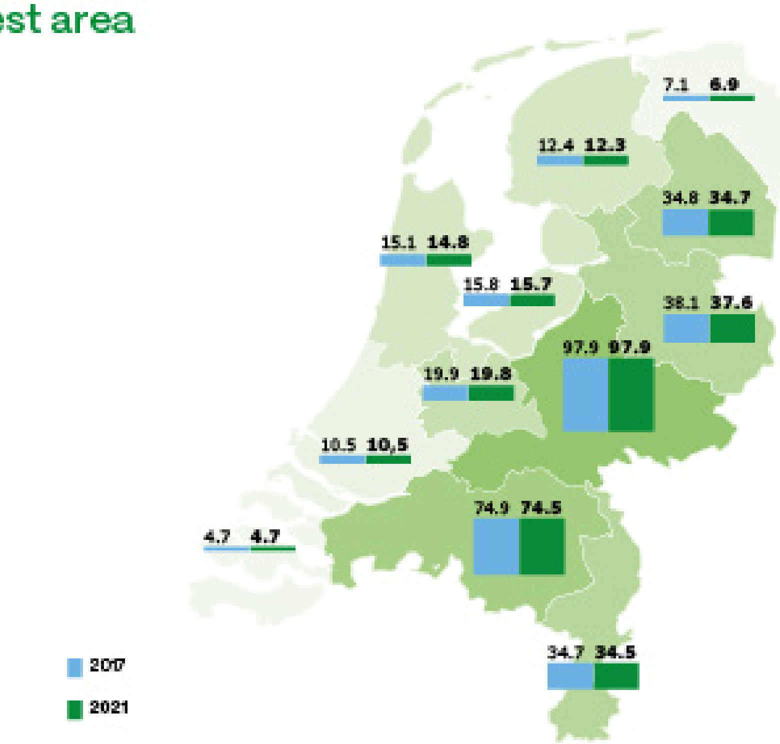


Fig 5 – Edited by author, Forested area in 2017 and 2021, Source – The 7th Dutch National Forest Inventory [Brochure], WUR.

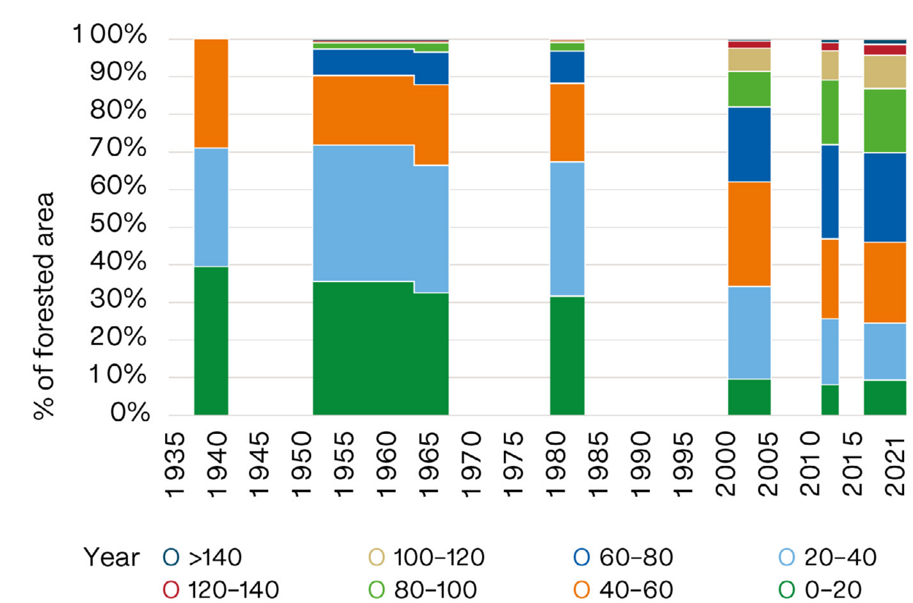


Fig 6 –Age of Dutch Forested area from 1935- 2021, Source – 7th Dutch National Forest Inventory, WUR.

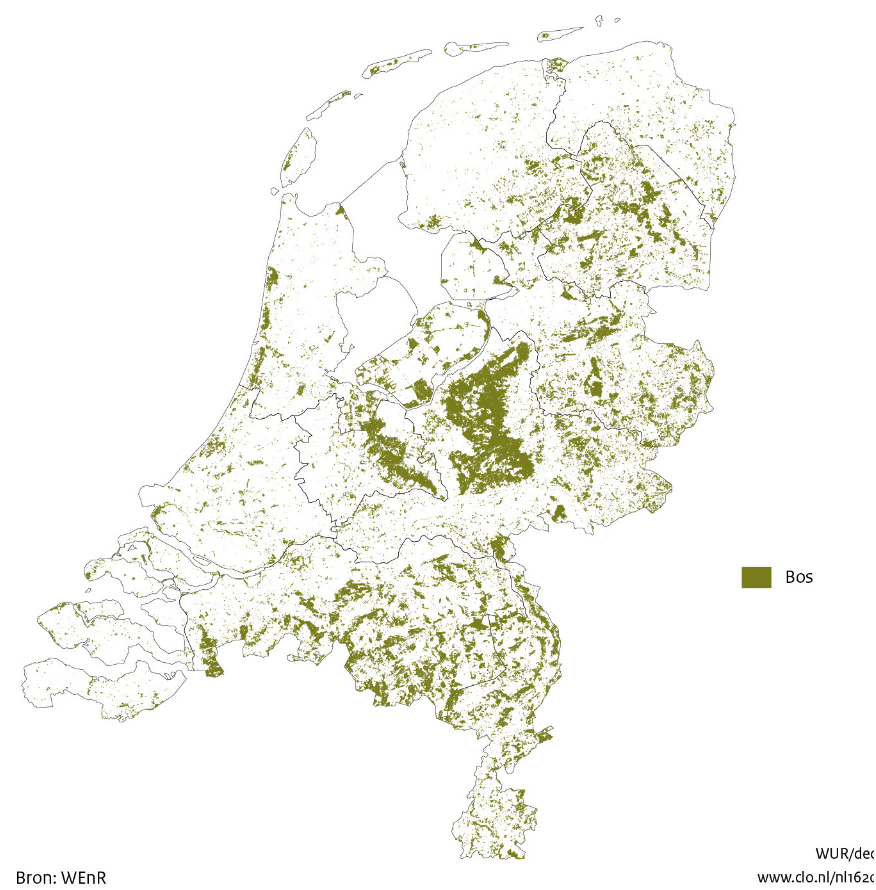


Fig 7 –Forested area in 2021, Source – WUR/dec22. www.clo.nl/indicatoren/nl162001-oppervlakte-bos-in-nederland-1970-2021

Forest & Climate

Forests have an important role in the capture of CO_2 from the air and in the production of oxygen. Through photosynthesis, plants absorb CO_2, utilising the carbon for growth and releasing oxygen back into the atmosphere. Forests are carbon sequesters (Grassi, G., et al. 2017).

The current forests of the Netherlands sequestrate 2.7 megatons of CO_2 every year, which accounts for only 1.3% of the total emission by manmade sources (Atlas Natuurlijk Kapitaal). Climate change and increasing pests and diseases pose serious threats to the long-term survival of Dutch woodlands. This research aims to suggest strategic approaches to mitigate this pressure.

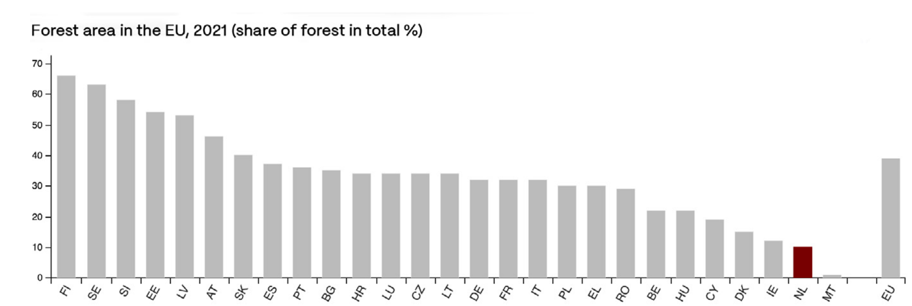


Fig 8 – Edited by author, Estimates for 2021 in EU countries, Source: Eurostat (online data code: for_vol_efa)

Integrating Recreation and Conservation: The New Role of Forests in the Netherlands

Most of the forests in the Netherlands are not used for production purposes anymore. The decline in the productivity of forests since the 1990s is also due to a transition toward multifunctional and nature-oriented forest management. Forests offer many opportunities for hikers, runners, horse riders, nature lovers, and bird spotters. A large part of the Dutch forests has therefore been opened to recreationists to a certain extent. The map (*Fig x – Distance (km) to the nearest forest, Source – CBS 2021*) shows that the distance to forests as recreational places is large, especially in the west and north of the Netherlands. Transitioning the farms and countryside areas by implementing Silvoarable Agroforestry and/or Silvopastoral Agroforestry can create small forests that are easily accessible for recreational purposes.

Besides production and recreation, forests are also effective for the protection of soil and water, and conservation of biodiversity. Most forests are multifunctional as people see Dutch forests as their backyard. As space is scarce, the intertwining of the functions is logical. Integrated forest management is considered ideal, as it allows for a combination of functions, and trees can be felled more to reshape the forest than to obtain timber.

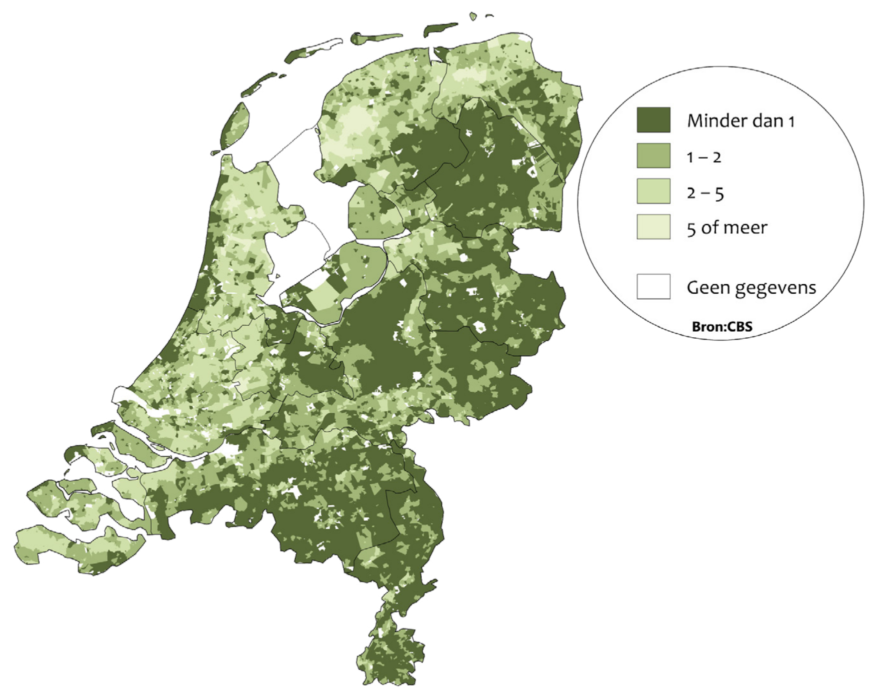


Fig 9 – Distance (km) to the nearest forest, Source – CBS 2021

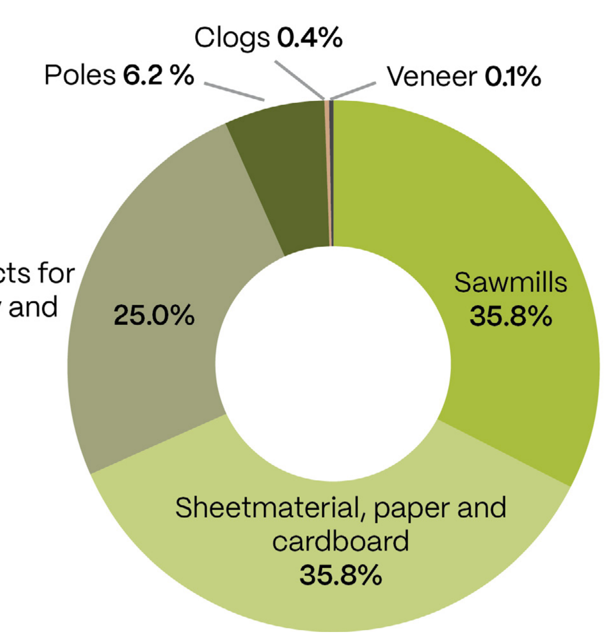


Fig 10 – Edited by author, application of industrial roundwood sourced from the Netherlands 2021, Source: Wood production and use in the Netherlands 2021.

Economic Viability of Dutch Production Forests: Challenges and Functions

Production forests are of limited economic importance in the Netherlands. The applications of timber produced by Dutch forests range from high-quality saw and veneer wood to lower quality fibre wood to produce fibreboards, sheet materials, paper, and cardboard. It is usually required that, in order to be graded as high-quality, timber is straight and without imperfections such as knots. Such timber needs to be extracted from tall trees, usually conifers. Firewood and wood for other applications can be extracted from branches, crooked logs, or trunks with growth imperfections. The fibre wood therefore accounts for the largest share of the harvest. Subsidies play a crucial role in keeping production going on, as profits are small due to low harvests and a decline in timber prices (Van der Maaten-Theunissen, M. & Schuck, A. 2013). Other functions of forests contribute to the economic feasibility of their management.

Rising Timber Demand and Its Environmental Impact: A Global and Dutch Perspective

Wood and wood products are increasingly used thereby increasing the demand for wood at a global scale. Global tree plantations would need to be expanded by 200% to meet the demand for engineered wood (Abhijeet Mishra et al.). It is important to know the origin of construction timber supplies in the Netherlands.

In 2023, Probos, commissioned by PIANOo, RVO and Centrum Hout, mapped out the import and origin of construction wood in the Netherlands for 2021. The Netherlands imports approximately 4.6 million m^3 per year (92%) of construction wood and produces approximately 390,000 m^3 itself (8%). Of the imports, 82% comes from Europe, 9% from tropical countries such as South America, Africa and Southeast Asia, 7% from Russia and about 3%

Theoretical Framework

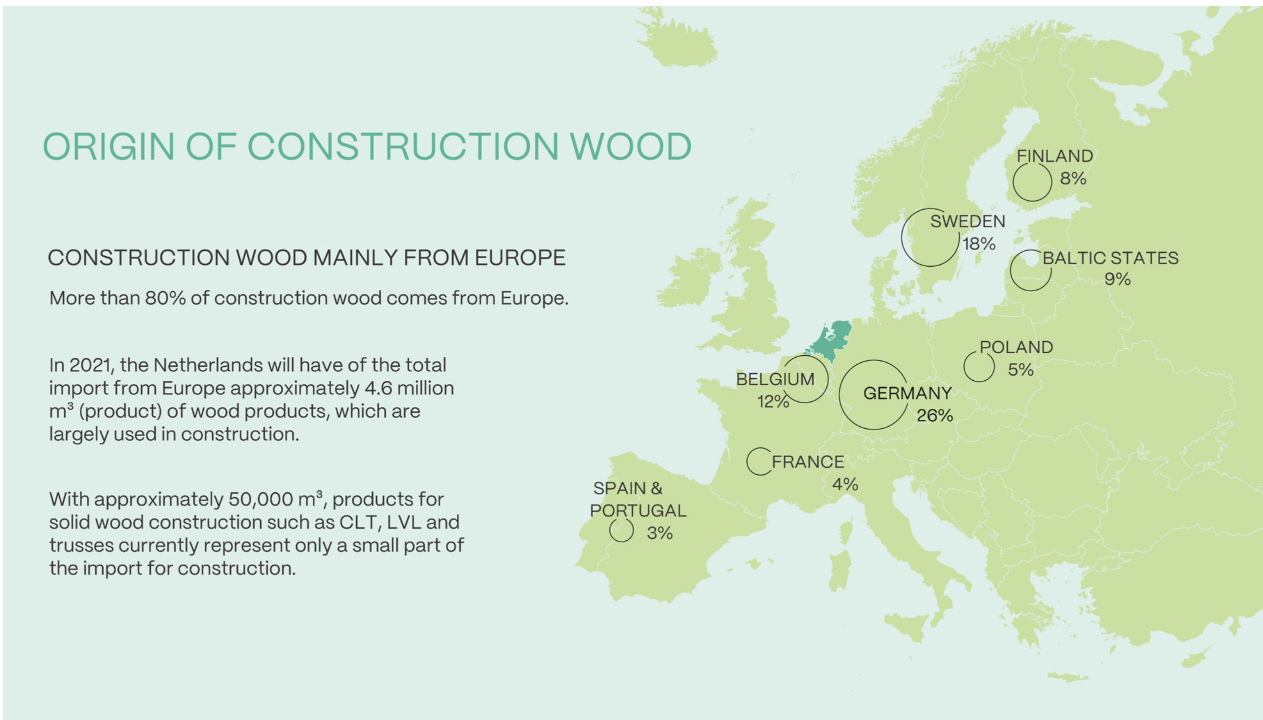


Fig 11 – Edited by author Origin of construction wood. Source: Probos Bouwhout wereld en Europa.

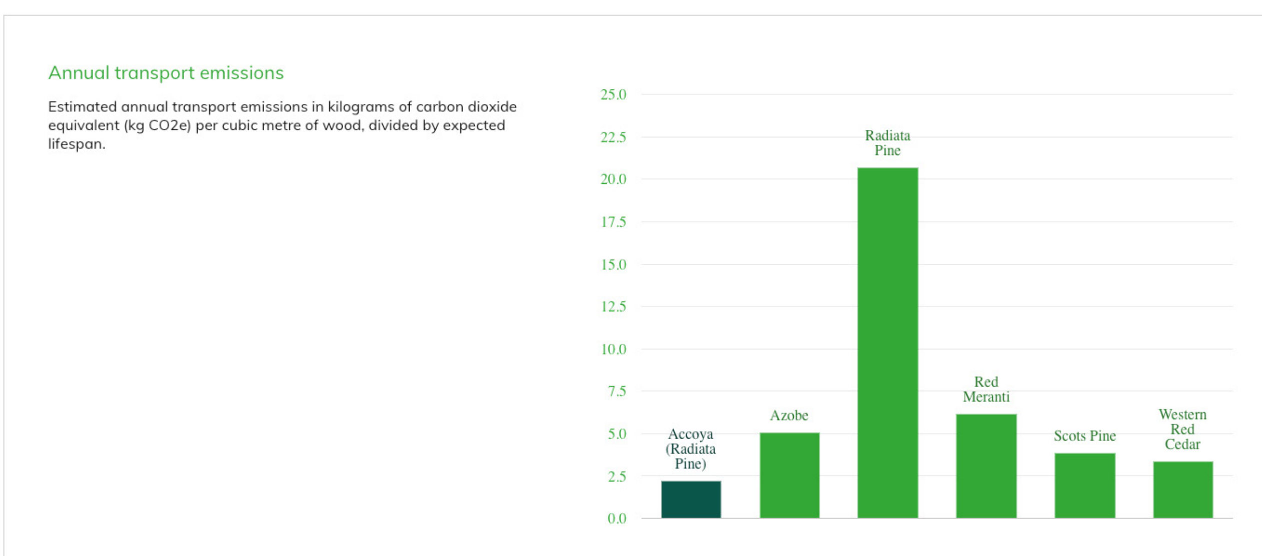


Fig 12 – Annual emissions from timber transportation, Source: Accoya https://www.accoya.com/transport-emissions-calculations/

from Asia, North America and Oceania. (Since the war in Ukraine, a European ban on timber imports from Russia and Belarus has been in force).

Due to the limited timber production and species diversity, the Netherlands must heavily rely on imports mainly from European countries but also from other continents. The transportation of timber implies a considerable amount of CO_2 emissions. To get a rough idea, Accoya calculated emissions based on some assumptions and considered Rotterdam as the final destination. The results were influenced by parameters like wood species, wood origin, wood density, vehicle, and lifespan. The results are shown in the bar chart (fig 12). The Dutch built environment is experiencing rapid growth, primarily fuelled by housing shortages attributed to immigration resulting from international conflicts (Pascoe, 2023), escalating prices, growing inequality, a scarcity of affordable housing, and the influx of foreign investors into the market (Henley, 2024).To address climate change and environmental concerns, the construction sector is increasingly embracing timber as a sustainable and circular construction solution. The long harvesting cycles for timber mean that the increase of production forests will not be able to provide more timber for construction in the coming years.

The emissions will amplify if the demand for imports increases. Additionally, European timber-producing countries—Finland, Sweden, and Germany (Bavaria)—cannot fulfil the increased demands linked to the ambitious 1.5°C target (Blattert, C., Mönkkönen, M., Burgas, D., et al., 2023). To alleviate the pressure on timber, several strategies need to be investigated to reduce transport emissions and explore alternative materials.

Why Net Zero Isn't Enough to Prevent Global Warming?

Natural and human systems are experiencing severe changes due to climate change and global warming (IPCC, 2022). The main outcome of the 2015 Paris Climate Conference was an agreement to limit global warming to 2°C and if possible, below or equal to 1.5°C (European Commission, 2021b). A United Nations Environment Programme report (2022a) states that even after the implementation of the announced contribution by nations, global warming will be 2.4°C thus exceeding the agreed threshold. Dr Klaus Lackner says nearly half of the CO_2 released stays in the atmosphere for centuries (Jackson, 2021). Natural and geological processes remove excess carbon from the Earth's surface over thousands of years. If we consider this on a human timescale, the carbon emissions from fossil sources are permanent. Net Zero carbon is no longer enough to avoid climate disasters (CCAG 2021). In Net zero, switching to renewable energy reduces the operational energy emissions but not the embodied emissions, and embodied emissions are a significant contributor. Hence, incremental changes are no longer enough to deal with climate change. To respond to global climate change, mitigation and adaptation strategies must be formulated.

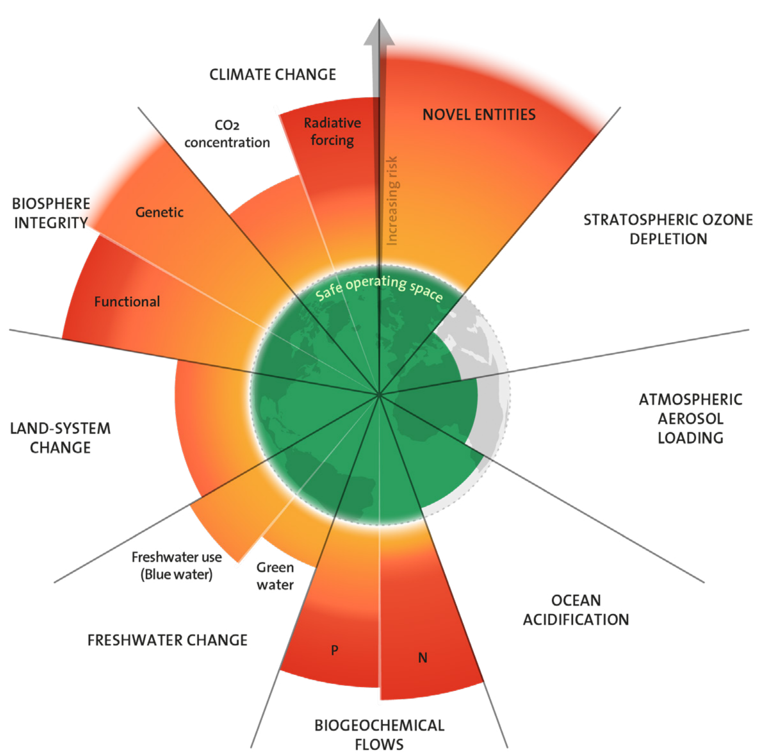


Fig 13 – Current impacts compared to planetary boundaries. Source: Azote for Stockholm Resilience Centre, based on analysis in Richardson et al. 2023.

Planetary boundaries for a healthy and safe Earth

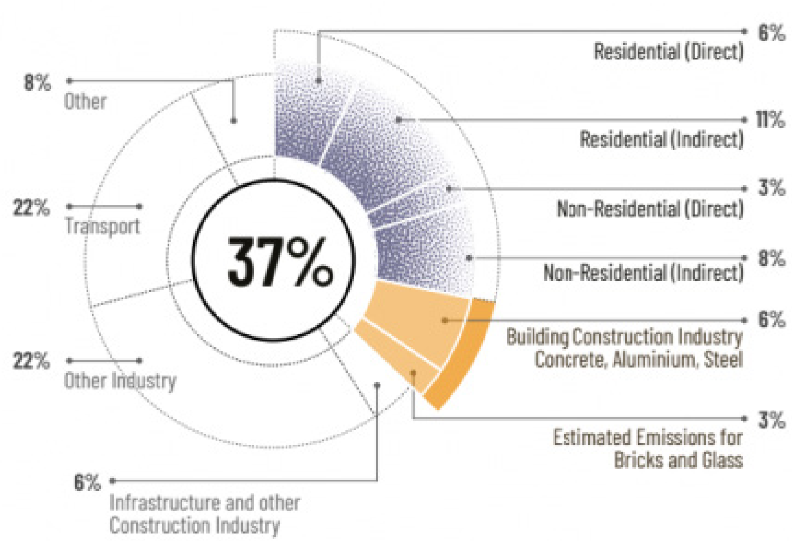
Sustainable development is broader than just preventing further climate change and biodiversity loss. As per Azote for Stockholm Resilience Centre, Stockholm University, there are nine 'planetary boundaries' which we must not cross to maintain a healthy and safe space for people on Earth. As a result of all the man-made activities, we are crossing more and more boundaries. We're facing the challenge of climate change, marking a shift from the stable Holocene to the Anthropocene era, where human activity dominates the Earth's systems. We need to both reduce our impact on the planet and adapt to the changing environment. In addition to climate change (global warming), there are eight other 'planetary boundaries' that pose major challenges. Recent scientific insights show that we have now exceeded six of the nine boundaries (climate change, availability of fresh water, land use, biodiversity, novel entities, biochemical flows). The dangers of crossing these boundaries, such as biodiversity loss and chemical pollution, are increasing. At each of these boundaries, in addition to reducing our impact, we must simultaneously work on recovery. (Persson et al. 2022). The built environment highly demands fossil-based materials and energy, which have a direct and indirect impact on many of the above-mentioned planetary boundaries. The contribution of the building sector to climate change is very clear. Moreover, the usage of chemicals in the production of materials that aren't organically decomposed at the end-of-life phase needs to be taken into consideration. To highlight the gravity of the impact caused by construction, global human-made mass was compared to overall natural biomass. The research conducted in 2020 at the Weizmann Institute of Science concluded that the Earth is at the crossover point with global human-made mass and the latter will surpass it in coming years (Elhacham et al., 2020). Recent assumptions suggest that this crossover point has already been surpassed.

The residential building sector: A significant contributor to climate change

Even though the world witnessed an unprecedented drop in CO_2 emissions during the pandemic, a rebound in the built environment sector was noticed as soon as the world resumed functioning in its pre-pandemic state. As per the latest global report for buildings and construction, the building sector was responsible for 34% of global energy demand and around 37% of global energy and process-related CO_2 emissions (IEA, 2022, United Nations Environment Programme [UNEP] 2022).

1.1 Global carbon emissions from the built environment sector, by source, 2021

Global share of buildings and construction operational and process CO_2 emissions, 2021



The built environment sector is responsible for more than a third of global energy-related carbon emissions.

Adapted from UNEP 2022.

Fig 14 – The built environment sector is responsible for more than a third of global energy-related carbon emissions. Adapted from UNEP 2022, Source: Building materials and the climate: constructing a new future.

The residential sector contributes 21% of the energy demand and 17% of the energy and process-related CO_2 emissions globally (Global Alliance for Buildings and Construction, 2019). IPCC (2022) stated a global increase in direct and indirect emissions from the residential sector by about 50% since 1990. In Europe, the building sector has an even heavier impact, representing 40% of the energy demand and thereby being one of its most significant climate change contributors (UN Environment Programme, 2022). In recent years, advancement in the field of generating energy from renewable sources has been significant, thereby reducing the operational carbon emissions in the built environment. Operational carbon currently accounts for 75% of total emissions associated to buildings, as illustrated in fig 15. However, due to the predicted constant drop in the operational carbon and increase in the business-as-usual infrastructure, the share of embodied carbon is predicted to increase from 25% to 49% by 2050 (OECD 2019).

Projected Contributions from Embodied and Operational Carbon within the Building Sector

From 2021 to 2050 with Business as Usual Projections

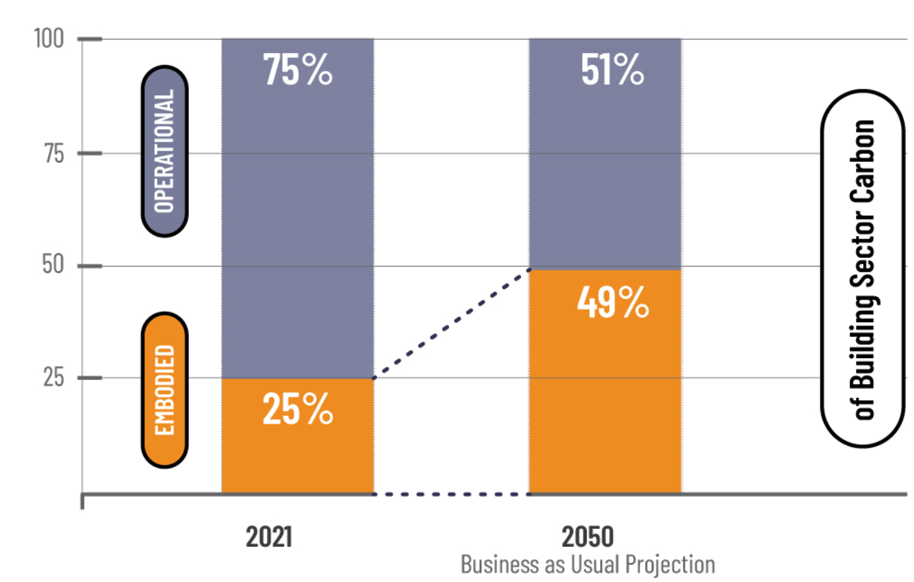


Fig 15 – Projected Contributions from Embodied and Operational Carbon within the Building Sector. Adapted from Architecture 2030. (2022), Source: Building materials and the climate: constructing a new future.

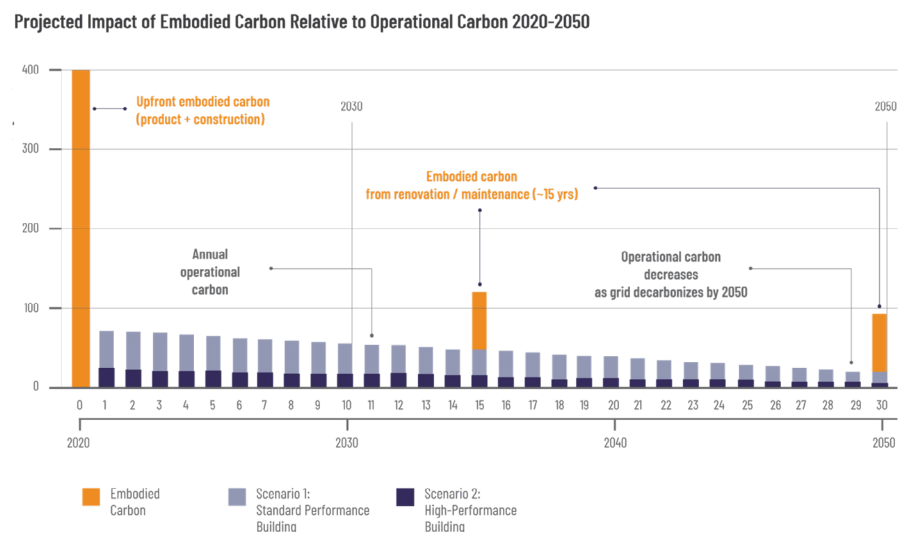


Fig 16 – Projected Contributions from Embodied and Operational Carbon within the Building Sector. Adapted from Architecture 2030. (2022), Source: Building materials and the climate: constructing a new future.

The emissions due to the production of materials are the main contributors to embodied carbon in the built environment. However, they do not play an important role in decarbonisation strategies. With the surging demand for materials, particularly those used in high-performance buildings which typically have higher embodied emissions, the share of embodied carbon emissions is predicted to increase by 49% by 2050. This increase is primarily due to the decrease in operational emissions, making the proportion of embodied emissions more significant. The urgency to reduce anthropogenic greenhouse gas (GHG) emissions is necessitated by the consequences of climate change. This imperative was prominently underscored during the UN's 2015 initiative and the IPCC's 2018 reports, which integrated climate mitigation measures into the Sustainable Development Goals (SDGs) (UN, 2015), and the Summary for Policymakers. Reports on global warming of 1.5°C respectively (IPCC, 2018).

Fig 17 graph indicates a consistent rise in embodied greenhouse gas (GHG) emissions across all trends for residential buildings. They also demonstrate a noticeable decrease in life cycle-related GHG emissions owing to the implementation of new energy performance standards for building operations. However, this reduction in operational emissions is projected for the future, suggesting that embodied GHG emissions will consequently increase. However, this reduction in operational emissions is projected for the future, suggesting that embodied GHG emissions will consequently increase. The carbon spike observed during the initial construction phase of new advanced buildings results primarily from the significant greenhouse gas (GHG) emissions emitted during the manufacturing and production processes of building materials and systems. Therefore, it is urgent to address and reduce not only operational impacts but, most importantly, embodied impacts in the context of limited GHG budgets if a global net-zero GHG emissions economy by 2040 needs to be achieved as per the IPCC-backed call for action (*Urgent Climate Action Can Secure a Liveable Future for All — IPCC*, 2023). Adopting circular, carbon-sequestering, short-cycle harvested biogenic, natural, low-technology, and local materials might play a significant role in reducing the absolute value of embodied emissions at a pace comparable to that of operational emissions.

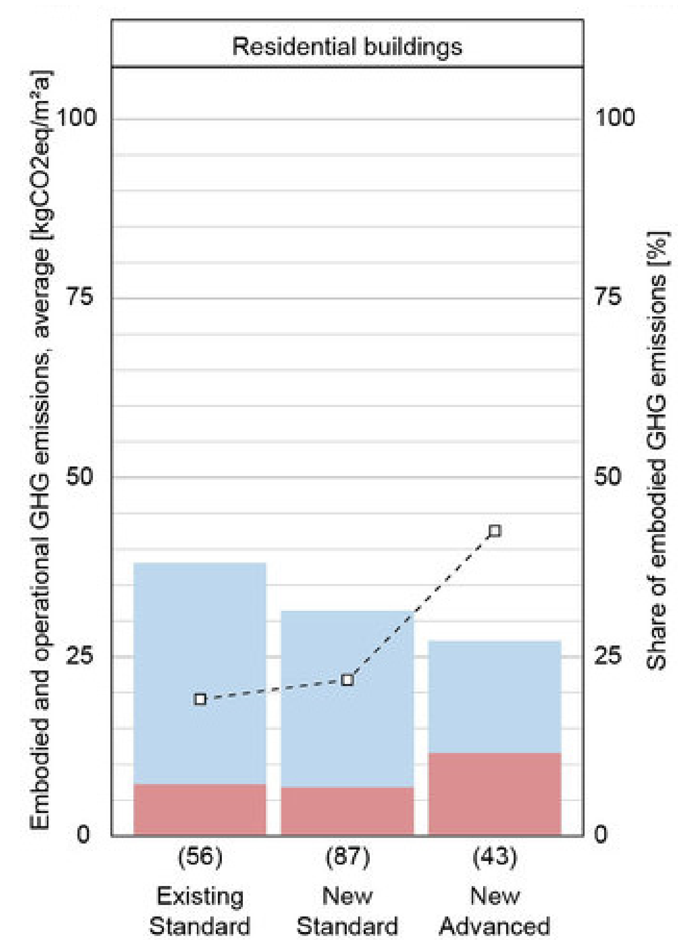


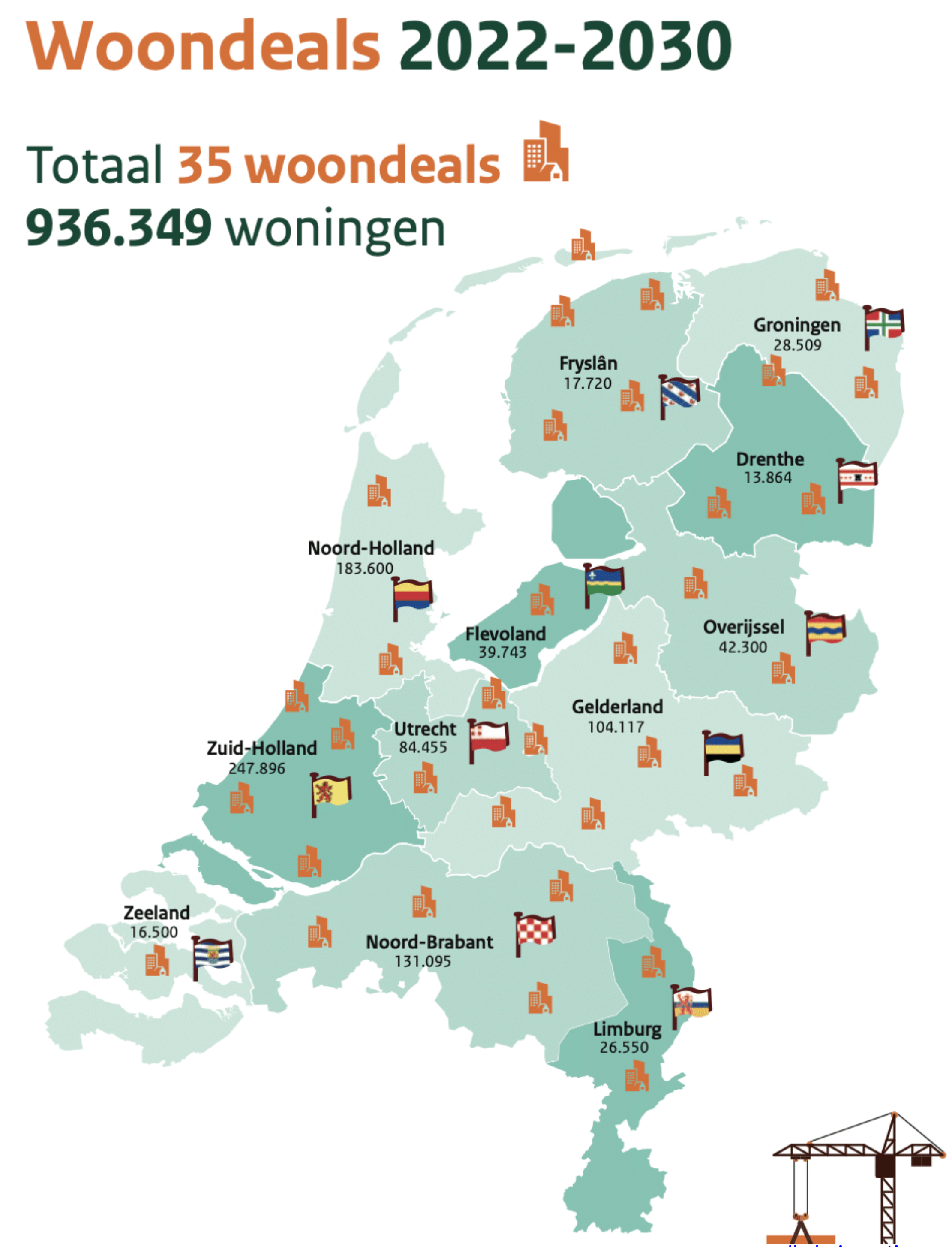
Fig 17 – Edited by author, Global trends in buildings' life cycle GHG emissions for residential buildings by energy performance class. (2022), Source: Embodied GHG emissions of buildings –The hidden challenge for effective climate change mitigation.

Balancing Housing Demand and Sustainability: The Netherlands' Construction Dilemma

Since the 2008 financial crisis, the Netherlands has faced a prolonged period of subdued residential construction (European Commission, 2021). This has exacerbated a significant housing shortage in the country. Additionally, factors driving this challenge include immigration stemming from international conflicts (Vissers, 2019), along with escalating housing prices, growing inequality, a lack of affordable housing options, and increased investment from foreign buyers (Henley, 2024).

This shortage can be addressed through more efficient transformation and reallocation of existing building stock, as well as through new construction. However, years of insufficient construction activity have created a significant backlog in housing supply that cannot be fully resolved by transforming existing buildings alone. 8 million existing buildings are in the process of being insulated and the government wants to build almost a million houses before 2030 (Rijksoverheid (2022) Nationale woon- en bouwagenda). The target also understates the actual building requirements going forward, so even if it is met, shortages may persist (European Commission, 2021).

The Dutch built environment is known for its complexity which to a certain extent is influencing the major sustainability challenges. To limit further global warming, the goal is to reduce CO_2 emissions by more than half by 2030 and the country wants to be fully circular by 2050 and operate within planetary boundaries. (Rijksoverheid, 2023. Nationaal Programma Circulaire Economie 2023-2030). The construction sector is responsible for approximately 50% of national raw material consumption and 11% of national CO_2 emissions (Rijksoverheid, 2023. Nationaal Programma Circulaire Economie 2023-2030). The goals for the reduction of CO_2 and nitrogen emissions conflict with the production of construction materials. The policies are managed independently of each other but integrating them would help in achieving National and European environmental objectives. It is certain that if the construction trade continues as "business-as-usual" with indus-



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trialised and mass-produced toxic materials the goals will not be reached.

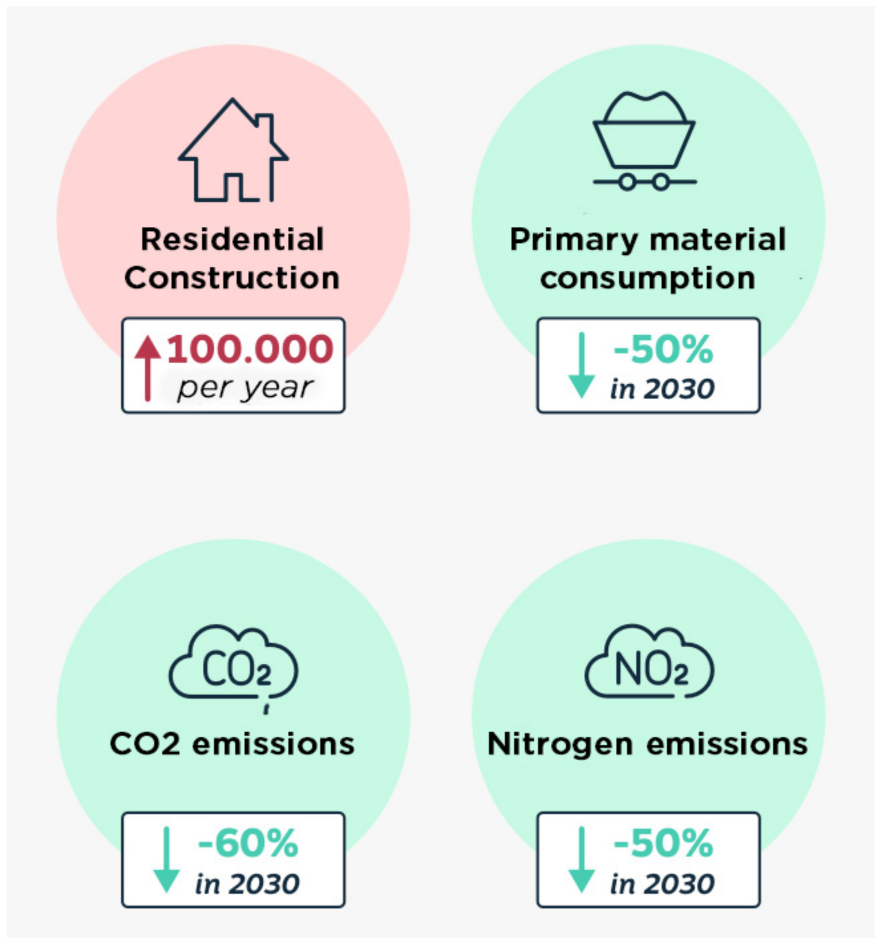


Fig 19 – Edited by author, Goals of the Dutch national government for 2030, Source – Woningbouw binnen planetaire grenzen

It is interesting to explore the current resource metabolism to understand how materials are used to cater for the demand of construction. Additionally, the source of raw materials and the end-of-use are investigated to complete the chain and comprehend the accumulation of materials around us.

In the current Dutch built environment the ratio of renewable materials to overall material composition is only 4%. These materials as timber, wood products, and fibres are produced through natural cycles and are derived from plants. Apart from renewable materials, 88% of the total waste is reused and recycled. (Economisch Instituut voor de Bouw (EIB) & Metabolic 2022)

Material Metabolism of the Dutch Built Environment

Fig 20 illustrates the materials used in the Dutch built environment. Material inputs are broken down into four categories based on their composition and raw ingredients. It is evident that concrete and brick dominate in terms of mass employed: the built environment is mainly made of minerals and very little of bio-based materials. Even though some materials are recycled, virgin materials still dominate the newly built environment. Overall, residential buildings account for almost two-thirds of the total material consumption.

The end-of-life phase illustrates the volume and type of waste, and it is being cycled back into the chain. Chemical-based materials and various adhesives make it difficult to disassemble and recycle or repurpose, and they are also resource-intensive. This debris ends up in landfills or is incinerated. The statistics also convey that demolition is preferred over less destructive solutions. Efforts are made to make use of salvaged materials to their highest value and to repair the buildings, but the demand for housing is so high that it cannot be met solely by these measures. Sustainably managed renewable materials can help to boost circularity when virgin materials are needed.

This confirms that there is an urgent need for new ways of building, especially when the country faces enormous construction challenges and a highly polluting conventional construction sector. However, instead of just seeking ways to minimise damage to the surroundings, we should approach all the stated issues in agriculture, nature, and housing as a whole system rather than fragmented parts. Finding ways to reconnect to the local context and surroundings is crucial, transitioning from fragmented sustainability to a restorative and regenerative approach.

MATERIAL METABOLISM OF THE BUILT ENVIRONMENT

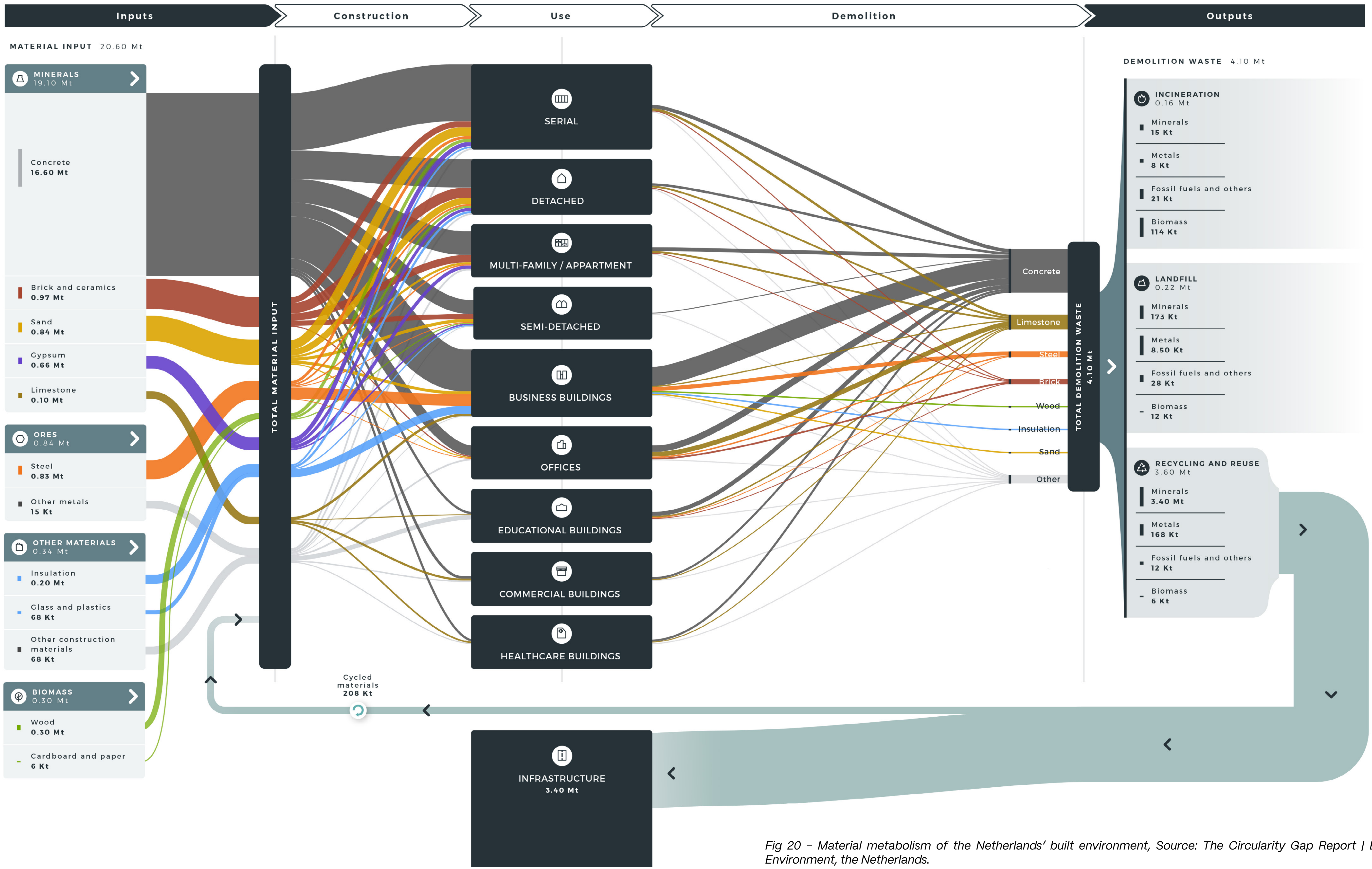


Fig 20 – Material metabolism of the Netherlands' built environment, Source: The Circularity Gap Report | Built Environment, the Netherlands.

Imminent urgency to advocate fast-growing biobased materials

The Potential and Challenges of Biogenic Materials and Timber in Sustainable Dutch Construction

The production of building materials in the Dutch built environment significantly contributes to anthropogenic greenhouse gas (GHG) emissions (Dutch Green Building Council, 2021). Additionally, the housing crisis due to the prolonged period of subdued residential construction (European Commission, 2021), immigration stemming from international conflicts (Vissers, 2019), escalating housing prices, growing inequality, a lack of affordable housing options, and increased investment from foreign buyers (Henley, 2024)—needs to be addressed primarily through new construction. The government aims to build almost a million houses before 2030 (Rijksoverheid, 2022, Nationale woon- en bouwagenda) and refurbish 8 million existing buildings and implement energy efficiency measures. This calls for increased material demand for constructing new, highly energy-efficient buildings and for adapting existing buildings for future use. To meet the housing demand, simultaneously limiting GHG emissions and limiting the rise in global temperature (IPCC, 2018), buildings must act as carbon sinks.

Biogenic materials have the potential to store carbon accumulated over decades or even as little as a year. These materials typically contain approximately 50% carbon by mass (Røyne et al., 2016), making them effective for achieving carbon sink in built environments. Large construction companies in the Netherlands are setting up timber prefab production factories with the ambition to build approximately 1,000 homes each year (Wassink, 2023). This is due to its possibility to automate and prefabricate, efficiency, rapid on-site assembly, moderate costs, and compliance with qualifying regulations apart from the ability to store carbon. However, from an environmental perspective positive long-term effects can only be achieved if the carbon is stored in the anthroposphere for a relatively long timespan before eventually being released as CO_2 into the atmosphere (Pittau et al., 2018) and the availability of local timber for construction in the Netherlands is scarce. Construction timber in the Netherlands mainly comes from EU forests and forests account for approximately 38% of the total land surface, out of which more than 95% is managed (Eurostat, 2021). Forests play a crucial role in mitigating climate change by sequestering carbon, which represents the most significant negative climate-forcing mechanism. About 10% of total EU GHG emissions are currently offset by forests (European Environment Agency, 2022) and a striking rise in the harvested forest areas has been noticed in recent years with the prediction of a moderate increase in the harvest of mature forests in the coming decade (Grassi et al., 2018). Additionally, recent years have seen an uptick in wildfires across EU27 Member States (*European Forest Fire Report*, 2022), with predictions of further increases, particularly in southern Europe, as temperatures rise.

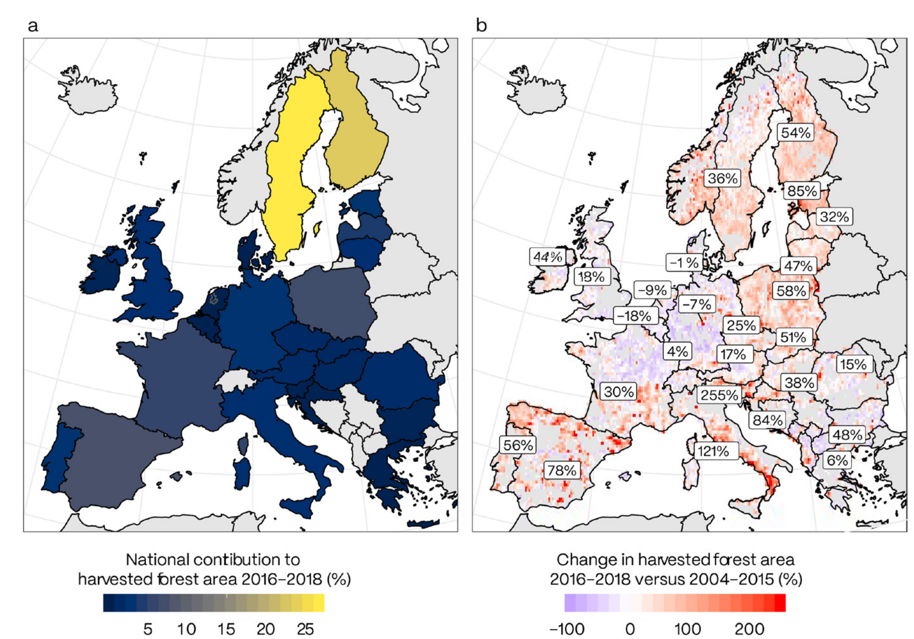


Fig 21 - Spatial statistics of European harvested forest area. a Percentage of national contribution to the total harvested forest area of EU26 during 2016– 2018. b, Percentage variation of European harvested forest area within each 0.2° × 0.2° grid cell, for 2016–2018 versus 2004–2015 (labels refer to aggregated national values). Grey areas represent countries not included in the analysis. Source-Abrupt increase in harvested forest area over Europe after 2015. https://doi.org/10.1038/s41586-020-2438-y

Harvested wood products do offer a solution to tackle embodied emissions of materials, but advocating HWP just transfers carbon from one pool (forests) to another (built environment) (Arehart et al., 2021). The significantly low emissions from harvested wood products (HWP) are only valid if the harvested area is replaced by another plantation, and it takes decades to compensate.

To achieve carbon neutrality in the built environment by 2040 and limit global warming to 1.5°C by 2050, HWP is not a viable solution as it is not climate-neutral in the short term (Hawkins et al., 2021), and the available resources are insufficient to meet the demand.

An increase in harvesting timber will certainly increase greenhouse gas emissions in the first 30 years (Soimakallio et al. 2021). Therefore, HWP should be used wisely in long-lasting applications, reuse, and recycling to store carbon for extended periods and maximise its carbon storage potential and lifespan.

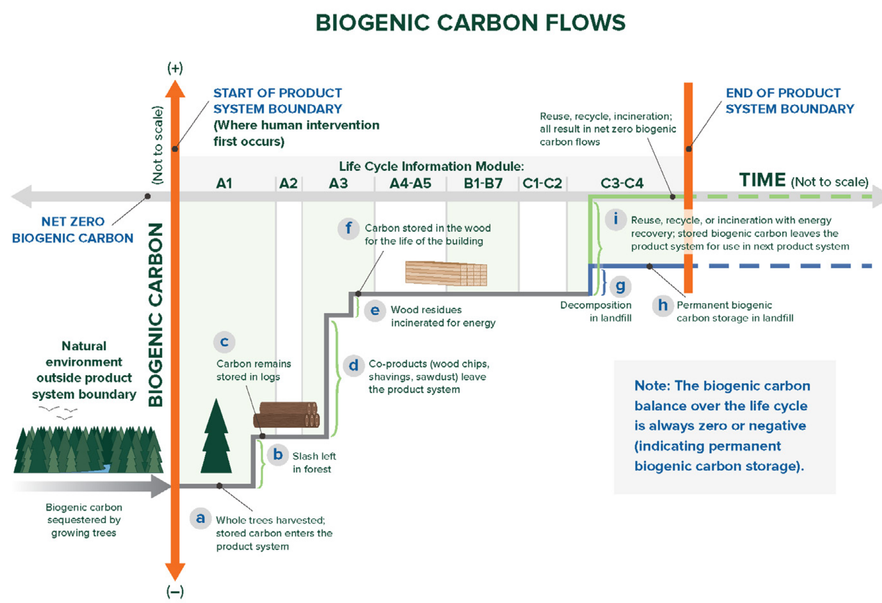


Fig 22 – Biogenic Carbon Flows for Wood Products. Source – WoodWorks – Wood Product Council, 2023. https://www.woodworks.org/resources/how-to-include-biogenic-carbon-in-an-lca/

The Netherlands being the second-largest exporter of agricultural goods in the world (Netherlands – Agriculture, 2024) generates ample agricultural residual. Fast-growing plants like straw, hemp, flax, miscanthus, reed, and so on sequester carbon through photosynthesis, typically on an annual cycle. Materials produced from these fibres can be implemented faster and are more compatible with the local availability of biomass resources. The European Union is promoting the use of biogenic residuals instead of cultivating dedicated energy crops for energy production (European Environment Agency, 2013). However, prolonged storage of carbon in biogenic building materials will deliver larger GHG savings. However, because the European Union (EU) encourages the use of agricultural wastes rather than producing dedicated energy crops, demand from the energy sector is projected to increase. (Einarsson & Persson 2017).

Long-rotation species require more time to absorb the same amount of carbon as short-rotation species, and this extended period negatively impacts their Global Warming Potential (Guest et al., 2013). Additionally, in comparison to harvested wood products, where the cooling effect on the climate is achieved after decades, short-term harvested materials can achieve net cooling impacts more quickly due to their short rotation periods. Fig 23 demonstrates straw achieving cooling impacts faster (almost within a year) while glulam and sawn wood start achieving cooling impacts almost 2 decades after construction (Göswein, Arehart, Phan-huy, Pomponi, & Habert, 2022). Pittau et al. (2018) explored the use of fast-growing bio-based materials for external walls, considering the time factor in their life cycle assessment (LCA). They concluded that these materials have a negative impact on radiative forcing (i.e., better than climate neutral) throughout their lifecycle.

The use of fast-growing bio-based materials as insulation to achieve thermal comfort, has the ability to store a significant amount of carbon captured during short-term growth. This remarkable quality of locally available, abundant materials to sequester carbon enables designs aimed at climate regeneration. Simultaneously, it delays emissions, earning carbon credits (Guest et al., 2013). This approach represents a viable alternative to harvested wood products. Therefore, the imminent urgency to reduce GHG emissions can be addressed by increasing the use of fast-growing bio-based materials.

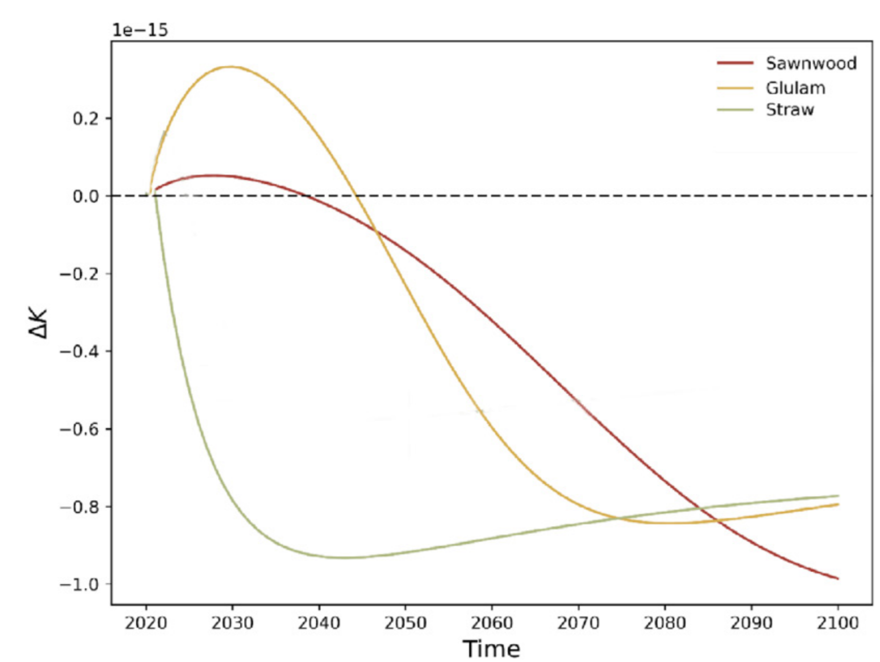


Fig 23 – Global temperature change (GTP) of different biobased construction materials considering the production (cradle-to-gate) emission and subsequent biogenic carbon sequestration from replanting of 1 kg of each. Source – Barriers and opportunities of fast-growing biobased material use in buildings (2022). https://www.researchgate.net/publication/364212668_Barriers_and_opportunities_of_fast-growing_biobased_material_use_in_buildings

Theoretical Framework

Aim

The theoretical framework establishes a background encompassing various issues – including a brief history of transition, practices, climate change, and the current state of agriculture, nature, and housing development in the Netherlands – it becomes clear that these topics are multi-layered and complex.

The Netherlands has achieved high agricultural productivity through practices of monoculture and homogeneity. Nevertheless, it relies on neighbouring countries to meet its climate and nature goals, such as reducing greenhouse gas emissions and establishing additional natural reserves and protected forests. However, doing so puts pressure on the land, and the soil structure is disturbed. Agriculture should no longer be viewed solely as a means to meet the increasing demand for food but as a critical factor in considering ecological aspects.

Forests are used as multifunctional areas but with limited accessibility as they are few and small. They are no longer beneficial as production forests due to limited opportunities and low economic value (low harvests and a decline in timber prices) (Van der Maaten-Theunissen, M. & Schuck, A. 2013). Yet, the use of structural timber and engineered wood in the Netherlands is growing rapidly due to its ability to store carbon in the fabric of buildings for the long term. But as local forests cannot meet the demand, this puts pressure on imports mainly from other European countries, but also from the rest of the world.

Lastly, the country is facing a major housing crisis and the need for new construction in the coming years is inevitable to meet the demand. However, looking at the current material metabolism of the Dutch built environment, and the increasing share of embodied carbon emissions to operational carbon emissions (Dutch Green Building Council, 2021), there is an urgent need to explore building materials and alternative ways of building. At present the developments in tackling the aforementioned issues are carried out separately. Despite that, these approaches fail to solve multi-layered and complex problems.

Considering all this, the research aims to **integrate/intertwine nature, agriculture, and housing with a restorative and regenerative approach, thereby promoting harmony with nature while restoring the soil, boosting biodiversity, and enhancing overall well-being by adopting locally produced bio-based materials.**

With this approach, buildings aren't a threat to nature restoration but assist in facilitating the transition.

The thesis aims at addressing the following main questions:

- The central question is: What opportunities exist in the Noordoostpolder for crops usable in the building trade? How can agriculture, nature and architecture work together with a restorative and regenerative approach in Noordoostpolder? How might growing plants for construction have positive outcomes for people, plants and animals across our bioregion?

- What are the possibilities for using locally sourced biobased and natural materials as building materials?

- What would the built environment look like if the health of Dutch landscapes were prioritised over the never-ending demands of industry's monoculture landscapes?

Objectives

This research is carried out at Kumiki in Amsterdam under the supervision of Professor Andrea Bocco Guarneri from the Inter-University Department of Regional and Urban Studies and Planning, and Kevin Veenhuizen from Kumiki as a part of a master's thesis focusing on exploring the potential of various bio-based materials and their application in a model house located in Noordoostpolder which would showcase the integration of nature, agriculture and living. This investigation is performed in collaboration with Building Balance, which acts as a facilitator to establish local supply chains.

The research has a twofold objective:

Firstly, to explore alternative farming approaches that harness the potential of various fibres, focusing on their cultivation, harvesting, contribution to biodiversity, ecological impact, and transformation into sustainable building materials. Not only environmental issues and climate challenges in the peatlands of Noordoostpolder are addressed, but also a better understanding of selecting locally sourced materials and construction methods that can mitigate the negative impact of new buildings.

Secondly, to build a demonstrator house in the Noordoostpolder drawing on the Permaculture principles advocated by Bill Mollison and David Holmgren (Permaculture: Principles & Pathways Beyond Sustainability, 2011), as well as the theoretical concepts of 'Vegetarian Architecture' promoted by Andrea Bocco Guarneri (Vegetarian Architecture: Case Studies on Building and Nature, 2022) and the 'Vernacular Architecture of the 21st Century' (Bocco Guarneri & Habert, 2024).

The objective is to embrace the potential of locally available bio-based materials in the form of substructure, superstructure, insulation, boards, and cladding while integrating living into agriculture and nature through a restorative and regenerative approach by implementing permaculture principles.

In the end, an evaluation is performed to demonstrate potential environmental savings by selecting locally sourced biobased materials and implementing low-impact technology in the Kumiki Model House.

Methodology

Given the twofold objective of the research, the research employed a triangular methodological approach, combining research, fieldwork (qualitative data collection), and quantitative analysis. A hierarchical structure within the research process gradually provided deeper insights, adding informative layers to the study.

Literature reviews were conducted to establish the research context, and workshops, stakeholder meetings, and visits to farms, processing sites, and the model house site were organised. With the facilitation of Building Balance, diverse stakeholders have been engaged in the proposed construction of the model house. Key insights were provided by farmers, production foresters, millers, and the municipality of Noordoostpolder, which were instrumental in developing this research. The understanding generated through these stakeholder inputs made identifying opportunities for intervention at both regional and local levels possible. The problems related to arable farming were analysed using recent literature, and consultations were held with farmers practising natural farming at De Groene Griffioen in Weesp and food forest Emmeloord. Additionally, to study the variety of biodiverse fibres and their use in building elements, literature from regions around the world where these fibres are widely used was reviewed. To experience the flax farming process firsthand, a workshop organised by Building Balance included a visit to Bas Bouma's fields in Flevoland.

The second phase of the research focused on material investigation, which included a market study to analyse local suppliers for procuring construction materials, alongside a literature review. The impact of cultivating fibre crops on soil structure, ecology, and biodiversity was considered before final selection. The most crucial aspect of designing the model house is the application of various biobased materials. In addition to Andrea's extensive input, inspiration was drawn from both old and modern literature, as well as from studying projects from around the world.

The spatial design was the result of brainstorming sessions with the Kumiki team, user analysis, and consideration of the context to select the appropriate building technology, as well as the constraints of using locally produced biobased materials. The quantitative approach analysed the environmental impact of the materials associated with the design. This will inform material choices and identify areas for future improvement.

This mixed-methods approach provided a robust framework for exploring the potential of locally sourced biobased materials and the introduction of permaculture farming in the countryside of the Noordoostpolder. By combining qualitative insights with quantitative analysis of materials and environmental impacts, the research offers a comprehensive understanding that informs the design of the Kumiki model house and the integration/intertwining of nature, agriculture, and housing.

Noordoostpolder – from land to sea to land

Food shortages during World War 1 and catastrophic floods in 1916 were the main reason for the largest land reclamation projects in the Netherlands (Canon the Noordoostpolder 2019). On the 9th of September 1942, the Noordoostpolder was officially dry. The Noordoostpolder is characterised by village and city centres surrounded by farms. This young polder consists mainly of mineral-rich marine clay. Dutch agricultural areas on clay soil in Noordoostpolder can generally be characterised as a flat, wide landscape, divided by ditches, with a scattering of buildings here and there in a yard (Terpstra, P. 1977). Every square meter of this reclaimed land was destined to practice agriculture (Steenhuis, M. 2009). As a result, the Noordoostpolder attracted many people focused on food production, successfully addressing the food supply shortage.

The problems associated with clay soils are closely related to exhaustive land use in Noordoostpolder (Römkens, P.F.A.M. & O. Oenema, 2004). Intensive agriculture causes issues in both the soil and the landscape, leading to large-scale consequences. Although clay is a very fertile soil type due to its high mineral content, it is also vulnerable and must be treated with care.

The changing climate will create additional challenges in the future. Moreover, the current common method of soil cultivation relies on freezing temperatures. In the autumn, the soil is ploughed, leaving large lumps of clay. The freezing cold causes these large clogs to break up into smaller, manageable chunks. If it no longer freezes in the future, this method of soil cultivation will lose its effectiveness, and farmers will need to seek alternatives.

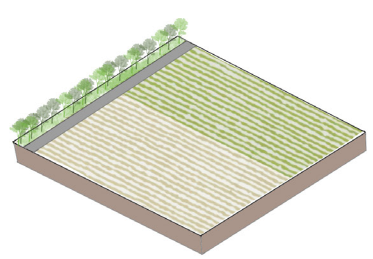
Fig 24 – Satellite image of Noordoostpolder. Source – Copernicus Data Space Ecosystem. https://dataspace.copernicus.eu/

Spatial planning of Noordoostpolder

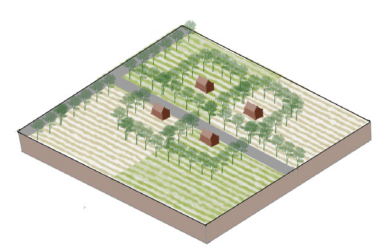
The polder is completely man-made (artificial) and therefore, it has a lot of structure and regularity. The central place theory of the German geographer Walter Christaller influenced the planning of the polder (Canon the Noordoostpolder 2019). This assumed an optimal distribution of village centres across the area, with the distance between the residential centres based on the proximity and accessibility of facilities for residents.

The polder has a concentric spatial structure, with Emmeloord as the centre and around it a ring of villages within cycling distance. The village centres are connected by canals and roads that together form a cross-axis. The green avenues were designed based on the axis. The yards have a yard hedge, linked to green avenues. The planting of the yard hedges is broader and more robust on the southwest side due to the prevailing wind direction. The more sandy parts of the polder, not suitable for agriculture were developed as recreational forests (Terpstra, P. 1977).

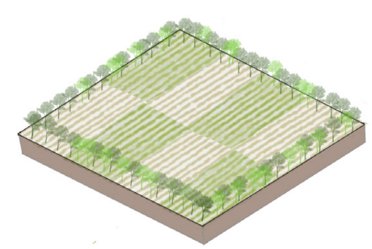
Fig 25 – By author, spatial planning of Noordoostpolder



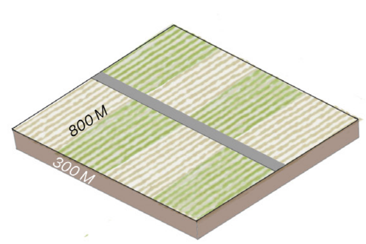
Unobstructed view over the fields



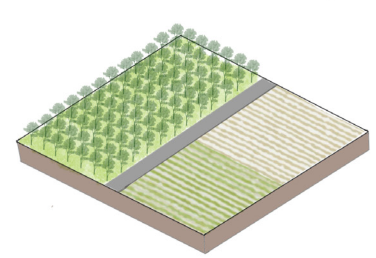
Green avenues forming yards acts as wind screens and privacy to the shelters



Room like agricultural land designed considering infrastructural and safety requirements



Farm sizes optimised for production and services



Production forest in sandy soils

Fig 26 – Topographic map of the municipality of Noordoostpolder. Source – Janwillemvanaalst. https://commons.wikimedia.org/w/index.php?curid=36066088

The polder has an open and agricultural character. Most roads are planted with one or more rows of green avenues, occasionally breaking the open landscape. The rigid structure and regularity are showcased in the plot sizes generally grouped as two polders deep (16,000 m) between the road structure due to the optimised plot size for production being 300x800 m. The size of the plots was restricted to 300 m due to the maximum allowance permitted by the drainage technology available at that time (Geurts, A. J. 2000). The repetitiveness creates a room-like structure and transparency in the edges enables clear perspectives of the fields from the road. The green avenues were intended to provide the crops with some protection from the wind, but also serve the purpose of screening and privacy around the homes.

Fig 27 – The typical polder landscape. Dead straight roads, large rectangular plots, farms with canals. Source – Canon de Noordoostpolder. [*https://www.canonnoordoost-polder.nl/en/organized/alloca-tion*](https://www.canonnoordoostpolder.nl/en/organized/allocation)

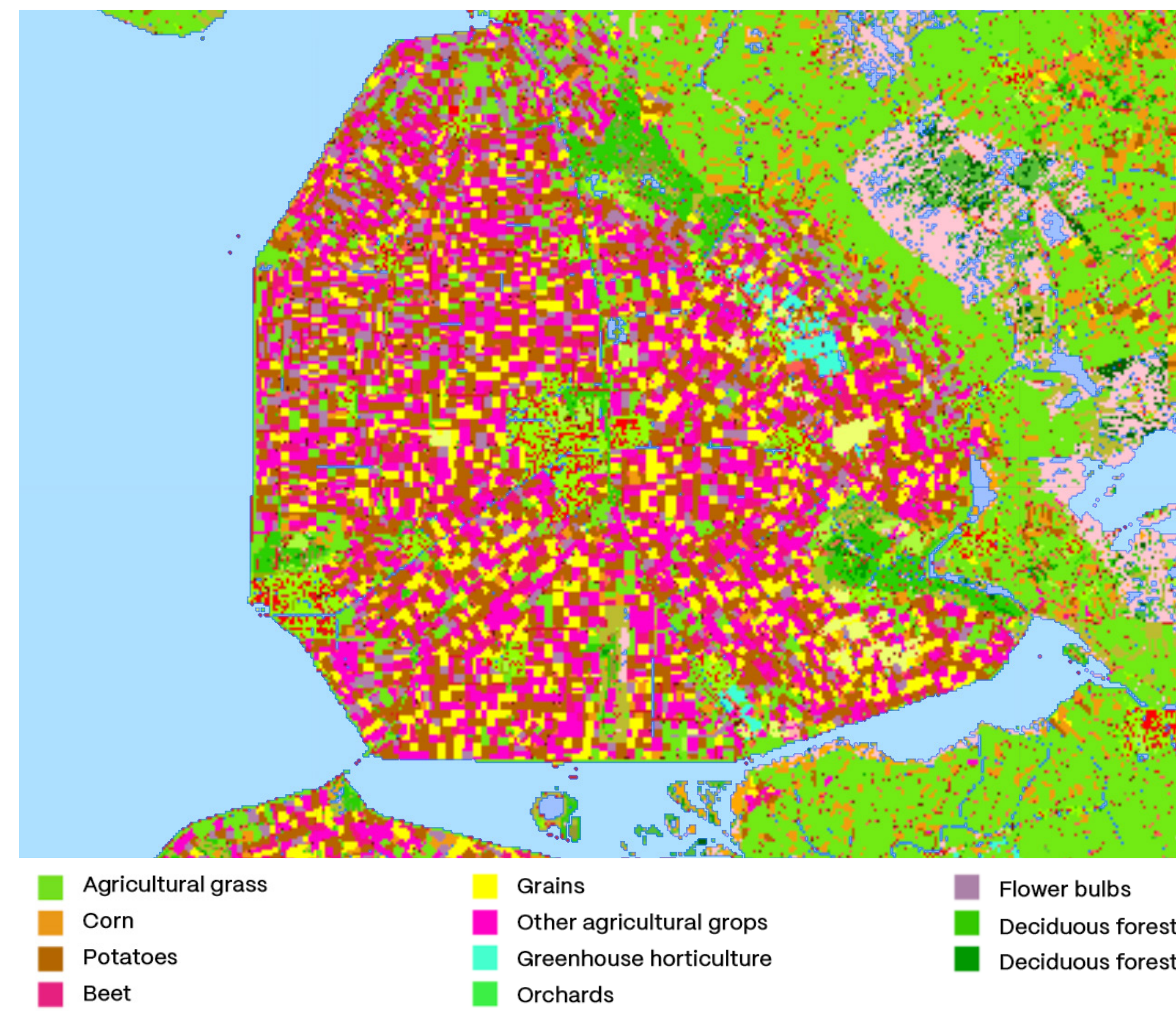
Fig 28 – Rigid and linear patterns of field for the ease of using heavy machines in this case, to harvest potatoes. Source – Harry Farm. [*https://www.pieperprijsvraag.nl/piep-ers-oogsten/*](https://www.pieperprijsvraag.nl/piepers-oogsten/)

Land Use

After the drying of the polder, the soil structure was improved by cultivating crops (clover, reed, grains) with deep roots to help with soil drainage and to stop the growth of weeds (Geurts, A. J. 2000). Cultivation of clover and reed was diminished after the attainment of optimal fertility levels in the marine clay subsoil. The steps taken to enhance the soil structure in Noordoostpolder transformed it into the prime choice for agriculture, making it both highly suitable and valuable.

At present, large-scale arable farming mainly takes place in the polder. The profitability and demand solely drive the choice of farming cultivation. Hence, the intensive cultivation of beets, potatoes corn, and grains, places great demands on the soil. This intensive utilisation implies that soil nutrients are depleted at an accelerating rate hindering soil recovery. Additionally, high-productivity agriculture is achieved here by using machinery that effectively wages a war of annihilation, causing soil compaction.

Fig 29 – Edited by author, rural land use map of the Noordoostpolder, Source – LGN viewer. Wageningen University & Research [*https://www.wur.nl/nl/onder-zoek-resultaten/onderzoek-sinstituten/environmental-re-search/faciliteiten-producten/kaarten-en-gis-bestanden/landelijk-grondgebruik-ne-derland/lgn_viewer.htm*](https://www.wur.nl/nl/onderzoek-resultaten/onderzoeksinstituten/environmental-research/faciliteiten-producten/kaarten-en-gis-bestanden/landelijk-grondgebruik-nederland/lgn_viewer.htm)



Environmental Challenges and Agricultural Impacts in Noordoostpolder

The top layer of the polder consists of marine clay with subsoils of sandy or peaty materials. There are several types of clay, each of which has different problems due to diverse properties. Clay soils retain water better as compared to sandy soils, but at the same time the heavier the clay, the more difficult it is for water to infiltrate. In addition, compaction also ensures that too much water remains on the surface, causing plants to drown during wet periods (Basisregistratie Ondergrond (BRO) 2018).

Fig 30 – Tiles laid out in the shape of the Noordoostpolder reflect the great diversity of the soil within the region and the differences in mineral composition, Source – Polderwall. Atelier NL. https://www.ateliernl.com/projects/polder-wall

Soil degradation

Soil is essential for production in the agricultural sector, but soil quality is under pressure in some parts of Noordoostpolder. The physical quality of soil is degrading due to soil compaction that is occurring because of the use of heavy machinery, tillage at the wrong times and persistent cultivation of harvested crops. Biological soil quality is a concern due to the increasing presence of soil diseases caused by nematodes, bacteria, fungi and insects (Is something up with soil?, WUR 2022). Frequent cultivation of harvested crops is also responsible for this. Additionally, the amount of organic matter in the soil plays an important role in chemical (and physical) soil quality. It is not yet predictable which parts of Noordoostpolder soil degradation will lead to restrictions on agricultural land use. Hence, soil quality safeguarding should be prioritised for future-proof agriculture.

Peat thickness substrate and clay maturation

Peat was formed before the reclamation of the area where the reclaimed Noordoostpolder is now located (PWS NOORDOOSTPOLDER: Het ontstaan en de inrichting 2019-2020). Additionally, clay developed on top of the peat when the Noordoostpolder was still underwater. During dry periods, large quantities of water are pumped in to irrigate the crops. As a result, peat present in shallow layers oxidises due to dewatering and eventually sinks. This is an irreversible process. Over time, the ground level will move closer to the groundwater level, and the soil will become too wet for effective agriculture. Under these wet, low-oxygen conditions, the peat does not oxidise, and the soil does not subside further.

However, lowering the water level remains necessary to maintain optimal conditions for agriculture. Peat that was previously flooded under anoxic conditions (without oxygen) now becomes dry, which restarts the oxidation process and causes the ground level to sink again (Römkens, P.F.A.M. & O. Oenema, 2004).
Immature clay has a relatively large volume of pores that are filled with water. This soil is soft and has little bearing capacity. During dewatering, the soft sediment gradually changes into a firm, well-

Territorial Framework

drained soil with structure. This 'maturing process' is accompanied by an irreversible loss of water and a volume reduction (Subsidence in Flevoland, 2020). This volume loss causes the ground level to drop. Therefore, soils with a weak clay layer are at risk of subsidence.

Risk of surface compaction

Surface soil compaction is globally recognised to threaten agricultural soil quality and productivity (Hartemink, A. E. 2008). According to the research, 43% of Dutch subsoils are suspected to be compacted below the annual plough layer. (Brus, D. J., & Van den Akker, J. J. H. 2018). Compaction is created by external exertion on the soil essentially during the tillage or wheeling of the soil. In wet periods, subsoil compaction is visible even without a soil sample due to the formation of puddles in the fields. Use of heavy machinery can reduce permeability, water retention, root growth, nutrient uptake and pore connectivity. The compaction is often related to the soil carbon stock (the more organic matter, the less compaction). Increasingly heavier machines, more intensive cultivation plans with fewer soil improvers and harvesting in wet periods increase the risks of subsoil compaction in this polder. The map shows the risk of subsoil compaction in the Noordoostpolder.

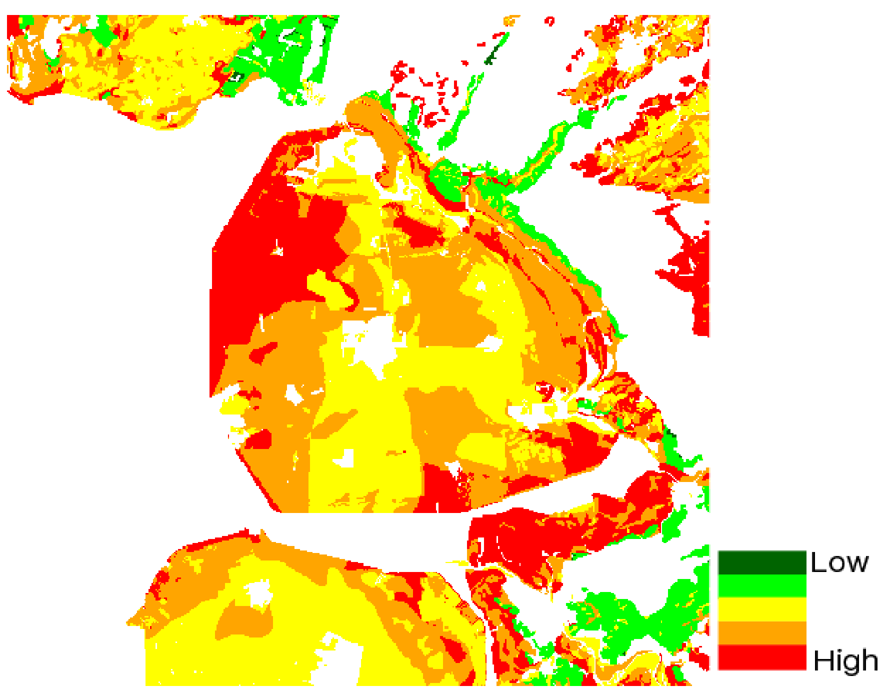


Fig 31 –Edited by author, Map of risk for subsoil compaction, Source – van den Akker et al., 2013

Fig 32 –Satellite images of the same agricultural plot in Noordoostpolder captured in 2018 and 2021 showcasing within-field heterogeneity, visible as slowly drying wet spots within the field. In 2021 (image on the left) some of these patterns were still visible, Source – Practical implications of the availability of multiple measurements to classify agricultural soil compaction: A case-study in the Netherlands.

Soil Carbon Stock

Plants need organic matter (50% of which is carbon) to grow (Lof, M. CBS 2017). The carbon cycle is therefore important for the carbon and energy balance of the ecosystem. High soil biodiversity indicates a stable system, without many disturbances, and is important for all soil functions. Intensive and monoculture cultivation ensures that a lot of organic matter disappears from the soil, affecting the nutrition availability to the cultivation. The map gives an idea of the carbon stock available in the top 30 cm layer of soil in the Noordoostpolder (fig 35). The level of carbon stocks is influenced by the type of subsoil and the plantation. Thehighest stocks are in areas with peat soils, the lowest in those with sandy soils and an average in the clay layers (Römkens, P. F. A. M., Oenema, O., & Alterra. 2004).

CO_2 deposition

The primary cause of CO_2 emissions from the soil is the oxidation of peat (Römkens, P. F. A. M., Oenema, O., & Alterra. 2004). In Noordoostpolder sand on peat is extensively used for agricultural purposes. Hence, highly contributing to CO_2 emissions. The Paris Climate Agreement, EU legislation and the current coalition agreement provide frameworks for climate policy. Specific to the soil, this involves limiting greenhouse gas emissions from (peat meadow) soils and additional carbon sequestration in the soil.

The reduction of CO_2 emissions from soils can mainly be controlled by raising the groundwater level. The sequestration of carbon in the soil also offers good opportunities. A side effect of the increasing carbon percentage in the soil is that the water storage capacity increases and the soil structure improves (Römkens, P. F. A. M., Oenema, O., & Alterra. 2004). This is positive, as less irrigation is necessary during periods of drought and less flooding occurs during periods of heavy precipitation.lder. The map shows the risk of subsoil compaction in the Noordoostpolder.

Nitrogen deposition

The larger farm size in arable farming and the larger number of cows in Noordoostpolder than the average in the Netherlands in dairy farming generate a manure surplus (Vogelzang, T., Smit, B., Kuiper, P. P., & Gillet, C. 2019). Due to the labour-intensive nature of using manure to improve soil health, it is either exported or burned to generate energy. Therefore, excessive use of fertiliser to keep production high results in a lot of nitrogen being emitted into the direct and indirect environment, which does not benefit biodiversity.

The larger farm size in arable farming and the larger number of cows in Noordoostpolder than the average in the Netherlands in

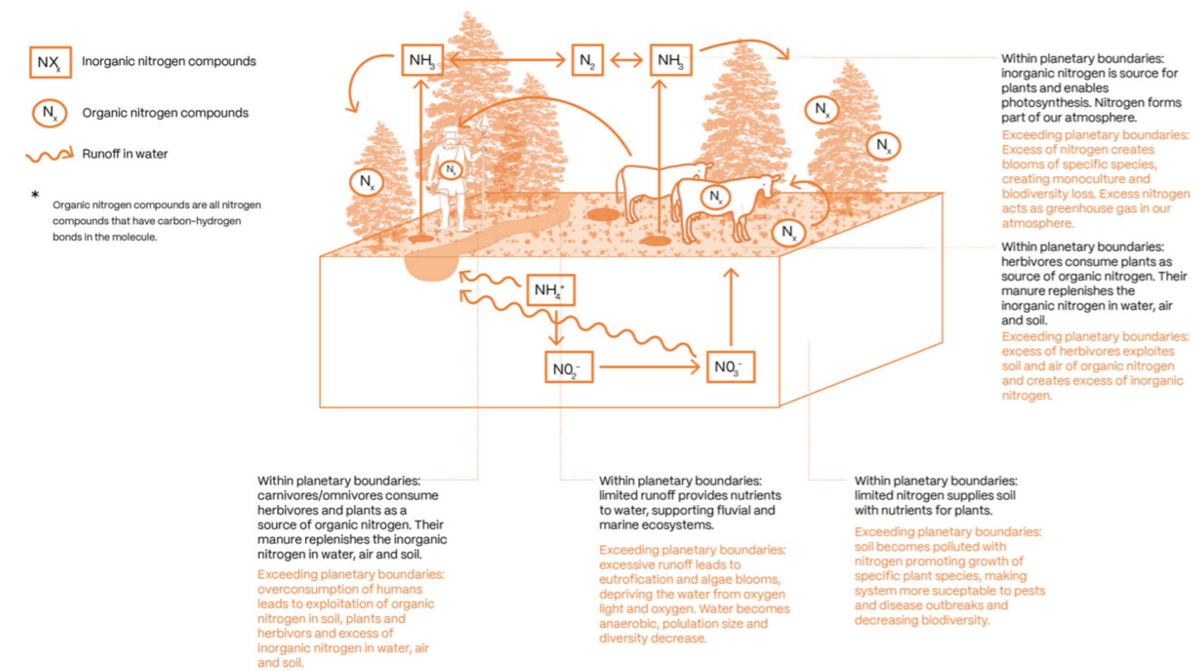


Fig 33 –Edited by author, The natural Nitrogen cycle, Source –Donut Diet – A vision and strategy for an agricultural transition towards a circular, collective, and regenerative future.

dairy farming generate a manure surplus (Vogelzang, T., Smit, B., Kuiper, P. P., & Gillet, C. 2019). Due to the labour-intensive nature of using manure to improve soil health, it is either exported or burned to generate energy. Therefore, excessive use of fertiliser to keep production high results in a lot of nitrogen being emitted into the direct and indirect environment, which does not benefit biodiversity.

Monoculture and hardly any biodiversity

The industrial food system strives to maximise output while minimising human input, which demands scalable, uniform processes. These uniform processes then require uniform ingredients, sourced from genetically uniform plants (Nature hates uniformity, Farmerama Radio, 2020). These crop choices influence soil soil quality. Harvested crops such as potatoes, sugar beets, onions and flower bulbs require more of the soil than harvested crops such as grains, legumes and cash crops. With harvested crops, there is a greater burden on the soil due to the use of intensive soil cultivation with harrows and cultivators in the spring, with harvesting machines in the autumn. Additionally, modern varieties require synthetic fertilizers and pesticides to thrive. As we adapt to climate change, reliance on these artificial inputs becomes problematic. Modern hybrid varieties have shallow root systems because they are bred to grow shorter, focusing energy on grain production rather than straw and roots (Nature hates uniformity, Farmerama Radio, 2020). This makes them less resilient in low-nitrogen, sustainable farming systems. This can lead to structural damage and damage to soil life.

The notably high cultivation frequencies of harvested crops in the Noordoostpolder (represented by the red and orange zones) are striking. Various issues are associated with such high cultivation frequencies, which are likely to be amplified by increasing changes in climate (Vogelzang, T., Smit, B., Kuiper, P. P., & Gillet, C. 2019). In this context, cultivation frequency is defined as the number of times (years) a harvested crop is grown within a 10-year period. The higher this frequency, the more intensive the cultivation plan and, therefore, the more intensive the land use. The share of root vegetables and vegetable crops on arable farms in Noordoostpolder is considerably higher than in other parts of the Netherlands. This relatively high intensity of monoculture cultivation is crucial to consider because of its negative influence on soil health and soil quality.

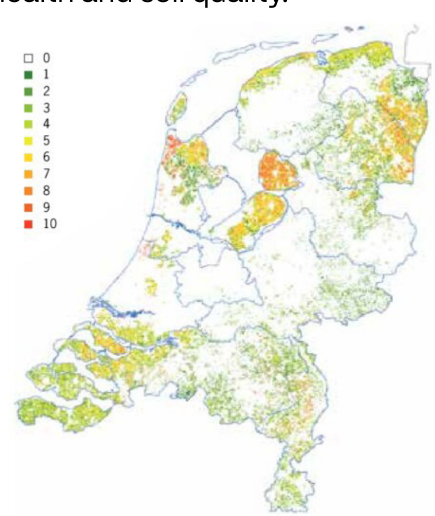
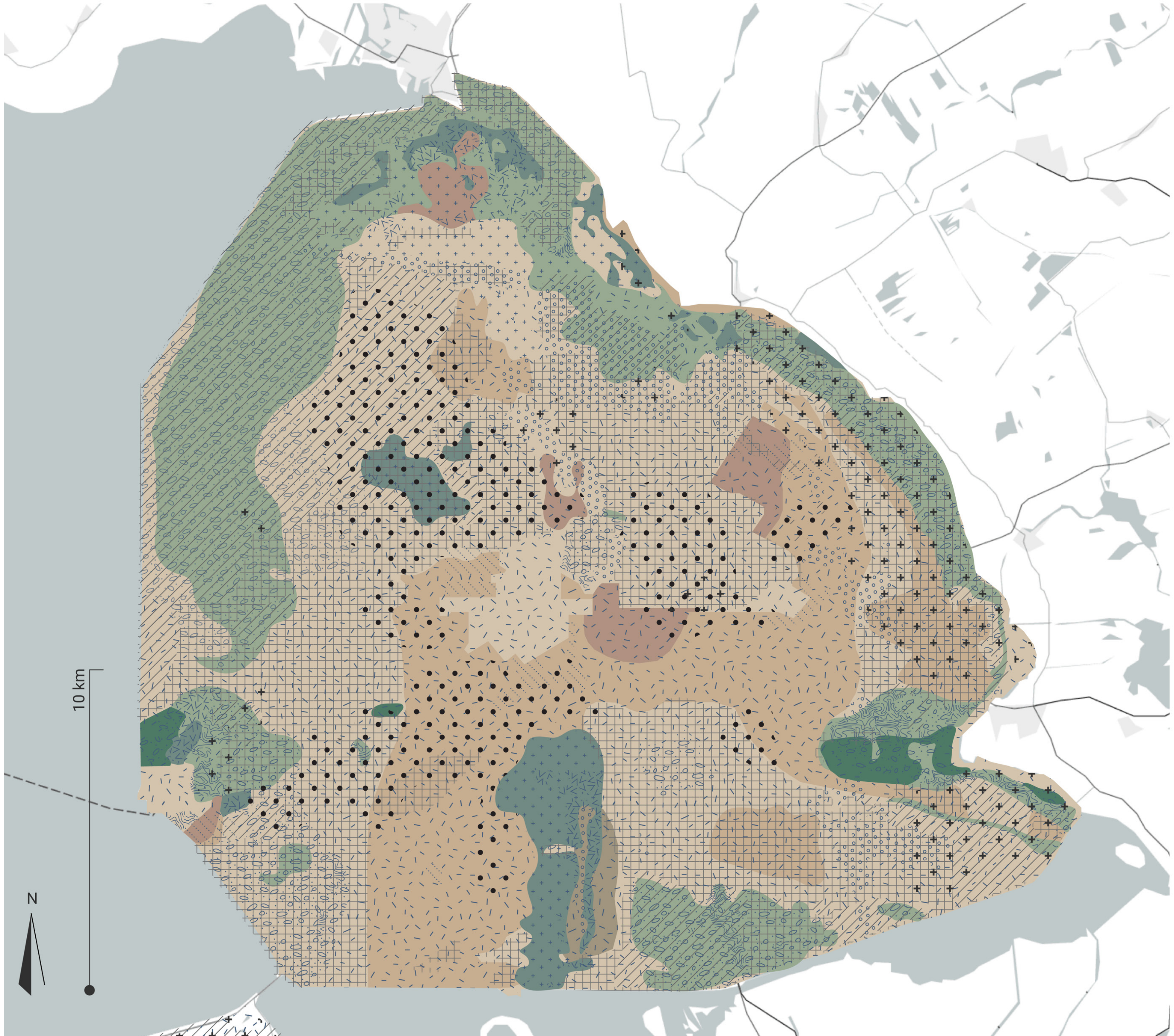


Fig 34 - Cultivation frequencies of annual harvested crops in the Netherlands, Source - Landbouweconomic Bericht, 2015.

All the aforementioned environmental problems in Noordoostpolder are the result of how the landscapes are used, specifically monocultures of arable farming and livestock farming. The accumulation of these problems will reduce productivity and profitability over the long term. A shift towards nature-inclusive, regenerative regional agriculture is necessary to address these issues. This approach will prioritise the health of landscapes over the never-ending demands of industry by introducing agroecosystems to tackle multi-layered and complex problems. This introduction by following the principles of permaculture will not only create a productive landscape but also provide a recreational space for people and an ecological habitat for plants and animals across the bioregion.

Mapping of Environmental Problems in the Noordoostpolder



Soil Type

- Light Zavel
- Light Clay
- Heavy Sablon
- Heavy Clay
- Sand
- Peat
- Loam

Substrate Compaction

- Big
- Very Big

Soil Carbon Stock

tons C/ha

- <50 Low
- 50–75
- 75–100
- 100–125
- 125–150
- 150–175
- >175 High

- CO_2 Emission (Peat Oxidation)
- Exceedance of Nitrogen Deposition

Fig 35 –By author, mapping of Enviromental Problems in the Noordoostpolder , Sources – Flevoland maps, Wageningen University & Research, CML, Gispoint, Strootman Land-schapsarchitecten

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Permaculture – Restorative, Regenerative Agriculture and Living in Noordoostpolder

Since the reclamation of Noordoostpolder, agricultural productivity has surged to meet the food demands of a growing population. However, this progress has often come at significant social and environmental costs, such as soil degradation, water scarcity, ecosystem stress, biodiversity loss, reduced forest cover, and high greenhouse gas emissions (refer to the previous chapter for a detailed summary). To address these problems, agricultural practices in the Noordoostpolder need a radical shift towards nature-inclusive, regenerative agriculture, prioritising soil health. By changing the way we grow our food, we can transform not only the quality of our produce but also our society and its values (FAO 2018). The proposed interventions in Noordoostpolder are grounded in the principles of permaculture advocated by Bill Mollison, an Australian researcher, author, scientist, teacher and biologist and David Holmgren, an Australian environmental designer, ecological educator and writer (Holmgren, 2011).

Permaculture is a design approach and practice framework for creating and managing sustainable and resilient agroecosystems, derived from the words "permanent" and "agriculture"(Holmgren, 2011). David Holmgren defines permaculture as "Consciously designed landscapes which mimic the patterns and relationships found in nature while yielding an abundance of food, fibre and energy for the provision of local needs" (Holmgren, 2011). The focus of permaculture has further evolved with a broader vision encompassing sustainable living and culture. Humans, habitat and organisation are central to the theory.

Implementing permaculture perfectly aligns with the aim of the research **"to integrate/intertwine nature, agriculture, and housing with a restorative and regenerative approach, thereby promoting harmony with nature while restoring the soil, boosting biodiversity, and enhancing overall well-being by adopting locally produced bio-based materials."** Additionally, permaculture's focus on regenerative living, self-reliance and minimising resource use combined with its distinctive integration of the entire process from observation to implementation is significantly helpful in answering the multi-layered and complex problems in the Noordoostpolder.

Permaculture is practised worldwide, and the implementation of its principles has consistently exhibited the possibility of earning a living through agriculture with relatively low inputs. Studies from Brazil and France showcased an increase in the interaction between systems, good environmental and economic performance and resilience against market fluctuations (Bonaudo et al., 2014). Respondents from Guatemala reported an increase in food accessibility and a more diverse and healthy diet. Additionally, prioritising the health of the landscape led to an abundant and thriving ecosystem in the built environment (Jerner & Bitic, 2019).
Live testimony of successful implementation (Jerner & Bitic, 2019), supported by scientific evidence of permaculture principles (Krebs & Bach, 2018), provides a robust foundation to implement permaculture in this research. The proposal aims to introduce permaculture not just as a way of performing agriculture but as a way of sustainable living. By doing so the linear and segregated monoculture model of farming and living would be replaced by an integrated circular model.

To develop design solutions catering to the unique conditions of the Noordoostpolder the twelve principles of permaculture are used as a design tool kit. To start with an overall vision the three main ethics **'care for the earth, care for people, and fair share'** (Holmgren, 2011), which focus on promoting enlightened self-interest by broadening the sense of community and encouraging a long-term approach to outcomes.

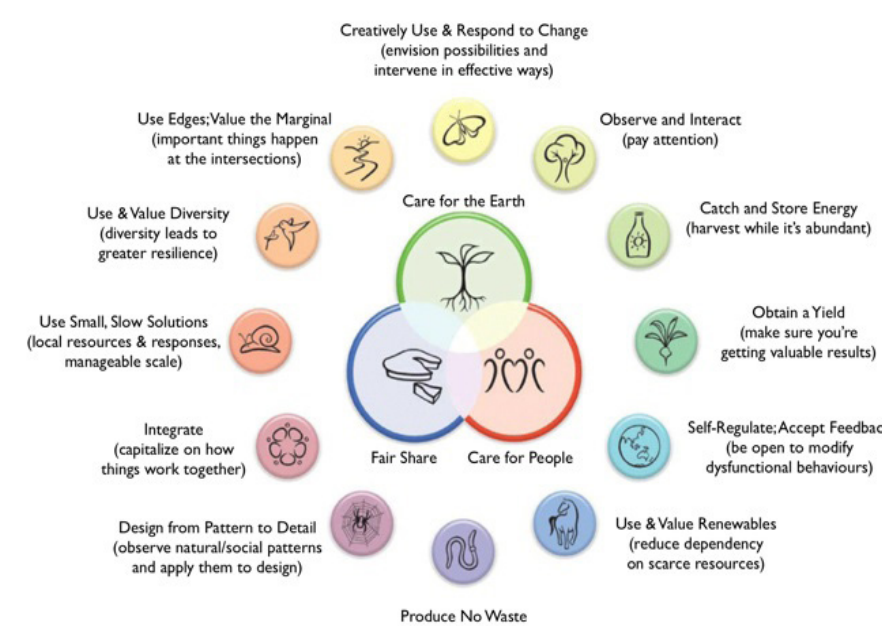

Fig 36 – Permaculture principles. Source: Urban Permaculture – Urban Sustainability Research Group. https://urbansustainability.seas.umich.edu/2013/04/urban-permaculture/

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The second and third ethics (care for people and fair share) are derived from the first. A clear indication of addressing issues related to the earth should be prioritised, forming a strong foundation for resolving other problems.

The intervention begins by assessing the damage caused by the application of technology, which is often applied with a limited perspective, focusing on immediate benefits, efficiency, or solving a specific problem without fully considering the broader context or potential long-term consequences. This narrow approach disrupts the harmonious relationship with nature. This underscores the importance of continuous interaction and reciprocation rather than isolation of design from its context. Therefore, I intend to carefully study the landscape and context and understand the subtle, persistent patterns created by nature and human activity. Tending resilient agroecosystems; growing perennials, wide-strip cultivation, and fast-growing plants that can be employed in the building trade; producing energy from renewable sources; and building exemplary construction will harness the human potential, minimise reliance on non-renewable resources, and consciously and continuously develop ways of living in the era of energy consumption decrease (energy descent) (Holmgren, 2020). **'Observe and Interact'** fosters ecological resilience by cooperating with nature rather than imposing on it. For example, improving the soil structure by cultivating crops (e.g. clover, reed, and grains) with deep roots to help with soil drainage and to stop the growth of weeds, exactly as it was done after draining the soil (Geurts, A. J. 2000). Wide strip cultivation instead of the narrow strip cultivation would avoid big harvest losses by mice as observed at the 'Farm of the Future' Lelystad (Wageningen University & Research, 2024). The approach also intends to enhance community-based building.

In the era of energy descent, capturing and storing energy in various forms will play a significant role. Capture and storing of energy is introduced in the proposal by improving soil fertility, utilising biogenic materials from fast-growing agricultural residues, growing perennial plants (especially trees), and enhancing water storage. Specific methods include the application of organic mulch (Tolk et al., 1999), channelling rainwater (Holmgren, 2011), capturing CO_2 in fast-growing plants and trees, storing carbon-rich fibres in the form of building materials, and generating energy from wind and sun. These features will increase soil water storage,

Fig 37 – Strip farming at the 'Farm of the Future' Lelystad. Source: Biodiversity, WUR. https://www.wur.nl/en/show-longread/biodiversity-longread.htm

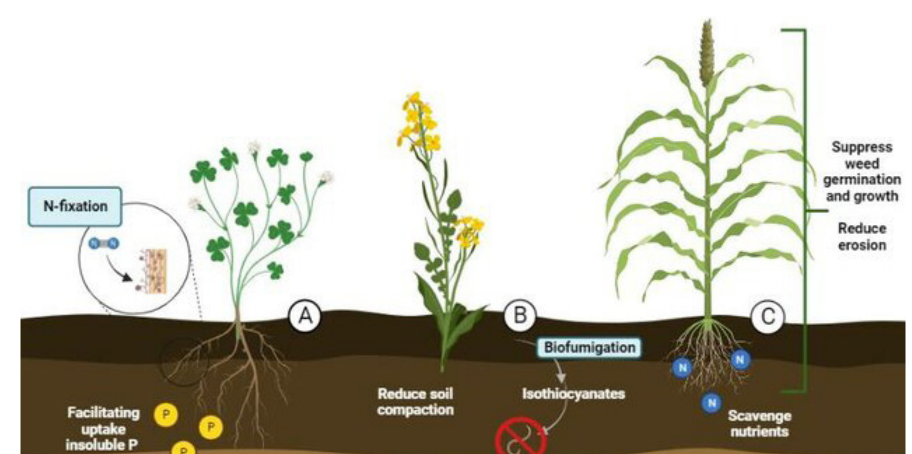

Fig 38 – Schematic diagram explaining the role of different types of cover crops in the agroecosystems and their main ecological services. A = Gramineous species, B = Brassicaceous species, C = Leguminous species. Source: Cover Crops for Sustainable Cropping Systems: A review. Agriculture. https://doi.org/10.3390/agriculture12122076 efficiency, water use efficiency of crops, increasing crop yields, high organic matter in the soil, reduction in greenhouse gas life cycle emissions, groundwater recharge, nutrient cycling (Pandey, 2001), biodiversity, and enhanced soil and air quality.

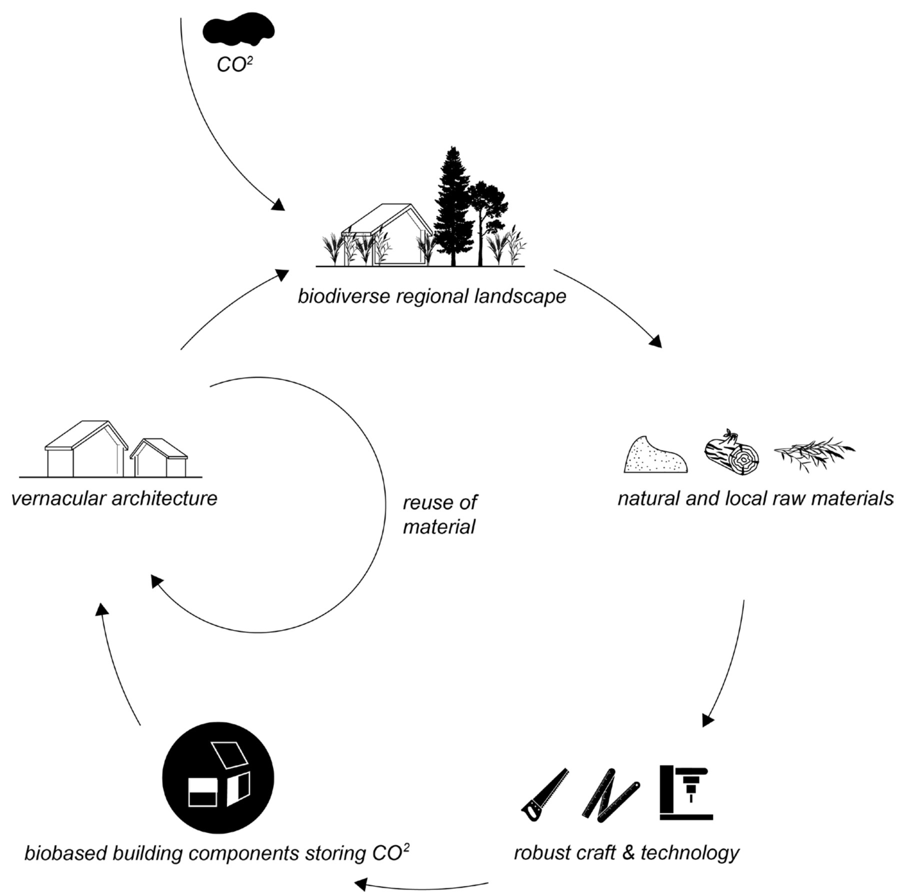

Fig 39 – Edited by author, Schematic diagram explaining capturing CO_2 in fast-growing plants and trees, storing carbon-rich fibres in the form of building materials. Source: Bouwtuin, Naar een Nieuwe Streekarchitectuur.

While implementing an alternative farming method, the first question that arises is the amount of economic yield. Permaculture promotes a more holistic definition of yield. The proposal aims at obtaining sufficient yield to provide humans with food, energy, and raw materials for building. This is accomplished by diversifying the yields by cultivating annual field crops, shrubs and perennial trees in a loop. An important approach is to use the yields in the most effective way that satisfies the demands of survival and tends to prevail over alternatives. This not only generates immediate economic yields but also ecological and social yields by maintaining high efficiency in terms of energy consumption and resources (Holmgren, 2011). Success in obtaining yields will result in long-term rewards that encourage growth and replication of the practice. Additionally, immediate yields from annual crops will contribute to construction using biobased materials, acting as a carbon sink, contributing to net cooling impacts.

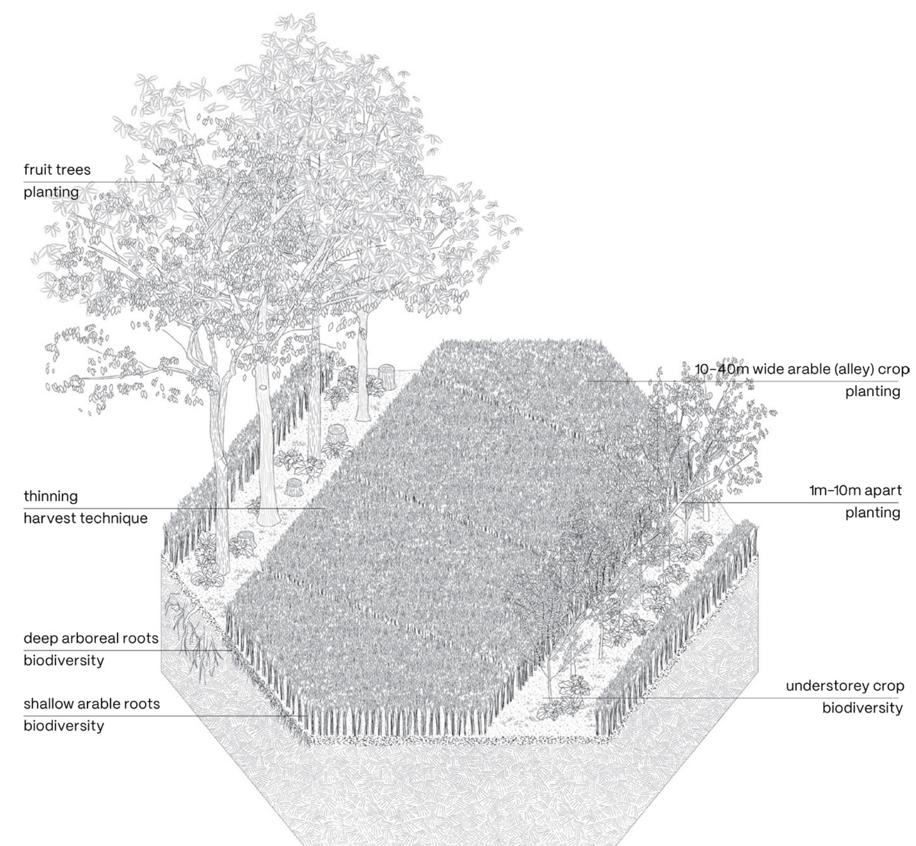

Fig 40 – Edited by author, Schematic diagram of Agroforestry: Enhancing biodiversity while diversifying income from land. Source: Mosaic landscape – Material Cultures.

The current farming practice heavily relies on chemicals throughout the chain, from cultivation to harvest and post-harvest processes. Similarly, in producing conventional building materials chemicals and harmful additives are used (Bocco Guarneri, 2020). Both systems are heavily dependent on energy. In the era of energy descent, a system that is as much as possible self-reliant will be more resilient against disturbance (Holmgren, 2011). Advocating strip cultivation, reintroducing flower-rich habitats, and creating plant guilds and animal associations could promote the development of a harmonious, self-regulating system. This will enhance natural pest control, pollination, nutrient cycling and water regulation. An increase in the yield of wheat by 10% was observed in Switzerland by introducing perennial species-rich wildflower strips, exemplifying a classic permaculture strategy principle (Tschumi et al., 2016). Similarly, the use of biobased materials sourced locally from agricultural waste or byproducts might have positive effects on the regulation of indoor temperature and humidity levels, and the carbon storage without extensive embodied energy, returning nutrients to the soil at the end of their life cycle.

Furthermore, the proposal aims to maximise the use of renewable resources without exhausting them. This is done by introducing agroforestry, cultivation of nitrogen-fixing plants (legumes), fertilisation with animal manure, construction with locally produced biobased and natural materials, production of energy from wind and sun, and water channelling. Shade provided by trees may create comfortable outdoors for chickens and pigs to roam around the barns where they are now relegated. This works and fertilises the soil, minimising the use of tractors and rotary hoes and spreading manure increasing soil organic carbon. Solar energy and animal manure used in the growth of legumes helps in the fixation of nitrogen and has proven higher yield resilience to drought stress (Pimentel et al., 2005). Additionally, agricultural waste used as building materials, timber used as structural material, and clay and lime finishings contribute to low embodied energy and neutral or negative embodied carbon.

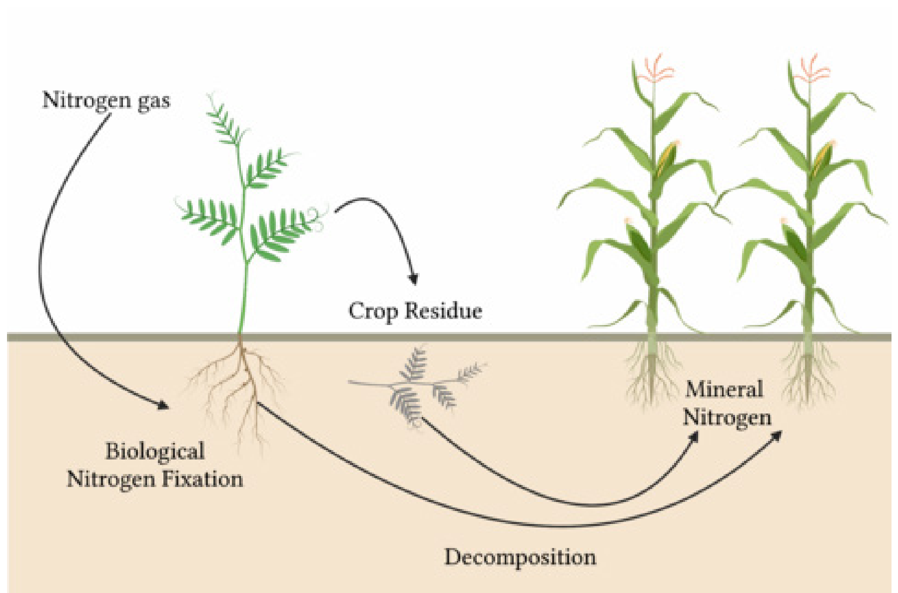

Fig 41 – The process of biological nitrogen fixation in a legume-based cropping system. Source: Inoculating Garden Legumes, University of Minnesota.

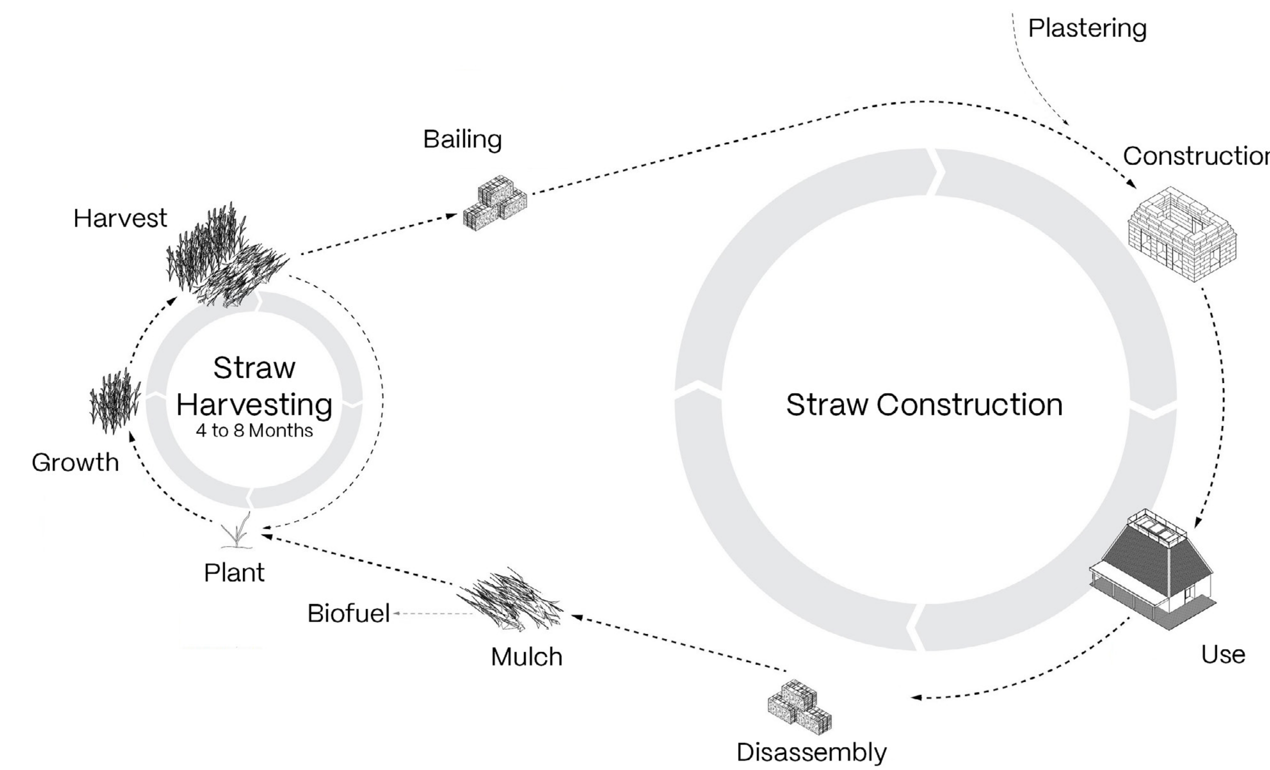

Fig 42 – Edited by author, Schematic diagram of the Cradle-to-Grave lifecycle using annually harvested straw. Source: Manual of Biogenic House Sections, LTL Architects.

The philosophy of mimicking the natural pattern and its ability to exchange and cycle matter and energy (Holmgren, 2011) is translated into seeing **waste** as a primary resource and replacing the linear model with a circular model. Integrating plant guilds and animal associations instead of segregating them (as in industrial agriculture) can reduce environmental problems, like eutrophication of ground and fresh water, heavy metal accumulation in topsoil, and emission of greenhouse gases (Jongbloed & Lenis, 1998). Using agricultural residues as main building materials, which would otherwise end up in landfills or incinerators and immediately release sequestered carbon would instead act as carbon sinks and reduce pressure on manufacturing toxic conventional materials. They would return nutrients to the soil at the end of their life cycle (potentially after reuse), thereby attaining circular model. Moreover, biobased materials can be biodegraded (Fischer & Korjenic, 2023).

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Fig 43 – The no-dig vegetable garden at Bodemzicht. Source: Bodemzicht

Permaculture's initial inspiration to develop a design model for agriculture started with analysing the dynamic pattern of forests and the relationships between various species, their response to the changing weather and the formation of a living, creative self-regulating whole. **Designing from pattern to detail** is described as "natural ecosystem mimicry" in the scientific literature (Krebs & Bach, 2018) and aims at increasing productivity by simultaneously maintaining the natural structure. The introduction of agroforestry with perennial species would initiate a pattern of amplifying diversity and complexity. Similarly, the hygroscopic behaviour of biobased materials may be taken advantage of, to regulate indoor moisture and temperature, thereby creating a healthy indoor environment.

The most important permaculture principle emphasises the **building of mutually beneficial and symbiotic relationships.** This resonates with the foundation of Kumiki's philosophy: integrate rather than segregate. Integration may take place on multiple levels and in various ways. The integration of agriculture with nature and living involves careful placement of plantations, earthworks, and animals in a thriving environment that would minimise human input and create self-regulating ecosystems. In addition to the annual harvest of root vegetables, cereals, berries and other crops, incorporating cover crops, adding mulch, wildflower strips, leguminous plants, perennial agroforestry, complemented by manure from poultry, pollination by bees, controlled livestock grazing would increase productivity and stability of the agroecosystem generating synergic effects. Each element in the agroecosystem would perform multiple functions and each function would be backed by many elements. The mutual biological interaction between subsystems has been proven to decrease dependence on external inputs and increase efficiency while maintaining good environmental performance and enhancing resilience (Bonaudo et al., 2014). Similarly, the Kumiki Model House proposal involves the participation of various actors who contribute their expertise and add appropriate elements in the right places with the help of the community. These components may further develop relationships that support one another.

Fig 44 – Community-built Workshop Eco-house building with straw bales, Friesland. Source: mas con menos (making more with less).

In addition, the proposal intends to exhibit the potential of small-scale farming. Managing small-scale farms avoids introducing technologically advanced, energy-intensive machines that require segregation and monoculture farming due to their limited workability. Research investigating an inverse productivity size relationship in Europe, Latin America, Asia, and Africa concludes that smaller farms are more productive per area (Krebs & Bach,

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2018). Most of the current problems are due to frequent cultivation and harvest cycles, which provide instant economic profitability but, in the long run, lead to productivity and profitability reduction. In contrast, small-scale and slow-developing agroforestry offers more than just immediate economic benefits. A well-managed ecosystem helps control erosion, mitigate climate change, enhance biodiversity, and maintain soil fertility with more productivity in the long run (Schoeneberger et al., 2012).

The materials sources for the construction of the Kumiki Model House are mostly from local small-scale chains with minimal processing, boosting the local economy and community, embracing natural and biobased materials from the region.

Smaller farms lead to a higher amount of field edges where wild species thrive adding greater biodiversity. This greater biodiversity enhances productivity by providing crop pollinators and pest predators (Marshall & Moonen, 2002). Furthermore, these margins contribute to the landscape of the countryside and act as a transitional element between human settlements and farming areas. Crops like hemp and perennial miscanthus are suitable for growing as buffer strips (Delphy ism Rusthoeve, 2024). These fibre crops can be used to produce building insulation materials.
Permaculture's '**Use and Value Diversity**' principle asserts that diversity enhances ecosystems' adaptability and stability (Holmgren, 2011). In contrast, current monoculture farms depend on toxic chemicals and energy to control pests and diseases. The introduction of agroforestry and agroecosystems brings diversity through different ages, species, varieties, and genetics, which is widely recognised for reducing vulnerability to pests, adverse changes, and market fluctuations. This diversity extends beyond the cultivation of various systems within a site to include different living and built structures. Production synergies benefit not only labour productivity but also soil quality, pollination, carbon sequestration, water-holding capacity, energy efficiency, and resistance and resilience to climate change (Lichtenberg et al., 2017).

Lastly, immediate action on farming issues should include implementing ecological succession by introducing fast-growing nitrogen-fixing trees to enhance soil health, thereby enriching fertility and providing shade and shelter to the slow-growing food forest. The introduction of diversity in the form of ages, species, varieties habitats, genetics and reservoirs like fertile soil, water and biomass forms the pillar of ecological resilience (Folke et al., 2002). Similarly, immediate action in the field of GHG emissions reduction might include the use of fast-growing biobased materials for construction, which will act as carbon sinks. The proposal therefore intends to utilise small section timbers obtained from locally sourced Paulownia trees due to their fast growth and annually harvested wheat straw and flax for thermal insulation and lining respectively.

There are many ways to practice sustainable farming, such as agroecological farming, fertility farming, organic farming, and others. These methods often overlap in their techniques and principles. Additionally, farmers have the knowledge needed to reverse the degradation caused by current land use practices. What sets permaculture farming apart is its distinctive approach, which is guided by specific principles for designing, implementing, and maintaining resilient agroecological systems. This enables us to cope with climatic changes, implement small and slow solutions and design from patterns to details (Krebs & Bach, 2018). This also suggests that in comparison to conventional farming which produces higher yields with heavy use of chemicals and monoculture produce permaculture farming would not lead to comparable yields in the short term. Another important consideration when introducing permaculture farming is the need to apply all its principles in a coordinated and interconnected manner. This can be challenging because the principles are often generic and intended to apply globally, lacking an iterative process or adaptation to changing contexts (Andy, 2024). Examples of successful applications of all permaculture principles are still rare, but a recent case in France demonstrates that it is possible to achieve sufficient yields and sustain a livelihood from agriculture on just 0.1 hectares, with relatively low input (e.g., no motorisation) (Morel et al., 2015).

Conceptual Framework

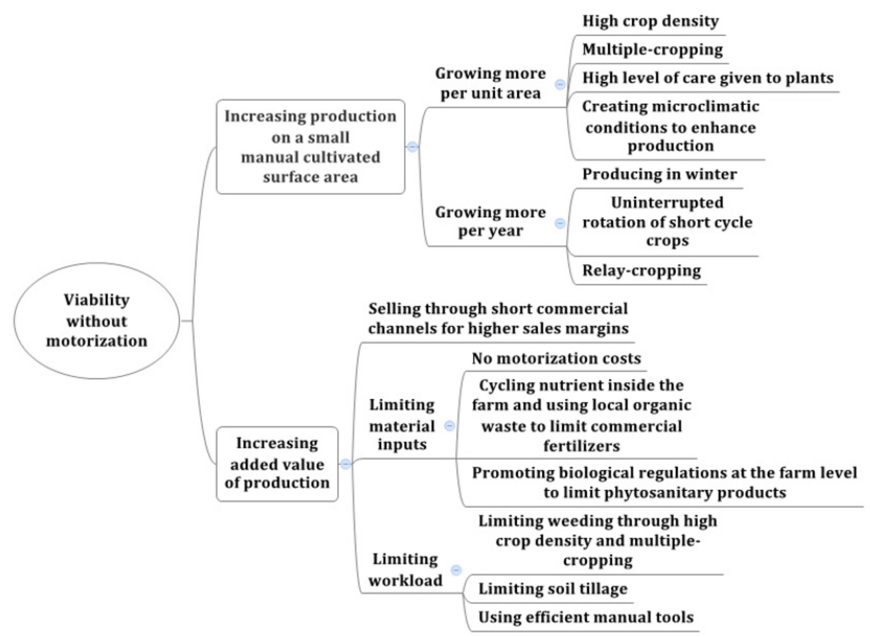


Fig 45 – Mind map of strategies implemented in a small village of Bec Hellouin, Normandy, France. Source: Can an organic market garden without motorization be viable through holistic thinking? The case of a permaculture farm. https://hal.science/hal-01178832v1/file/Morel_et_al_2015_viability_organic_market_garden_without_motorization.p

The farm's restoration in the allocated site by the Municipality of Noordoostpolder will be undertaken by applied biology students, volunteers, and environmentalists, working alongside a farmer. This collaborative revitalisation effort will raise awareness of urgent issues related to agricultural transition and ecology. The proposal aims to utilise Permaculture design principles to cultivate a diverse range of plants, including annuals, shrubs, semi-wildflowers, herbaceous perennials, cover crops, and both fast-growing and orchard trees, following the natural process of ecological succession. This approach involves interplanting semi-wildflowers, perennials, and cover crops within wide strips of food and fibre crops. This method breaks away from the traditional, rigid monoculture pattern, instead creating more diversity and "margins" in the field.

Although the area designated for this project is small, the proposal seeks to demonstrate how minor adjustments in farm planning can encourage sustainable farming practices. Additionally, fieldwork will incorporate controlled traffic farming to improve soil structure and reduce the need for tillage.

This approach will intend to showcase ways to address multi-layered and complex problems by integrating flexibility to induce resilience and deliberately harness natural processes of change to create a more robust and sustainable agroecosystem ensuring long-term agricultural viability. The Kumiki Model house, by providing shelter, is meant to strengthen the vital connection between humans, nature, and the agricultural environment.

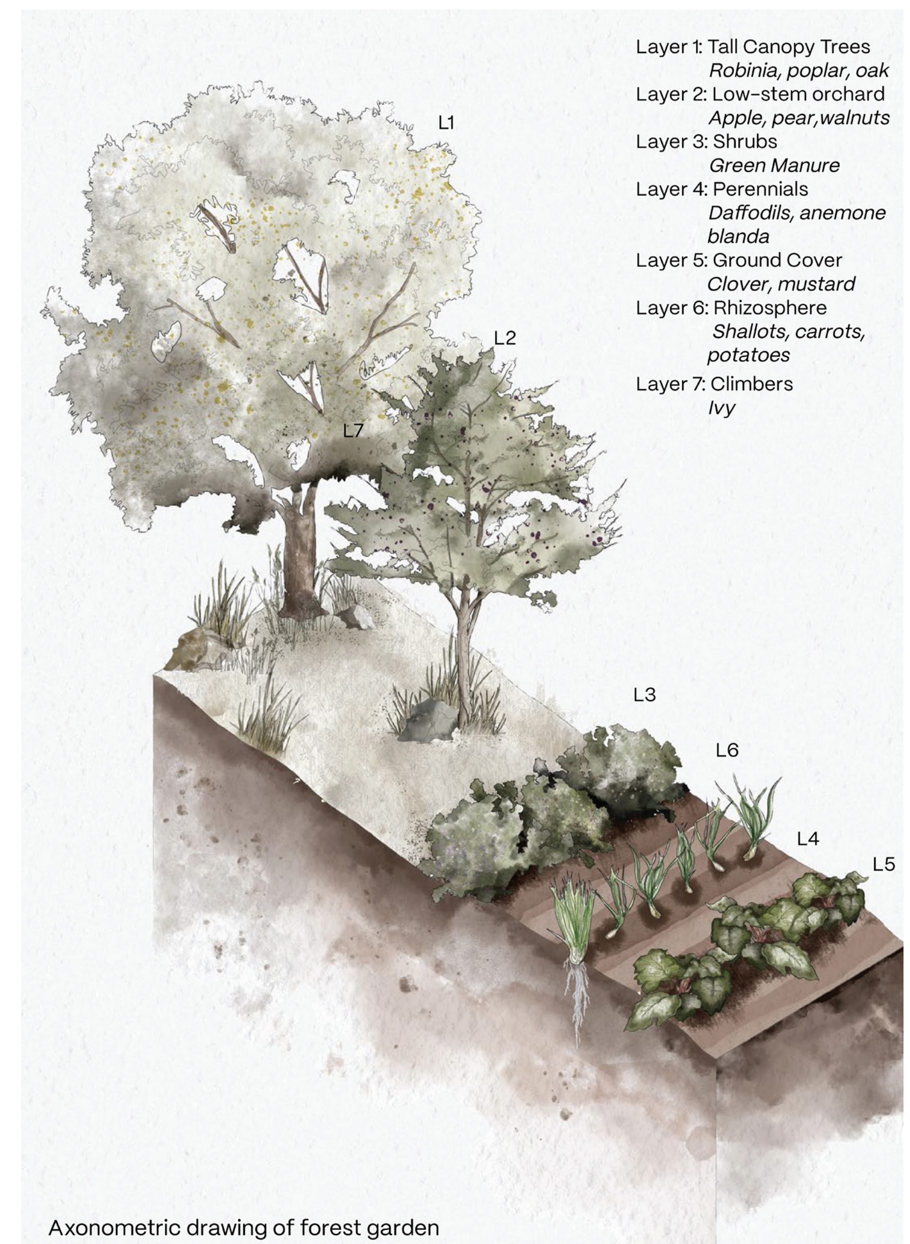


Fig 46 – Edited by author, the seven layers of a food forest, featuring species that thrive in the arable soil of the Noordoostpolder. Source: Constructive Land – Material Cultures.

Conceptual Framework

Permaculture – Collage
Agriculture and Living in Noordoostpolder

The Kumiki Model House's Approach to Building Techniques and Bio-Based Materials

The Noordoostpolder is characterised by villages and towns surrounded by farms. This young polder consists mainly of mineral-rich marine clay. With a great diversity of fertile soil within a relatively small area, the region is an ideal environment for developing regional construction methods and building strategies based on circularity and craftsmanship.

Before the Industrial Revolution and the advent of patented building products and systems, building a home was often a local affair, with craftsmen from the region working together within an open network of knowledge and skills. Expertise in the application of local materials — such as earth (brick), wood, and fibres (reed) — was passed down through generations, with building skills usually acquired through hands-on practice.

Paul Oliver defines vernacular architecture as encompassing "the dwellings and all other buildings of the people. Related to their environmental contexts and available resources, they are customarily owner- and community-built, utilising traditional technologies. All forms of vernacular architecture are built to meet specific needs, accommodating the values, economies, and ways of living of the cultures that produce them" (Oliver, 1997).

Much of the regional knowledge and expertise has been lost due to the globalisation of the construction industry and the introduction of innovative, mass-produced, and therefore often cheaper materials such as concrete, rock wool, steel and many others. These modern, globally sourced materials often negatively impact the environment due to the substantial amounts of energy needed for production and transportation, as well as the ecological damage caused by mining raw materials and depleting resources. Despite recent technological advancements, the building trade has done little to reduce its consumption of the Earth's resources (Davidson, 2015). Additionally, as the global population continues to grow, the per capita fair share of the services and resources provided by ecosystems diminishes, further straining the environment (Vale & Vale, 2013).

The principles of the Kumiki model house are inspired by the Permaculture principles advocated by Bill Mollison and David Holmgren (*Permaculture. Principles & Pathways Beyond Sustainability*, 2011), as well as the theoretical concepts of "Vegetarian architecture" promoted by Andrea Bocco Guarneri (*Vegetarian Architecture: Case Studies on Building and Nature*, 2022) and the "vernacular architecture of the 21st century" (Bocco Guarneri & Habert, 2024).

The Kumiki Model House aims to demonstrate these concepts by using regionally produced, locally available natural and bio-based materials and employing exemplary construction techniques. Furthermore, the proposal seeks to minimise high-tech components, using them only when necessary to enhance overall performance. This approach reflects Peter Harper's concept of "low carbon + industrial vitamin" (Harper, 2012).

The Kumiki model leverages fast-growing, locally sourced, biodiverse, biobased materials such as straw, flax, paulownia wood, willow, and black locust and Douglas. These materials enable the model house to sequester substantial amounts of biogenic CO_2, resulting in a carbon-negative footprint. Additionally, natural materials like clay, and compressed earth blocks are used. Biobased materials sourced with the help of the Building Balance organisation are mainly based on a reasonably established chain. Further, the selection of these materials prioritises the existing skillsets known by the contractors in the construction industry.

Norway spruce used for composite timber pile foundations will be sourced from Germany, as the current production forests in the Netherlands do not include Norway spruce. This highlights the need for planting more trees specifically for construction purposes, ensuring that the right trees are planted for specific functions. Lastly, the use of high-tech components, such as triple-glazing windows with timber framing, along with EPDM sheets, metal flashings, and gutters, is essential in maintaining the performance and longevity of the other bio-based materials. The roofing corrugated aluminium sheets will be reclaimed from nearby barns.

Material Investigation and Application Framework

Reviving Tradition: Exploring the Possibility of Composite Wooden Pile Foundations

The Noordoostpolder consists mainly of mineral-rich marine clay with a peat substrate as subsoil. Due to the weak load-carrying capacity of the top and subsoil, pile foundations are used to bypass these layers and transfer the load to the bearing ground located at a greater depth below the surface (Well-behaved Piles, 2022).

The current Dutch built environment heavily relies on concrete piles due to their ease of installation, structural reliability, and durability. However, this choice of substructure comes with significant environmental issues such as high GHG emissions, ecological impacts concerning soil, and loss of soil organic matter. Thiel et al. (2013) highlighted that materials such as concrete and structural steel contribute substantially to the environmental footprint of buildings, in the context of net-zero energy structures. Further, foundations, structural components, and electrical equipment were identified as major contributors to environmental impacts (Hoxha et al., 2017).

For instance, in the Ugakei Circles Centre House, despite incorporating carbon-negative biogenic materials in the superstructure like timber frame systems for walls and roof, timber floor systems, timber cladding on the façade and tea bark shingles for the roof, the reinforced concrete strip foundation alone accounted for a staggering 66% of the building's carbon emissions (Erik, M., 2023). This underscores the critical impact that the choice of materials and systems for the substructure can have on the overall embodied carbon of a building, even when sustainable choices are made for the superstructure.

For centuries, wooden piles have been used to support buildings constructed on unstable soil in Europe and many other parts of the world (Klaassen, R. K., & Creemers, J. G., 2012). However, after World War II, there was a decline in the use of wooden piles and an increase in the use of concrete piles. This shift was due to various problems associated with wooden piles, such as decay underwater, excessively low groundwater tables, and the inability to support high loads. On the contrary, millions of wooden foundation piles are still in service, carrying a diverse scale of buildings and infrastructures (Klaassen et al., 2012). Archaeologists have discovered holes in the sandy soil where wooden piles had been installed (Klaassen et al., 2023). This suggests that the

Fig 48 – Edited by author, Ugakei Circles Centre House. Source – Structural engineers declare summit 2023. https://www.youtube.com/watch?v=AkYNRpi8EoE

timber structures may have outlived the expected lifecycle of the buildings they supported. In the Netherlands, a significant portion of the built environment stands on wooden foundation piles that are still in service, supporting a diverse range of buildings and infrastructures (Klaassen et al., 2023).

Further, prominent topics emphasising sustainability in the built environment to solve the climate crisis include achieving carbon neutrality, utilising renewable materials, implementing low operational energy housing concepts, and adopting cradle-to-cradle design principles are being actively researched and developed through substantial investments in technology-based solutions. However, these solutions are not feasible for mass implementation as the required tools, equipment and skills come at high costs (Allwood, 2018). In the Kumiki model house, one of the key principles is to explore and embrace the potential of biogenic materials. The use of wooden piles fits perfectly with the principles, the context, and the intention of returning to a traditional building culture. Advocacy of wooden piles will provide a significant carbon sink and revive the importance of planting trees locally to produce piles.

More commonly, to secure the longevity of wooden piles, the upper level of the groundwater table is made with concrete (Kiwa N.V., & Kiwa, C. V. D. C. B. 2008). This restricts the reusability and recyclability of the substructure and has environmental impacts. An alternative approach is to use composite timber piles (fig 49), treating the top part above the groundwater level with various preservatives to avoid or reduce the wood's degradation (Shrestha et al., 2021). The choice of timber for a composite timber pile foundation is based on its suitability, inherent properties, local availability, size, and natural resistance to rot or degradation. Spruce is chosen as the wooden pile submerged under water in a saturated, anoxic environment due to its sapwood's low permeability, which makes it less susceptible to bacterial decay (Sellin, A.,1996). This will ensure decay at a much slower rate and thereby increase the element's life.

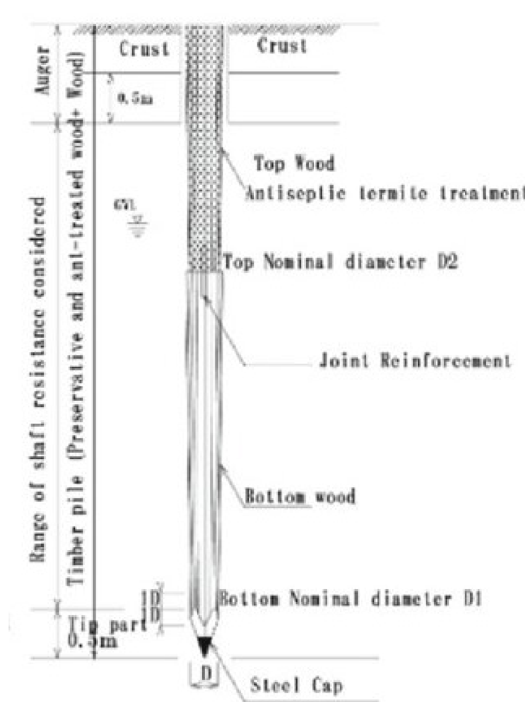


Fig 49 – Schematic of Jointed-timber with treated timber as a cap. Source – Bearing Capacity Determination of Jointed-Timber Piles in the Saga Lowland, 2021. https://doi.org/10.1007/978-981-16-0077-7_46

The top part of the pile is critical because the unsaturated environment exposes it to oxygen and fluctuating moisture levels. These conditions create an optimal environment for fungal and microbial activity, which accelerates the decay rate. Modification is necessary for the longevity. The choice of robinia pseudoacacia, a medium-sized, fast-growing native species from North America but notorious for its invasive growth also in Europe (Sitzia et al., 2016), is being considered for use as the wooden pile above the groundwater table. This selection is influenced by its high density and its classification as the only European wood species with a durability class of 1–2 (in accordance with DIN EN 350-2) (Fraunhofer Institute for Wood Research, Wilhelm-Klauditz-Institut WKI, 2022). The natural durability of robinia, without any alteration, makes it a popular choice for outdoor areas. Its resistance to pests, even without biocide treatment, is remarkable—unlike spruce, which requires treatment. However, slight modifications are necessary to use robinia as a structural element in unsaturated environments. Beyond its physical and mechanical properties, robinia's high CO_2 storage capacity, ability to thrive in diverse soil types (including sandy or nutrient-poor soils), relatively short harvesting time (30-40 years), and nitrogen-fixing capability align perfectly with the philosophy of the Kumiki model house.

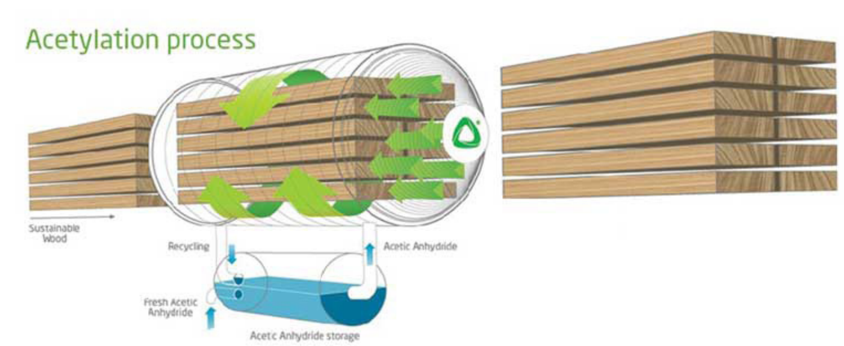


Fig 50 – Acetylation process. Source – Accoya. https://www.youtube.com/watch?v=4OWEkUMW9tU.

Acetylation of wood modifies the wood to the extent that it does not absorb water and resist fungi growth, allowing it to be used in partly submerged conditions due to the hydrophobic treatment (Accoya, 2016). The modification introduces acetyl, already present in small quantities in all the wood species (Hill, 2006), ensuring no toxins are added to the environment. Acetylation will improve the properties of robinia, which is already durable and resistant to decay, but Industrial-scale acetylation processing is not yet performed with robinia.

Another potential method involves the lamination of robinia bonded with adhesives. Small sections of treated robinia are joined together. Research carried out by the Fraunhofer Institute for Wood Research advocates the use of recycled carbon-fiber-reinforced plastics instead of chemical adhesives. This allows for better opportunities for reuse and recycling at the end-of-life phase by melting the inducted coating of electric conductive recyclate (Fraunhofer Institute for Wood Research, Wilhelm-Klauditz-Institut WKI, 2022).

Fig 51 – Robinia wood as highly resistant glued laminated timber. Source – Fraunhofer Institute for Wood Research, Wilhelm-Klauditz-Institut WKI, 2022. https://www.wki.fraunhofer.de/en/research-projects/2022/ROBINIA_glued-laminated-timber-made-from-robinia.html

Fig 52 – Surface structuring by means of lasers improves the bonding of the boards. Source – Fraunhofer Institute for Wood Research, Wilhelm-Klauditz-Institut WKI, 2022. https://www.wki.fraunhofer.de/en/research-projects/2022/ROBINIA_glued-laminated-timber-made-from-robinia.html

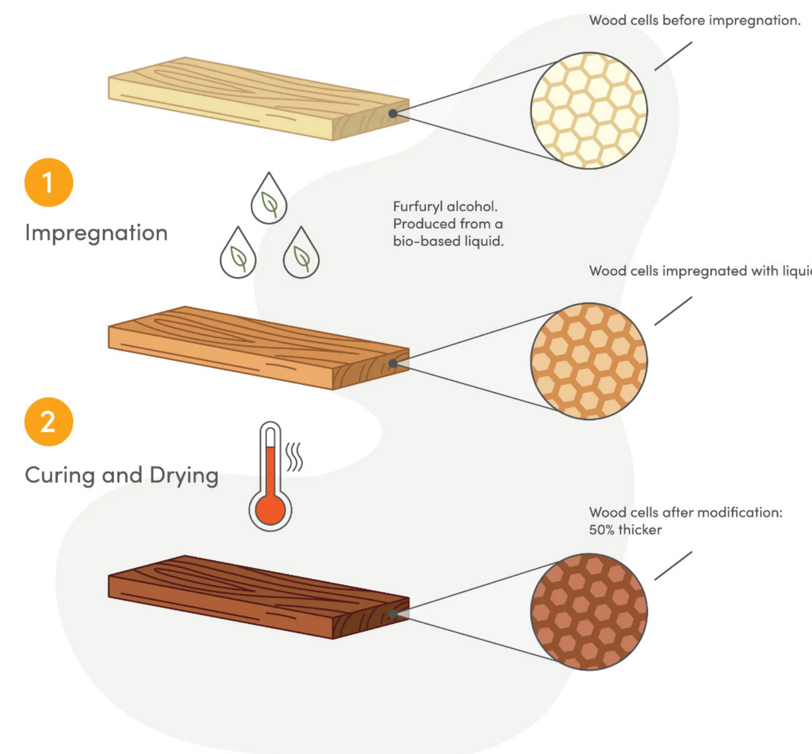


Fig 53 – Process of Impregnation of wood. Source – Kebony. https://kebony.com/technology/the-dually-modified-process/

Impregnating the wood with chemicals that diffuse into the cell or lumen can also be considered as a potential modification method. It is a passive strategy where modification is achieved without altering the chemical nature of the material (Hill, 2006). The wood cells are bulked by the impregnant, thereby reducing the permeability of timber, making it suitable for use in unsaturated environments. Kebony, a Nordic company, with a processing unit also in Belgium is using a patented and proprietary modification process called furfurylation (Kebony Norge AS, 2024). This process uses a biobased solution called furfuryl alcohol, derived from agricultural plant waste such as sugar cane, corn cobs, sunflower, and birch chips (Ramage et al., 2017).

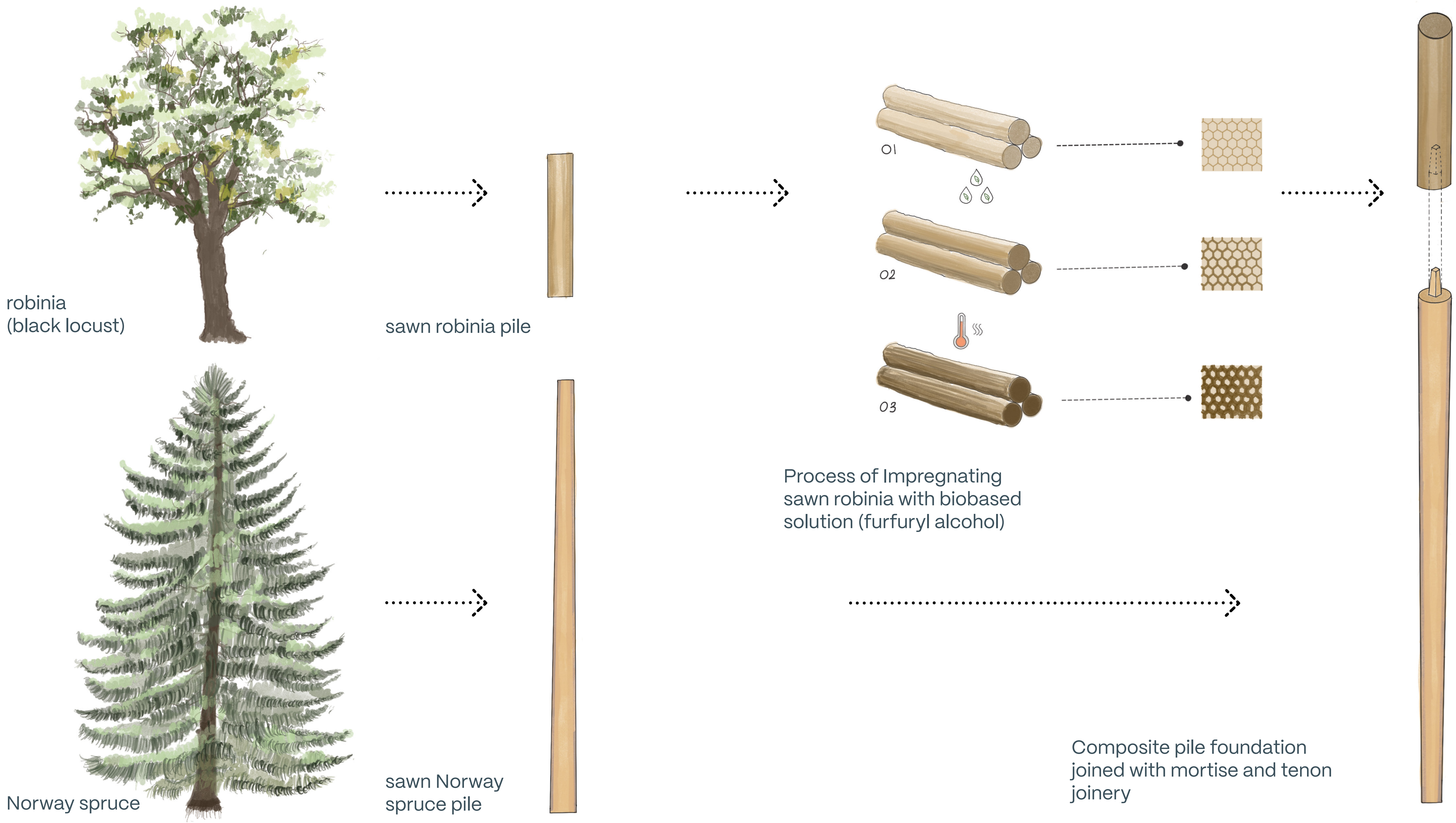
In this dual modification, the biobased liquid solution actively reacts with the timber's OH- groups and later forms a polymer (passive modification), reinforcing the wood. After curing and drying, the timber exhibits high dimensional stability and good resistance to rotting and insect attack. Additionally, an increase in the modulus of rupture and modulus of elasticity is achieved (Lande, Westin, & Schneider, 2008). The use of a biobased liquid solution ensures that the product is non-toxic during use and at the end of life. The current industrial-scale process of impregnating timber by Kebony comes with a 30-year warranty. The application is restricted to cladding and decking and is not yet performed with robinia.

The aforementioned modification methods are either in the experimental phase or not performed with robinia and come with a limited warranty. Biobased materials are prone to degradation and modification will only prolong the process of degradation. The modified robinia might last longer based on its properties but there are no tests available. The proposal aims to test biobased impregnation methods to prolong the durability of robinia wood, as these methods do not involve added chemicals or glues.

The last step after sourcing both the timber parts is the connection and installation. Timber joinery (mortise and tenon) is used to connect both parts to create a fully biobased element. For installation, the Norway spruce pile will be rammed into the ground and robinia will be joined after. Attention should be given to the fact that timber pile foundations cannot withstand high loads in comparison to concrete or steel piles, so they are suitable if the superstructure is light. In the case of the Kumiki model house since the superstructure is one storey and made primarily from lightweight biobased materials, timber pile foundations can be implemented. Additionally, the model house is raised above the ground, resting on piles with a humble presence in the landscape and minimally impacting its natural setting. This approach leaves few traces for future generations by avoiding the use of non-biobased, conventional, energy-exhaustive materials.

Material Investigation and Application Framework

Proposed Composite Pile Foundations for the Kumiki Model House



Exploring Local Fast-Growing Biobased Materials for The Superstructure

In a Dutch context, the superstructure predominantly comprises three main elements: the load-bearing structure of the building – the skeleton; the envelope; and the lining – the skin.

Structure

The Dutch timber frame tradition is centuries old, which means it is much older than the brick culture for which it is known (Van Tussenbroek, 2017). In the 19th century, timber construction became less popular due to urban fires and stricter fire regulations (Van der Lugt et al., 2023). Wood scarcity also led to a decrease in the use of timber in residential constructions. From the 1970s onwards modern timber frame construction commonly known as HSB method, using thin timber elements coupled with bracing sheets, was introduced in the Netherlands.

Noordoostpolder has limited forests, as they were only planted on soil not suitable for agriculture (Canon the Noordoostpolder 2019). The Kuinderbos, Urkerbos, Voorsterbos and Waterloopbos are all nature reserve forests and are used for recreation activities (*Natuur in De Noordoostpolder*, n.d.).

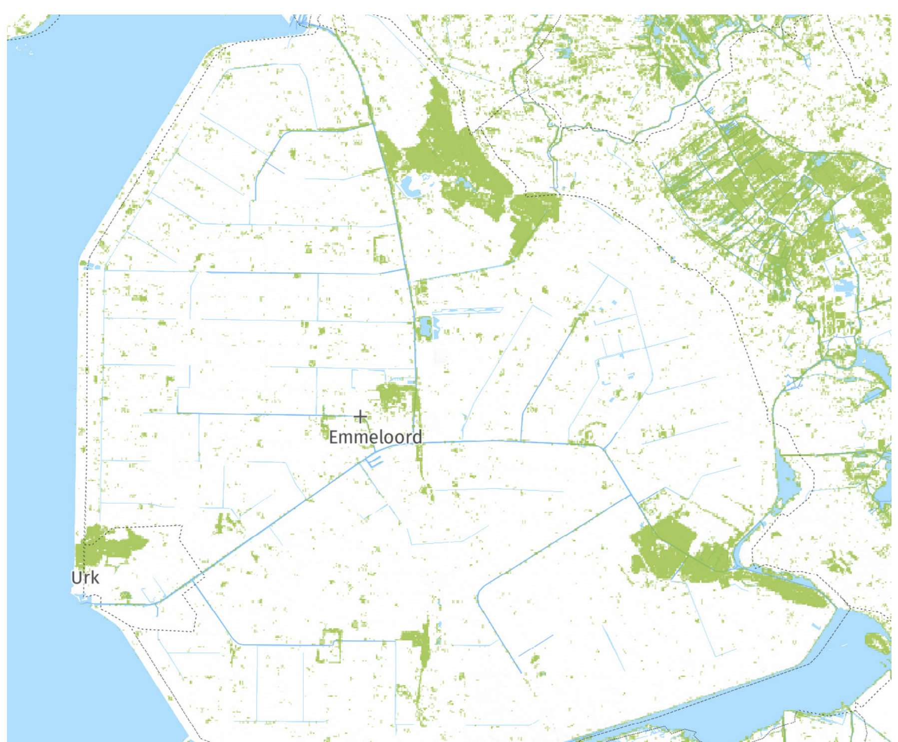


Fig 55 –Map displaying Tree cover with > 30% canopy density in the Noordoostpolder in 2010. Source – Global Forest Watch.

The Schokkerbos was initially planned as a production forest with conifers, ash and oaks (*Het Schokkerbos – Noordoostpolder e.o.*, 2022). Over time, a forest landscape has developed there with natural forest edges of shrubs and herbs, providing habitats for small mammals, birds, and insects. Scarce production forests and the time required for tree growth necessitate the investigation of alternative structural materials in the Noordoostpolder.

Load-bearing straw bale construction, also known as the Nebraska style, consumes less timber and was first developed in the wood-poor state of Nebraska (Drozd et al., 2019). The intensively farmed, reclaimed land of the Noordoostpolder produces a lot of products and by-products. Winter wheat is the most grown grain amongst summer wheat, barley, oats, triticale and rye. In the construction trade, straw is used as an insulation material coupled with structures mostly made from timber. However, straw has much more to offer. Straw bale walls can support roof and floor loads and can resist wind and earthquakes (CASBA, 2007). Load-bearing straw walls are built by placing bales in courses, avoiding the alignment of vertical joints. Stiffness is often gained by incorporating vertical wooden or bamboo rods. In such kind of construction, wood is mainly used for roof members, sills, lintels, window and door frames.

The compression of the straw bales due to the dead load of the above structure is uncertain and there is no calculation method that a structural engineer can use. The current Dutch building regulations don't permit construction without structural calculation. Additionally, this method of construction demands adequate knowledge and experience, which restricts its implementation. Changes in building regulations and the interest of contractors and investors would allow sustainable development with regional materials and boost the local economy and community-built societies.

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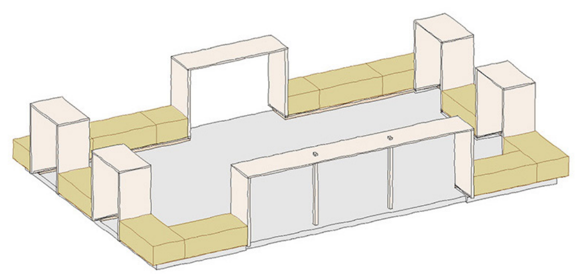

Fig 56 – Load bearing method of building with jumbo straw bales, Source – Chrith architects.

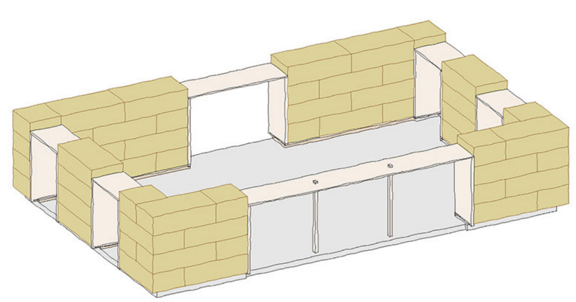

Fig 57 – Straw bales stacked on each other, Source – Chrith architects.

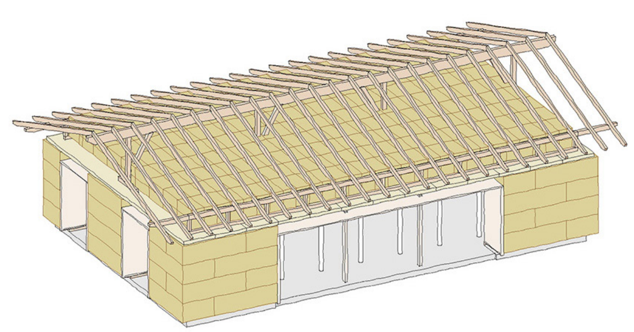

Fig 58 – Roof members exert pressure on the walls thereby stabilising and compressing the straw bales, Source – Chrith architects.

Another alternative material explored is fast-growing timber. Paulownia wood is one of the world's fastest-growing tree species; somebody has termed it "the tree of the future" (Jakubowski, 2022). Native to China, it has rapidly become popular across Australia, Asia, the USA and Europe (Woods, 2008). This umbrella-shaped, low-set crown tree has a grey-brown bark with large leaves (15-30 cm long and 10-20 cm wide) at the initial phase of growth, and smaller in the later phase (Zhu, Chao, Lu, & Xiong, 1986). Paulownia trees have a deep and well-developed root system. Approximately 550-750 trees/ha (Icka, 2016) are planted for roundwood timber production with a 6-10-year cycle. A peculiar quality of this light-yellow heartwood is that it is ring-porous in the core with distinctly visible annual rings around it. The physical and mechanical properties of Paulownia are comparable to that of poplar and willow (Jakubowski, 2022). Its high strength and low density make Paulownia suitable for constructing lightweight yet robust structures (Ayan, Sivacioglu, & Bilir, 2006). The current applications of Paulownia include the production of plywood, engineered wood, carpentry timber, veneers, as well as hand carvings, clogs, furniture, etc.

The proposal intends to utilise small sections obtained from roundwood logs of locally sourced Paulownia timber due to its fast growth. This approach highlights the potential for the construction industry to reduce reliance on mostly imported standardised construction timber, which requires years before harvest. Additionally, Paulownia timber's ability to sequester large amounts of carbon in a short period makes it an interesting contribution to meeting local material demands and carbon emission reduction targets. Furthermore, the thick walls made from biobased material insulation in passive or energy-saving buildings are advantageously coupled with timber I-beams made of small sections (Lokaj & Klajmonová, 2017).

The Paulownia timber will be sourced from a sustainable production forest managed by Dealin.green, located 9 km from the site. Johan Voragen, a Paulownia grower and member of Dealin.green, is a farmer based in the Noordoostpolder and aims to bring pleasure back into the agricultural business by bringing farmers back into contact with nature.

Fig 59 – One year of growth in the Paulownia plantation in Tönisvorst. Source – Henk Lok.

Fig 60 –Paulownia plantation in the Netherlands. Source – Dealin.Green.

Fig 61 –Paulownia harvested roundwood in Tönisvorst. Source – Henk Lok.

Sawn Paulownia timber is proposed as an I-joist beam structure, roof battens, purlins, and planks to encase the raised floor. Flanges are made using sections of Paulownia timber and the web is formed by OSB boards. While current OSB boards are produced using softwood strands with chemical adhesives, experiments are being conducted with hemp fibres and eco-friendly binding systems to create a structural sheathing board that can replace conventional OSB.

Fig 62 – OSB board made with 94 – 97% hemp fibres and 3 – 6% formaldehyde-free Resin. Source – Plantd Materials. https://www.plantdmaterials.com/product

The implementation of the I-joist beam withstands a comparable load to solid timber beams while using considerably less material. Additionally, lightweight I-joist beams are easy to manoeuvre. I-joist beams as structural skeletons are used in the envelope walls, floor and roof of Kumiki Model House. Solid lumber of size 150 x 150 mm is used as columns where a stud system using I-joist beams isn't required (openings, storage barn). The Width of paulownia boards is limited, necessitating a splice joint to encase straw-insulated raised floor.

Fig 63 (left)-Solid lumber of Paulownia. Source – ipaulownia.

Fig 64 (right) –Solid square lumber of Paulownia with ring-porous in the centre. Source – ipaulownia.

Insulation

Insulation limits the heat transmission through the envelope and can be applied internally, externally or within a cavity wall. Efficient insulation reduces the operational energy of the building. The R-value measures the resistance to heat conduction – the higher the R-value, the better the insulation (Aldawi & Alam, 2016).

Insulation materials come with a complete range of options from bulky packages consisting of rock wool, fibreglass, cellulose, and natural fibres to thin foils and rigid foam boards. Some materials resist conductive heat flow, some trap air or other gases, and some reflect radiant heat away from indoor spaces. Most insulation materials are manufactured with chemicals that negatively impact the environment (European Commission – DG Environment, 2010). Materials like EPS and phenol-formaldehyde (PF-2) emit TVOCs above standard values (Wi et al., 2021). Further investigation is needed into pollutant emissions from building materials that affect indoor air quality.

The embodied impacts of these materials need to be considered, as some have high embodied emissions that contribute to global warming. Hence, the use of most conventional materials for envelope insulation raises the risk of a lock-in situation, where the very measures intended to mitigate climate change may inadvertently contribute to it (Galimshina et al., 2022).

The introduction of 'sustainable', 'regenerative' and 'circular' concepts in the building industry stimulated research into developing thermal and acoustic insulating materials made from natural or recycled materials. Focus on natural fibres in insulation is closely tied to ecological building, where materials are selected prioritising factors such as recyclability, renewability of raw materials, and low-resource production techniques (Kymäläinen, 2008).

Using biobased insulation materials harvested in short cycles promotes sustainable construction that respects planetary boundaries. These materials require minimal processing and provide health benefits throughout the supply chain, from production and application to end users (Vardoulakis et al., 2020). However, as of 2019, the Dutch building sector consumed only 0.1% of resources made from biobased materials, excluding timber (*De Potentie Van Biobased Bouwen*, 2021).

The Dutch government recognises the dual challenges of the housing and climate crises and the lack of a market for biobased materials. In response, the use of biobased materials is being promoted by setting ambitious goals and introducing policies, in close cooperation with local authorities and market partners, including farmers, companies, and research institutions. The primary goal of the 'Nationale Aanpak Biobased Bouwen' (National Approach to Biobased Construction) is to quickly contribute to national objectives related to CO_2 reduction, nitrogen reduction, the circular economy, biodiversity, and spatial quality (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2023).

In 2023, 130,054 ha of land were cultivated with wheat (both summer and winter) in the Netherlands (Centraal Bureau voor de Statistiek, 2024). Straw, a natural fibre source rich in silica is a by-product of cereals such as wheat, rice, barley, rye, etc. (Mehravar et al., 2022). It consists of the plant structure from the crown of the root to the base of the seed head. Noordoostpolder produces an ample straw.

If stored under favourable conditions, it can last for hundreds of years (Sandak et al., 2019). Using by-products as primary materials is always preferable and makes one of the principles of permaculture ('produce no waste'). This minimises the need to produce new materials or cultivate plants solely for building purposes. If stored under favourable conditions, it can last for hundreds of years (Sandak et al., 2019). Using by-products as primary materials is always preferable and makes one of the principles of permaculture ('produce no waste'). This minimises the need to produce new materials or cultivate plants solely for building purposes.

In addition to its local availability, straw has the lowest embodied energy value (Lushnikova, 2016) and in appropriate thicknesses it offers insulation values exceeding most framed wall systems using conventional insulation. Further, thermal resistance can be optimised by density, and orientation of the

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fibres with regard to the heat flow direction (Mehravar et al., 2022). Straw not only keeps the building warm in winter but also cool in summer. In spite of being an insulation material, it has a remarkable heat storage capacity, ensuring a balanced indoor temperature. It stores approximately 60 times more carbon than it emits during the cradle-to-gate phase (CASBA, 2007). Building with straw requires no additives, though small amounts of toxic substances may be present due to the cultivation methods used. This helps keep the indoor air quality healthy as no noxious gasses are released as straw bales age. To avoid excess moisture entering the wall and to protect the straw from ignition, straw bale walls need to be rendered with thick clay plaster or lime plaster. Additional moisture protection in temperate maritime climates (as in the Netherlands) can be provided with roof overhangs and rain screens (Carfrae et al., 2009).

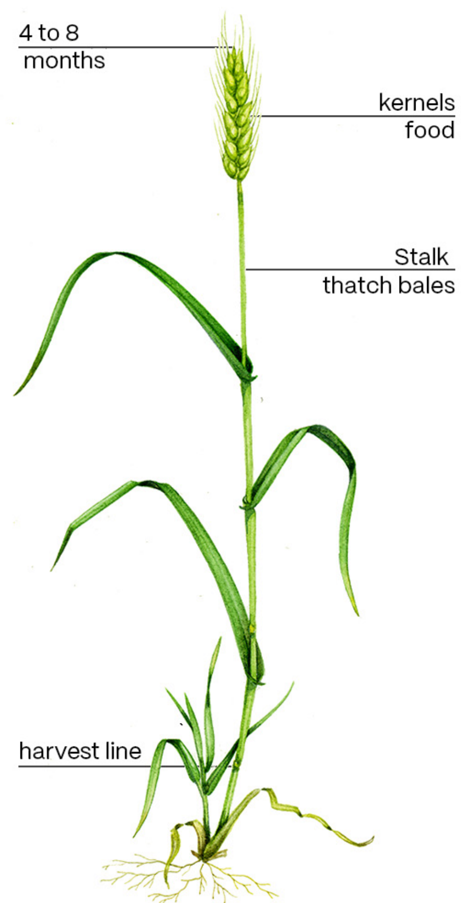

Fig 65 – Edited by author, Schematic diagram of wheat plant, Source – Lizzie Harper

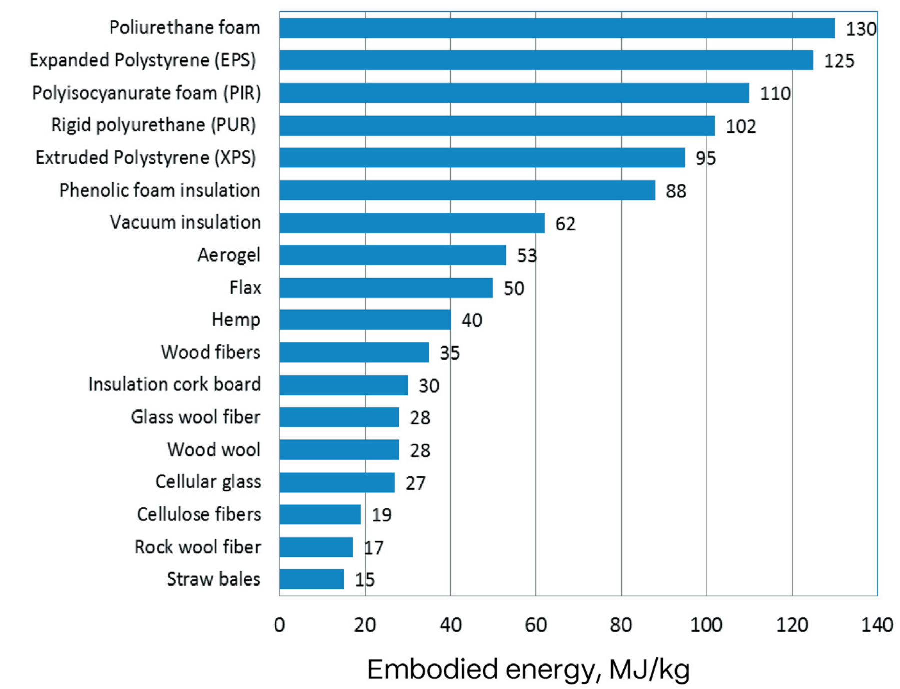

Fig 66 – Embodied energy (from cradle to gate) of insulation materials, based on accumulated data, Source – Approaches to Teaching Building Materials and Technologies for Energy-Efficient Sustainable Construction, Lushnikova, 2016.

Fig 67 – Prefabricated elements for Bombasei, in Nänikon-CH, Source – Atelier Schmidt.

Fig 68 – The first load-bearing straw bale house in Austria with building permission, Source – European Straw Building Association.

The traditional uses of straw include thatch and substrates for plasters. Straw is widely available and is considered an affordable building material. When implemented appropriately and protected from moisture uptake, straw is a durable and insulating material that in the bale form can even take a load-bearing role (Walker et al. 2017). Load-bearing walls may be built with small bales or jumbo bales. Moreover, bales may be used as infill in prefabricated timber panels; and loose straw may be used as blown-in insulation.

For the Kumiki Model House, straw bales will be used as infill because current building regulations rule out any load-bearing role for straw bales, while blow-in insulation and prefabrication involve technology that is unnecessary for the scale of the Kumiki House.

Straw bales for the construction of the Kumiki Model House will be sourced from Loonbedrijf Witkop, an arable farming and contracting company located 19 km from the site. The company intends to transform surplus straw into a high-quality building material. The bale size will be 800x450x360 mm with a 100 kg/m^3 density.

The research also aims at investigating the impact on the soil structure which can play an important role in crop choice and sustainability of cultivation. Cereal harvesting has an impact on

the soil structure which can play an important role in crop choice and sustainability of cultivation. Cereal harvesting has an impact on the soil structure as heavy machines are used. Soil compaction can be reduced if a Controlled Traffic Farming system is used as this method will reduce the need for tillage (De Wolf, 2024). Further, the loss of organic matter by removing straw for building purposes must be compensated. Winter wheat is usually harvested in mid-August and sowing under cover crops such as black radish or yellow mustard (Delphy ism Rusthoeve, 2024) will partly compensate for the removal of straw. The application of manure and biosolids will increase the soil organic matter significantly (Cook. et al. 2013).

Diversity also plays a crucial role in maintaining soil structure. The decline of biodiversity in agriculture is caused by disturbance (disruption of the living conditions of different species), uniformity (monoculture) and scale (intensive farming). Further operations such as ploughing and harvesting, are moments when everything comes to a standstill. Grains allow the possibility of growing other crops, and of mixed cultivation on the same plot (Dawson & Noren, 2019). The current monoculture of genetically identical wheat can be replaced by population wheat or Cross Composite Populations, which will bring diversity to the crop and the field. The genetic diversity within the crops brings resilience and thereby avoids external inputs which are high on chemicals-based fertilisers (*YQ Population Wheat at Wakelyns – Wakelyns*, n.d.).

Fig 69 – Left – Regular wheat showcasing monotony. Right – Population wheat at Wakelyns showing its diversity, Source – Wakelyns. https://wakelyns.co.uk/yq/

Permaculture's 'Use and Value Diversity' principle asserts that diversity enhances ecosystems' adaptability and stability (Holmgren, 2011). This applies to construction materials as well. Moving from petrochemical-derived to biobased insulation materials does not imply switching only to straw. Diversifying the use of biobased materials across different projects helps prevent negative land use competition and loss of biodiversity. Selecting materials based on criteria that align with the ecosystem adds value to local practices and development. Supply chains of biobased materials like hemp and flax exist in the Noordoostpolder. These fibres are also used as insulation materials.

Hemp is a fast-growing annual plant that thrives in various soil types and climates. It is a deep-rooted plant that enhances soil health and does not require pesticides or chemical fertilisers (Stanwix & Sparrow, 2014). Additionally, rapid-growth hemp acts as a weed suppressant and is introduced sometimes to clear the land of chemical-resistant weeds. All these properties in addition to being profitable to obtain a high-value construction material make hemp an ideal rotational crop.

Hemp shiv fibres (woody inner portion of hemp stalk) and lime binder form hempcrete, a non-structural, vapour-permeable insulation material. The air trapped within hemp stalks and the matrix of the hemp shiv make it a good insulating material and the binder adds thermal mass. This enables the storage of heat and its slow release allowing the use of natural ventilation. The cellulose of the stem paired with lime mortar results in a good ability to absorb and release moisture (Stanwix & Sparrow, 2014). The binder also acts as a fire and moisture protection and insect attack inhibitor.

The hemp shiv used for construction purposes should be dry, clean, dust and fine free; the length of the pieces should be between 10 and 25 mm. This results in good thermal performance and vapour permeability. Attention should be given to avoiding dust content as in extreme cases it may lead to the collapse of a structure (Stanwix & Sparrow, 2014). This is because dust soaks up water, leading to binder failure.

There are various ways of building with hempcrete.

Cast-in-situ hempcrete - hempcrete is cast around the structure which is usually made of timber. A formwork is made and the freshly mixed hempcrete is placed and compacted by hand or with a machine.

Hand placing - Hand placing is a labour-intensive process but produces a high-quality finish due to good control. The low-tech and hands-on nature of hand placing is preferred by self-builders and community projects as it is cost-effective (since you don't pay the workers).

Spray-applying - In the spray-applying method, a finer grade of hemp shiv is used. The method calls for an open and accessible framework as the machine cannot reach corners easily.

Fig 70 - Hand placing cast-in-situ hempcrete, Source - Grist. https://grist.org/indigenous/hempcrete-lower-sioux-housing/

Fig 71 - Spray-applying cast-in-situ hempcrete, Source - HempBuild Magazine.

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Precast hempcrete – This method involves the use of hempcrete blocks or panels. The off-site production reduces the on-site construction time. This system is mostly used for large-scale projects. The block method has limitations among which the high ratio of binder to hemp shiv, and a higher embodied energy. This affects the insulation performance but increases the thermal mass (Yadav & Saini, 2022).

Panels – Hempcrete panels comprise of structural framework usually made from timber, a built-in insulation layer and a breathable vapour-control layer. Panels are joined on-site and do not require mortar hence waiting time for setting is avoided. This technique is completely mechanised and even the drying is done by blowing hot or cold air. This results in high embodied energy consumption in comparison to the cast-in-situ technique. Additionally, to achieve airtightness synthetic expanding tapes are used which add up to embodied energy. This technique is implemented for institutional, industrial or multistorey residential projects.

Fig 72 – Flat house in Cambridgeshire made from hempcrete panels. Source – Practice Architecture.

Fig 73 – Hempcrete blocks, Source – HEMPBUILD

Lastly, apart from hempcrete, quilt Insulation made from hemp fibres provides a biobased alternative material to mineral or glass wool products This offers a safer and healthier alternative to conventional materials made from irritants and toxic materials (Stanwix & Sparrow, 2014).

Fig 74 – Industrial hemp non-woven batts being installed as a non-toxic insulation for walls and ceilings, Source – What Is a Hemp House? | LinkedIn

Hemp plantation also impacts soil structure. The emission of greenhouse gases and the environmental impact on water and soil are significantly lower in the cultivation of hemp compared to other crops, while the contribution to the maintenance of healthy agricultural soil is higher. Hemp is very sensitive when it comes to soil structure, waterlogging and soil compaction (Van Den Oever et al., 2023). High level of risk of subsoil compaction observed in the Noordoostpolder might hinder the future growth of hemp.

Further, while hemp can initially thrive on soils rich in phosphorus and potassium, sustainable cultivation practices need to be implemented to prevent soil degradation over time (Visković et al., 2023). Harvesting hemp for material production is carried out with large machines, making cultivation on small areas or field edges practically uninteresting. Only 1,977 ha of land was cultivated in the Netherlands in 2023 (Centraal Bureau voor de Statistiek, 2024). This is due to the unfamiliarity of the crop and the complexity of harvesting and processing (Leendertse et al., 2020). Hemp presents certain issues for biodiversity, such as poor compatibility for mixed cropping and a lack of winter cover (Delphy ism Rusthoeve, 2024). Hemp also does not supply food to pollinators and other species. However, it has the advantage of not requiring insecticides.

Fig 75 – As a rotational crop, Hemp can provide direct biodiversity benefits, improving the soil as well as delivering potential economic benefits, Source – Circular Biobased Construction in the North East and Yorkshire, Material Cultures.

Another locally sourced and produced biobased material that can be used as insulation is reed. Currently, reed isn't cultivated in the Noordoostpolder, but it grows naturally in the surrounding peatlands of Overijssel and Friesland. However, reed is a pioneer species (Köbbing et al., 2013), and in the Noordoostpolder marginal areas with high peat subsidence and oxidation, there is an opportunity to raise the water level. Doing so will not only purify the water and prevent drought and pollution in nature reserves but also create a carbon sink, thereby contributing to the mitigation of climate change (IUCN, 2021).

When the land was reclaimed, the western part of the polder could not be sown immediately. Man-high reeds had grown and had to be removed first (Canon the Noordoostpolder 2019). Only after the thick reed roots had been removed could the seeds be sown. This highlights one of permaculture's principles: 'design from pattern to detail' where natural ecosystem mimicry is advised.

Reed (Phragmites australis) is a grass-like plant found in wetlands, marshes and along river banks. Reed is a tall and slender perennial plant and has been used as a building material for centuries. Its application in the Dutch built environment can be observed as thatch, but most of it is now imported (Vakfederatie Rietdekkers, n.d.). Apart from providing materials, reed plantation increases biodiversity by providing a habitat for dragonflies and aquatic fauna (Miljan, 2013).

Fig 76 – Common reed Phragmites australis, Source – Lizzie Harper.

Reed fibre stems have minimal mass due to their hollow form and gain strength from nodes (Fraanje, 1997). Additionally, the smooth texture of the reed's stem makes it resistant to water. If left unmanaged, the reed dead litter may dry out the beds. Therefore, reed demands regular management, and the harvesting is mostly done manually with the help of a sickle or scythe. The selection and sorting of the harvested reed is a labour-intensive process and hence local production is limited in the Netherlands. Even if machines are used for harvesting, the subsequent process still requires hand sorting.

Thatching with reed was once a primary roofing technique in Northern Europe. Thatch roofs made from reed can last 50-100 years, but their durability has now greatly reduced due to the presence of chemical fertilizers (Berge, 2015). Thatch roofing was discontinued because of the reed's high silica content. While the silica content contributed to increased durability and structural flexibility, it also posed a significant fire hazard (Almusaed & Almssad, 2015). Recently, thatched constructions have addressed fire hazards by clay impregnation, the addition of membranes, and the employment of less-burnable materials like straw. The application of reed as a structural material is restricted due to its low mechanical strength and easy combustion. Exceptions could be found in Iraq (Al-Tahla Floating Islands) and the floating islands of the Uros in Peru, as the species there are taller and bigger, with properties similar to bamboo (Watson, 2019). However, reed is still used in non-structural applications such as infills, and exterior and interior finishes.

Reed is tied with iron or nylon wires in the form of panels often employed as an insulation material. The thermal conductivity of a reed panel is between 0.045 and 0.056 W/mK, the density varies from 130 to 190 kg/m^3 and the specific heat reaches a maximum value of 1200 J/kgK (Asdrubali et al., 2015). Appropriate design of the orientation and thickness of reed stems allowed to produce panels which exhibited good acoustic properties. The good acoustic and thermal performance is mainly due to hollow spaces and air layers between reed stems. The panels are layered to achieve the desired insulation value. The addition of a breathable coat on both sides is necessary, as for other biobased materials.

Fig 77 – Wire bound reed panel manufactured by Hiss Reet. Source – Wetlands and Construction: An opportunity for Berlin-Brandenburg, Materials Cultures.

Cultivating common reed in marginal lands results in the emission of methane into the atmosphere (Brix, 1999). These emissions are higher when the water table is lowered, leading to the oxidation of methane, which contributes to the release of a global warming-causing gas. However, when considering the overall environmental performance, the ability of common reed to trap carbon dioxide and remove heavy metals (Ni, Cd, Cu, and Pb) (Srivastava et al., 2013) from the soil helps restore the quality of environmental matrices.

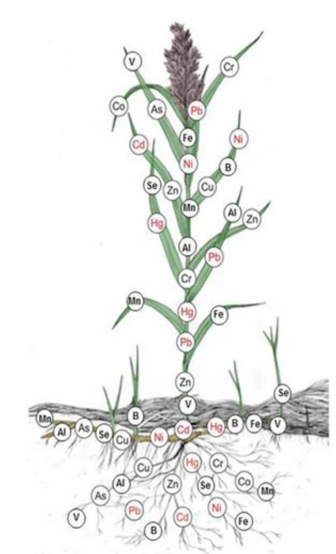

Fig 78 – Arrangement of heavy metals in various parts of P. australis. Source – The importance of biological and ecological properties of Phragmites Australis (Cav.) Trin. ex Steud., in Phytoremendiation of Aquatic Ecosystems.

Lining

Sheathing, lining boards and plasters form an important element of floor, wall or roof build-ups.

The conventional boards used are plasterboard, oriented strand board (OSB), and softwood sarking boards. While lining boards are usually placed on the inside of a wall build-up, they don't play a structural role. They can either act as a render-carrying board, where skim plastering is added or serve as a wall finish. Gypsum plasterboard is made from finite mineral resources and is energy-intensive to recycle (*Plasterboard Recycling – Roy Hatfield*, n.d.). Additionally, they don't allow moisture to escape which is critical for indoor air quality. OSB boards are produced using softwood strands bound together with chemical adhesives and there is limited regional production of softwood sarking boards. Hence, the proposal aims to investigate the potential of fast-growing fibre used to produce lining boards as an alternative to conventional boards.

The proposal will experiment with using flax panels made by a farmer named Bas Bouma. He is a co-owner and cultivator at Linum Nagele (8.2 Km from the site) and is keen on utilising woody particles (lemen/flax loams) that are released during the processing of flax fibres. The residual flax shives do not further require chipping operation. They are sheet-pressed in addition to biobased resin. A similar process is already carried out by the COMPOST BOARD based in Liessel, Netherlands. They use a mixture of hemp, flax and paprika plant fibres. These boards are 100 per cent recyclable and biodegradable. They are breathable and fire-resistant.

Fig 79 – Compost board panels made from agricultural residual fibres. Source – COMPOST BOARD, Rikaalsmeer. https://www.compostboard.bio/services/

Fig 80 – Raw materials produced from flax. A seminar given by Bas Bouma in his flax fields.

The boards will be used as roof linings from inside and wall linings in the Barn area where the walls are not insulated with straw. As the straw walls are more susceptible to moisture, they require a thick coat which will be provided by vapour permeable lime plaster.

In terms of ecological considerations, flax cultivation has a minimal negative impact on soil structure. The operations are usually conducted under dry conditions, and light machinery is often used. Harvesting flax leaves very little crop residue, resulting in a low contribution of organic matter. However, early harvest combined with cover crops can lead to a high rate of green manure and a significant supply of organic matter. Ryegrass is often sown as a cover crop under flax (Delphy ism Rusthoeve, 2024). Similar to hemp, flax presents certain issues for biodiversity, such as poor compatibility for mixed cropping and a lack of winter cover (Delphy ism Rusthoeve, 2024).

Rainscreens

Biobased materials are affected by the presence of excess moisture, which might lead to structural failure, particularly in a temperate maritime climate. In a temperate climate like the Netherlands, the indoor moisture content is higher due to heating, and the low outside temperature creates high vapour pressure. A permeable, hygroscopic rendering (clay plaster, lime plaster) is essential to allow moisture to travel through straw bales to lower pressure on the exterior façade. This will avoid vapour build-up which may convert into water droplets and cause condensation.

A thick rendering is applied to the inside to encourage vapour flow to the outside. This not only benefits the indoor air quality but most importantly protects biobased materials in this case straw and timber from moisture build-up and thereby potential damage that would ensue (Straube, 2000). However, the hygroscopic nature of lime-based renders presents a challenge. This means that moisture from driving rain can penetrate the wall. Although this moisture would typically evaporate from the wall's surface, continuous rain, often amplified by the strong southwest wind in the Netherlands, can cause an alarming buildup of moisture in the straw.

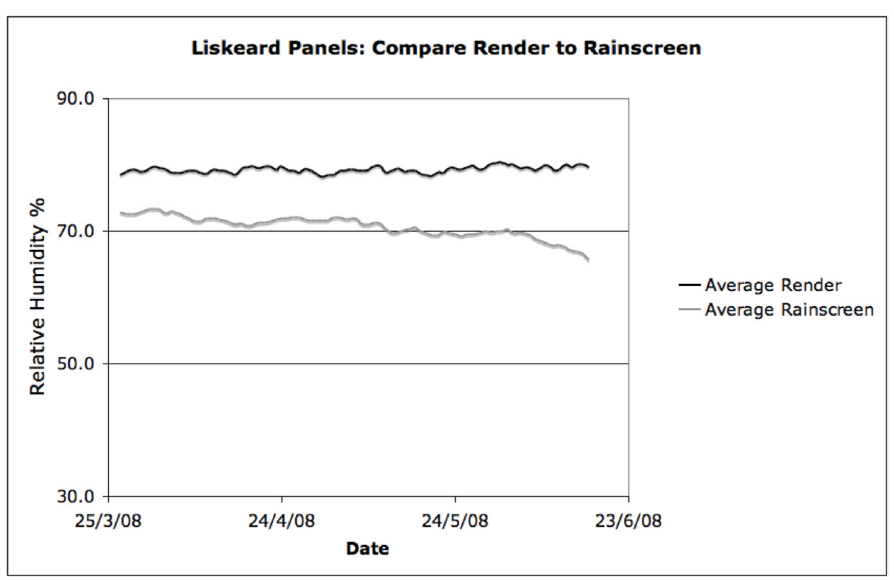

Fig 81 – Average readings of relative humidity for two of the panels (Straw bale panels protected with render and timber rainscreen). The higher trace is from the rendered panel, the lower is from the panel protected by a rainscreen. Source – Detailing the effective use of rain-screens to protect walls made from straw bales in combination with hygroscopic, breathable finishes.

Rainscreens as the name suggests will act as ventilated screening that will help resist the weather and still allow the dispersal of moisture. According to research conducted in Liskeard, a temperate maritime climate, on straw panels with render and render with timber rainscreen, the relative humidity data collected over three months revealed that the rendered panel consistently showed an 80% relative humidity. In contrast, the panel protected by rainscreen cladding was gradually drying out (Carfrae et al., 2009). This shows that screening will have a mitigating effect on the ingress of water. The Kumiki Model house in addition to a good hat (roof overhangs) uses fast-growing, woven, untreated, and unpeeled willow twigs to create a vented rainscreen cladding that protects against straw decay. Pollard willow is a crucial species in the Dutch Polder ecosystem. Planted along ditches, it reinforces the banks with its fibrous roots. Ecologically, it supports various insect species that generally cause minimal harm to the tree or shrubs. Additionally, the dense ground cover formed by the willows provides a habitat for a range of invertebrates, including earthworms, beetles, spiders, and butterflies which in turn invites mammals and birds. The fast-growing branches are harvested and used for applications requiring flexibility.

The choice of willow twigs aims to break away from conventional, often imported cladding materials, end uniformity, and showcase local craftsmanship and nature's diversity. This approach highlights the importance of returning to a building culture that leverages extensive material knowledge rooted in robust craft traditions. The twigs are sourced from the site and surrounding willow trees. The wall buildup consists of 25 mm lime plaster with jute net, 450 x 45 mm I-joist (45 x 45 mm flange with 360 mm web), Straw bales 800 x 450 x 360 mm, 20 mm lime plaster with jute net, Vapour permeable breather membrane, 20 mm dia willow rods vertical 280 mm c/c, 20 mm dia willow twigs horizontal 360 mm c/c, 8-10 mm dia willow twigs vertical. To fix the 20 mm dia vertical willow rods 280 mm c/c to the wall horizontal paulownia solid lumbers placed on every second course of bales. As the ventilated willow rainscreen forms an impervious outer layer, one coat of lime render is enough to protect against the surface spread of fire and vermin. The vertical and horizontal rods and twigs not only provide structure to

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the screening but also ensure airflow behind the screen, which is essential for removing water vapour that has migrated from the indoors.

Fig 82 – Edited by author, façade systems made using uncut willow rods. Source – pilebyg.

Fig 83 – RoSana Guest House, façade systems made using woven untreated and unpeeled willow wood. Source – Anna Heringer.

Interior walls – Balancing Insulation and Thermal Mass

Straw is an excellent insulating material with low thermal conductivity, which is further optimized by the perpendicular orientation of the fibres with respect to the heat flow direction (Fuentes et al., 2020). Consequently, the thermal mass of a straw bale is low, as it is largely composed of air. Massive elements with high thermal mass are added for heat storage and temperature moderation with well-insulated roofs and walls to achieve efficient buildings (Ziggy, 2019). In cold climates maintaining thermal equilibrium indoors is important and this is gained by using materials with high thermal mass like concrete, water, stone, compressed earth block etc. These materials absorb, store and release heat slowly. Normally concrete foundations are paired with straw bale walls and roofs. Thick renders on both sides of the straw bale provide reasonable thermal mass. However, the Kumiki Model House is raised above the ground, resting on timber piles. To reduce embodied energy and demonstrate the potential of locally produced biobased materials, the floor is constructed using timber I-joist beams with straw bales as insulation and cased with timber planks.

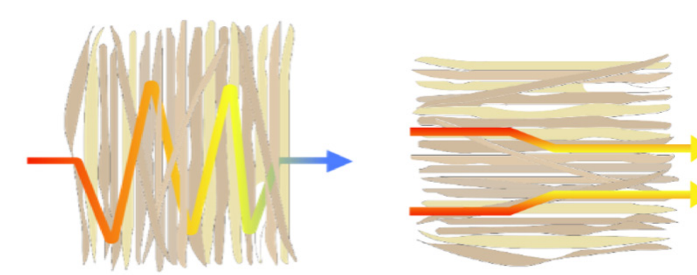


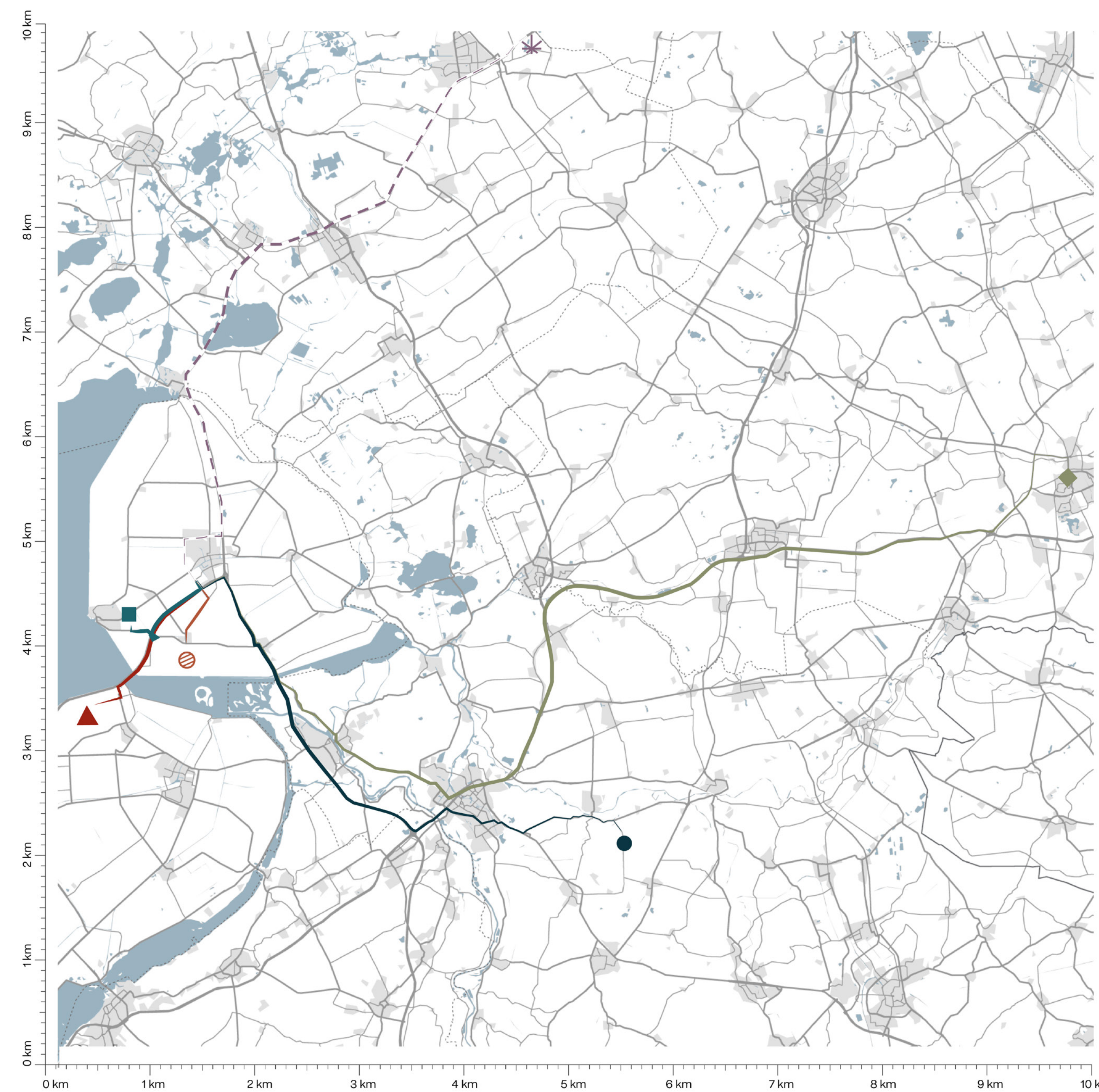
Fig 84 – Direction of the blades in the straw bales. Left – perpendicular direction to the thermal flow; Right – Parallel direction to the thermal flow. Source – Physical-thermal straw properties advantages in the design of a sustainable panel-type construction system to be used as an architectural dividing element. https://doi.org/10.1088/1742-6596/1587/1/012032

The change in climate, with a slight cooling requirement in summer and a high heating requirement in winter, makes adding thermal mass to the structure beneficial. It will passively aid in heating and cooling, thereby minimising operational energy consumption. Masonry walls provide good thermal mass if they are located internally or protected by insulation (Reardon, 2013). The use of compressed earth blocks as internal walls adds reasonable thermal mass to the Kumiki Model House. Compressed earth blocks have a density of 2080 kg/m^3, a specific heat capacity of 0.837 kJ/kg·K, and a volumetric heat capacity of 1740 kJ/m³·K (Reardon, 2013). Additionally, the blocks are made from Dutch clay soil and require low energy to produce. They help regulate moisture and store and release heat.

These blocks are sourced from a production unit based in Emmen, the Netherlands, 97 km from the site, and the entire production runs on solar energy. As the compressed blocks are unbaked and sundried, the properties of the clay remain unaltered, making recycling possible. The compressed blocks consist of clay, silt, sand, and 5% lime to make them moisture resistant. The blocks are laid using lime mortar and finished with permeable, hygroscopic lime plaster, ensuring the reusability and circularity of the blocks. Large glazing on the south side, and clerestory windows on the east and the west façade are designed to increase the absorption of heat by blocks. To minimise conductive heat loss, the glazed openings are recessed. This, along with roof overhangs providing shade, helps protect the thermal mass from the summer sun. Lastly, to increase the surface area of compressed earth blocks, kitchen counters, and open-shelf storage units made from blocks are designed.

Fig 85 – Oskam compressed clay blocks. Source – Oskam-V/F. https://oskam-vf.com/en/clay-products/compressed-earth-blocks/clay-blocks-brown-ocher

Source of Biobased and Natural Material from the Kumiki Model House Site

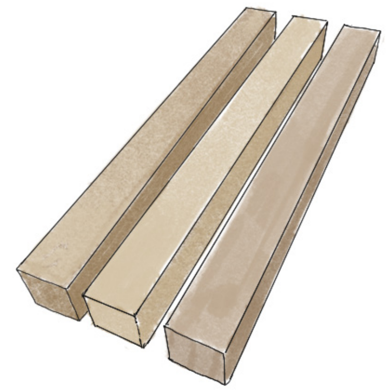


LEGEND

- Wheat straw-Swifterbant
- Paulownia - Tollebeek
- Compressed Earth Block - Emmen
- Robinia timber - Dalfsen
- Lemen/flax loams - Nagele
- Norway Spruce - Germany

Proposed wall built-up for the Kumiki Model House

Structure :
paulownia

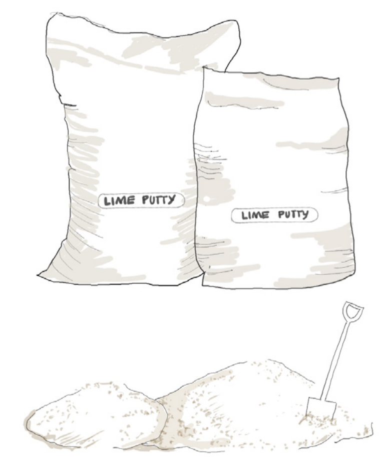


planed slats

OSB sheet

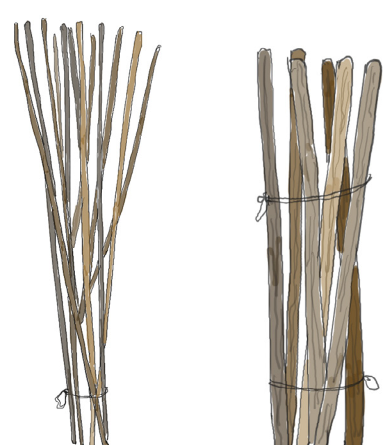
Envelope :
wheat straw

wheat strawbale

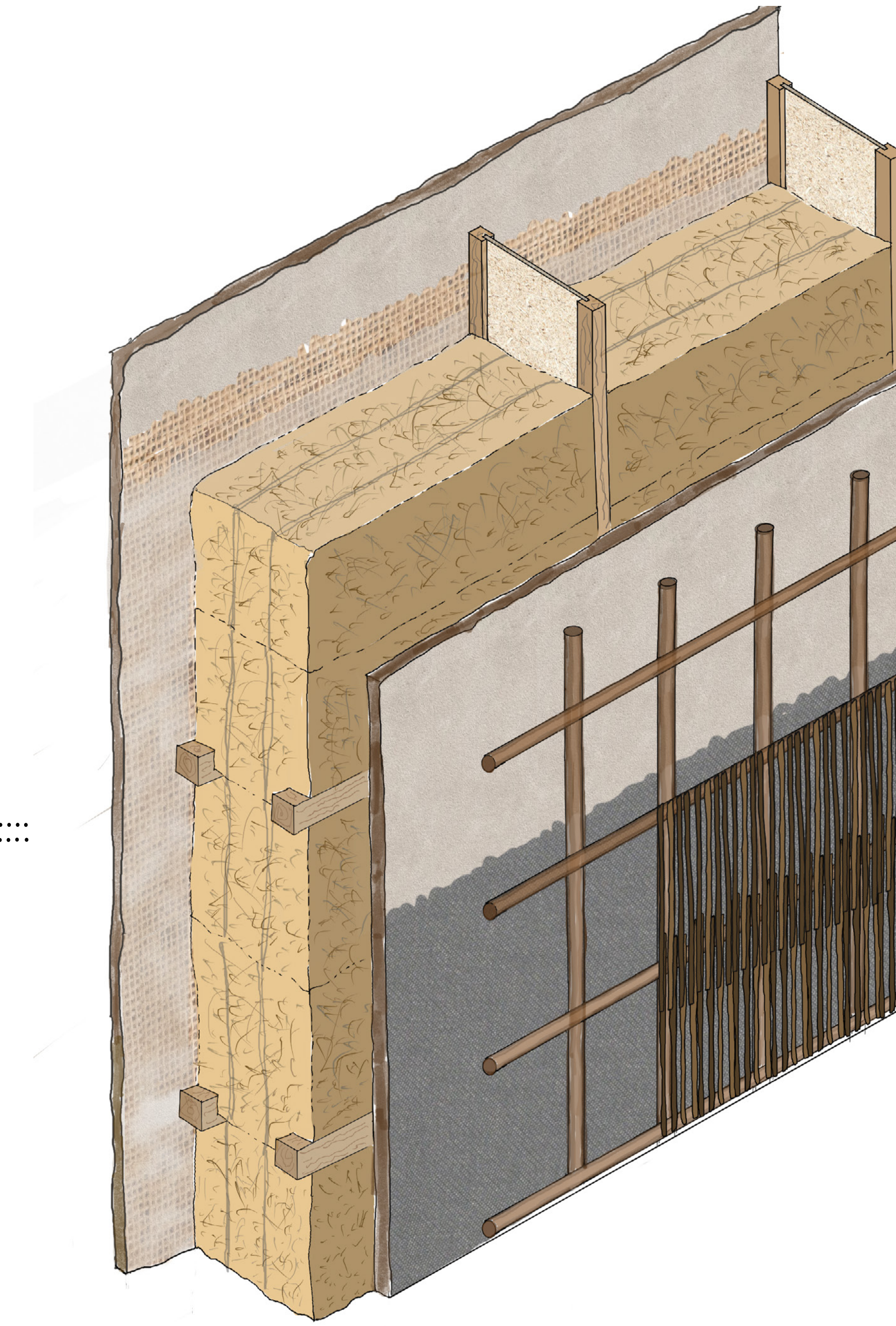


Lime plaster

Rainscreen :
willow



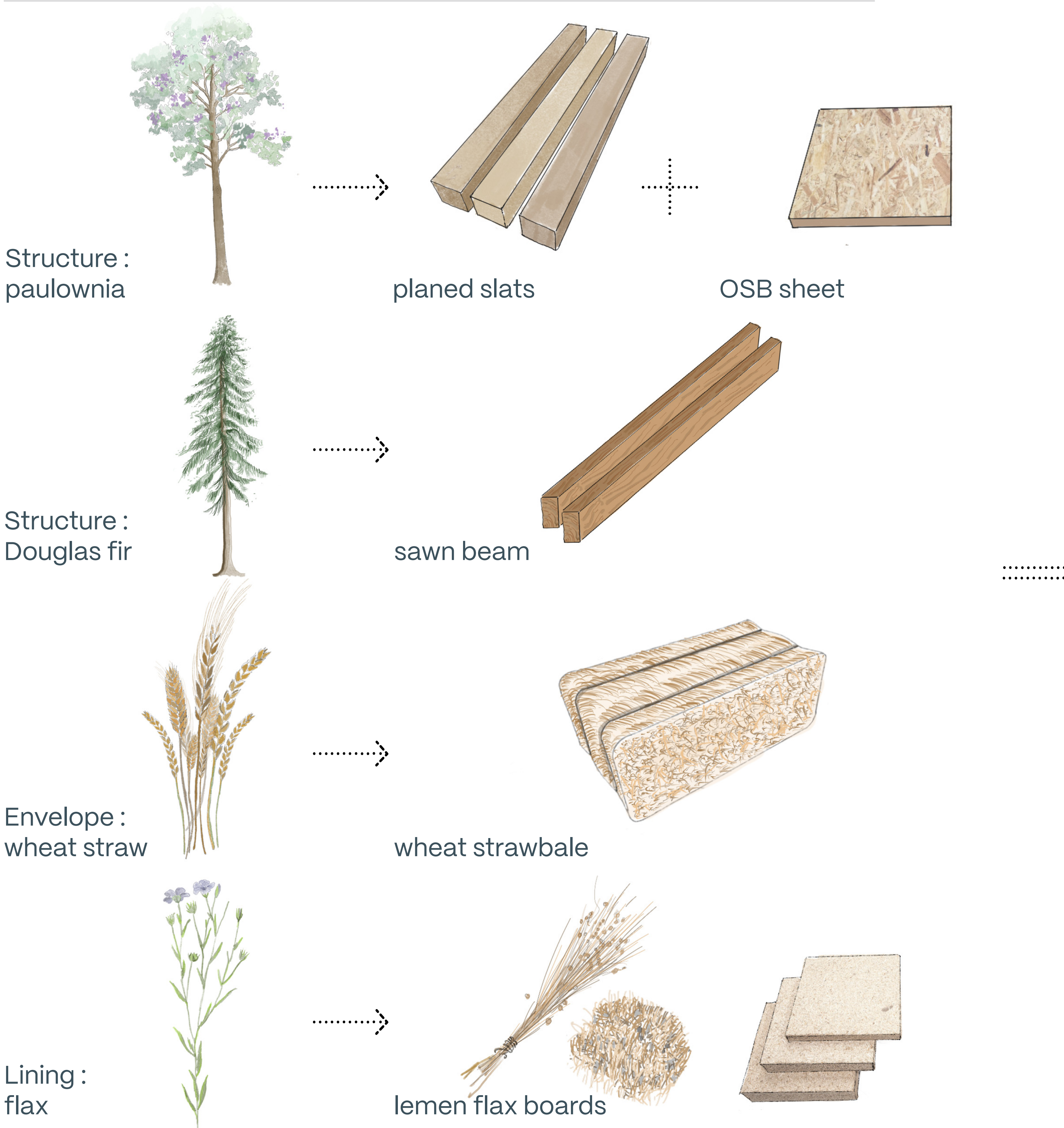
twigs and rods

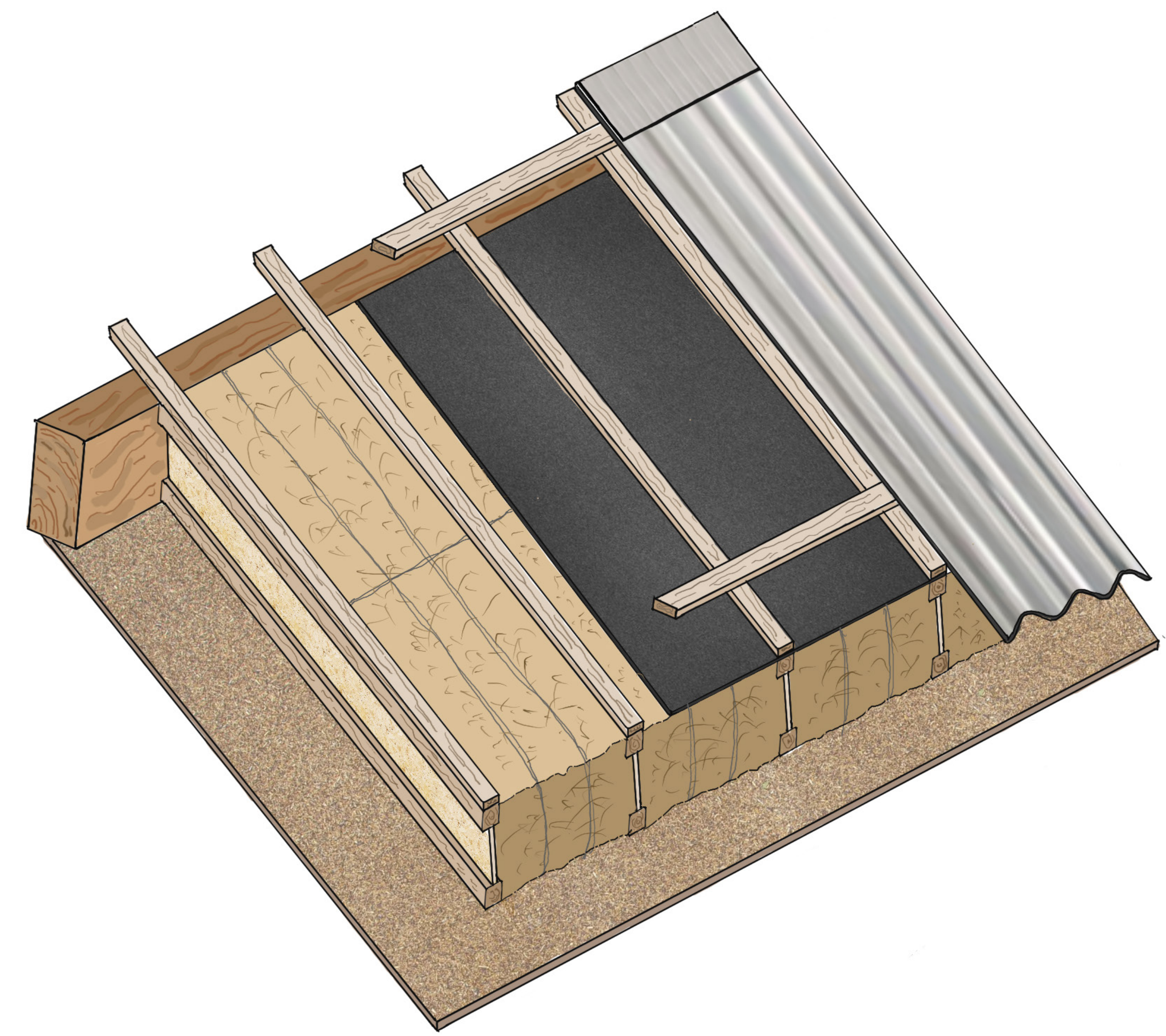


Wall built-up for Kumiki Model House

- 8 mm dia willow twigs vertical
- 20 mm dia willow twigs horizontal 360 mm c/c
- 20mm dia willow rods vertical 280 mm c/c
- Vapour permeable breather membrane
- 20 mm lime plaster with jute net
- 450 x 45 mm I-joist (800 mm c/c)(45 x 45 mm flange with 360 mm OSB web) with 100 kg/m3/ density straw bales
- 45 x 45 mm horizontal Paulownia stud
- 25 mm lime plaster with jute mesh

Proposed roof built-up for the Kumiki Model House





Roof built-up for Kumiki Model House

- 0.7 mm Aluminum corrugated sheet (reclaimed)
- 24 x 48 mm Paulownia purlins 1200 mm c/c
- 24 x 48 mm Paulownia rafters 450 mm c/c
- EPDM roof membrane
- 360 x 45 mm I-joist (450 MM c/c)(45 x 45 mm flange with 300 mm OSB web) with 100 kg/m3/ density straw bales
- 18 mm Flax boards

Crafting the Kumiki Model House

Kumiki house site analysis

Longitude: 5.77
Latitude: 52.71
Elevation above sea Level: -3 m
Köppen-Geiger climate Zone: Cfb. Marine west coast, warm summer.
Area : 8573 m2

Fig 88 - Edited by author, location plan. Source - Google Maps

Neighborhood and Surroundings

- East: The site is bordered by expansive farmland, situated at the rural fringe where Emmeloord town houses meet the polder farming landscape.
- West: A 3M wide road provides access to the site and connects it with nearby areas, offering potential for vehicular and pedestrian traffic.
- North: The Municipality of Noordoostpolder has plans to develop tiny social houses in the coming year, indicating residential demand and community growth.
- South: A small mosaic green patch enhances the natural landscape.

Access and Transportation

- A 3 M wide vehicular road located in the east provides access to the site and connects it with nearby areas. Since Noordoostpolder isn't connected by rail, access to the site is primarily via bus and private vehicles.

Topography and Soil

- Topography: The site is flat, reflecting its history as reclaimed land.
- Soil Analysis: The site's soil consists of a clay and peat substrate, which presents both opportunities and challenges. The high mineral content of this soil type makes it favourable for farming, as it supports robust plant growth and agricultural productivity. However, the soil is unstable due to issues such as clay maturation, peat oxidation, and general soil degradation (refer to chapter - Noordoostpolder from land to sea to land). These factors have negatively impacted the soil's structure and fertility over time.
- When considering construction, clay soil poses significant challenges due to its physical characteristics. It tends to expand when wet and contract when dry, leading to instability (Van Orsouw et al., 2022), which can affect the integrity of structures built upon it. In such cases, pile foundations are preferred as they provide stability by transferring the load of the structure to deeper, more stable soil layers.

Fig 89 – Schokbetonschuur, first large-scale application of concrete prefab barn in Noordoostpolder. Source – Schokbetonschuur monument voor wederopbouw. Wageningen University & Research. https://edepot.wur.nl/13039

Fig 90 –Buildings in the Noordoostpolder built around 1948. Source – Canon the Noordoostpolder. https://www.canonnoordoostpolder.nl/en/build-up/architecture

Vegetation

- The site is designated for agricultural use, although no intensive farming is currently being conducted on this chunk of the site. Vegetable farming present across the site during the site visit was carried out by renting the land from the Municipality. There is a planned green avenue of willow trees on the east side of the site, providing a buffer to the adjacent farm from southwest winds. Additionally, a few scattered trees are located along the edge of the west side.

Architectural Context

- On September 9, 1942, the Noordoostpolder was officially dry. Every square meter of this reclaimed land was destined for agriculture (Steenhuis, 2009). Due to World War II, there was a scarcity of skilled construction workers and building materials. Buildings that were already frugal in design became even more frugal in construction to save costs.
- Concrete and brick were the primary materials used for the envelope and structure, as they were cheap and easily available. To accelerate the construction of barns needed to store farm harvests, modular prefabricated building technology was used for the first time in the Netherlands (van Seggelen, 2005). While aesthetics and spacious volume were deprioritized, functionality with small floor plans was advocated in the construction of houses that no longer comply with present-day standards.
- In a short period, hundreds of agricultural worker's homes, tenant buildings, and farms were erected with very different roof types (Canon the Noordoostpolder, 2019). Experimentation with opening sizes, recessed entrance doors, framing around doors and windows, and repetitive rhythm in the modular facade systems are a few distinctive architectural features seen in the Noordoostpolder.

Site Pictures

Fig 91 – Panoramic perspective view from the site, Source – Kumiki

Fig 92 – 3 M wide vehicular road on the east of the site, Source – Kumiki

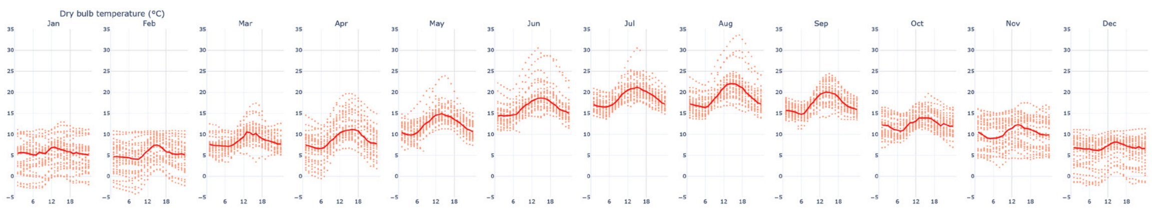
Fig 93 – Vegetation around the site, Source – Kumiki

Fig 94 – Vegetable Garden plantation Source – Kumiki

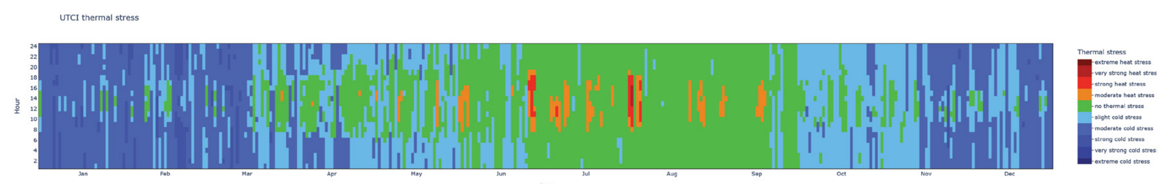
Spatial Framework

2020 climate data

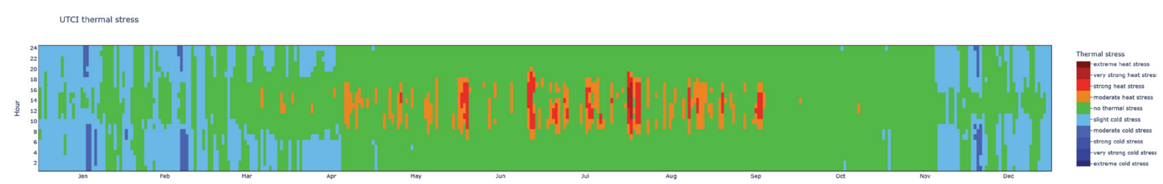
The set points taken into consideration are 18° for HDD and 26° for CDD



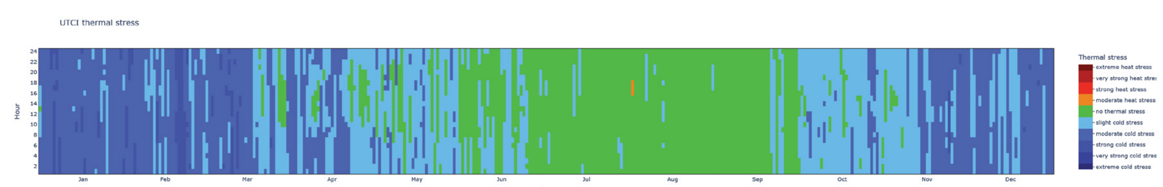
Daily dry bulb temperature



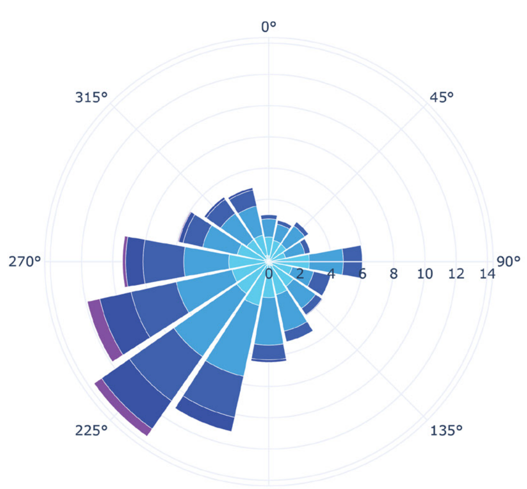
UTCI – Sun and wind



UTCI – Sun and no wind



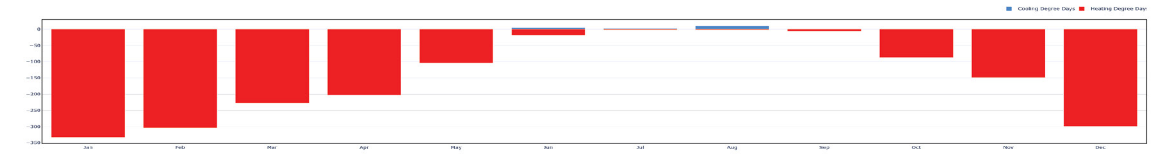
UTCI – Wind and no sun



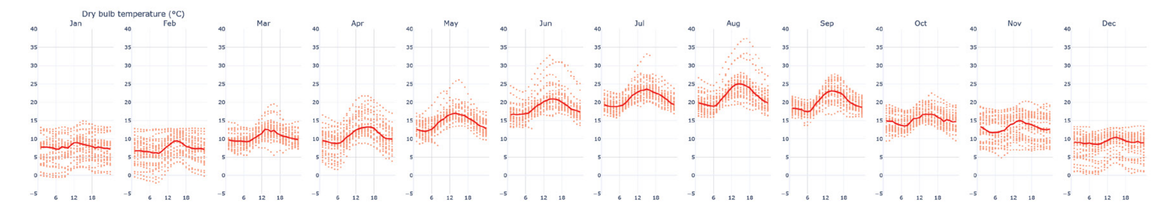
Annual wind rose

Average yearly temperature: 11.8 °C
Hottest yearly temperature (99%): 24.5 °C
Coldest yearly temperature (1%): -1.3 °C
Observation –
1. The town relies heavily on heating and barely needs any cooling as red is dominat-ing the graph.
2. The daily dry bulb shows the highly vari-able temperature from summer to winter.
3. High outdoor thermal comfort is been achieved in second case where sun is on and no wind.
4. The prevailing winds in the Noordoostpo-lder blow from the southwest with max 13.8 m/s

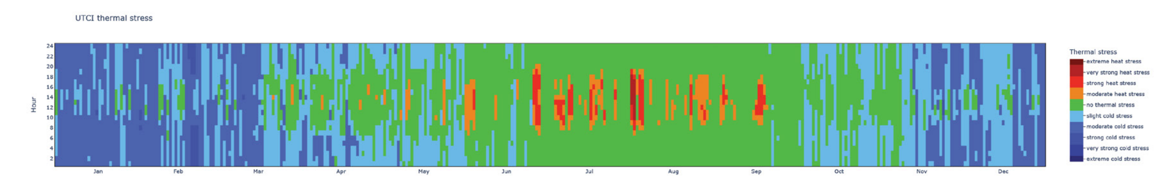
2080 climate data



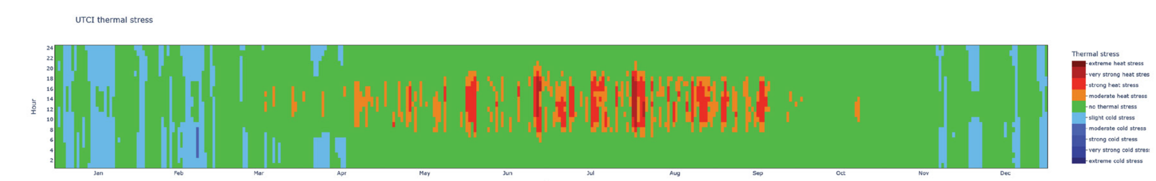
The set points taken into consideration are 18° for HDD and 26° for CDD



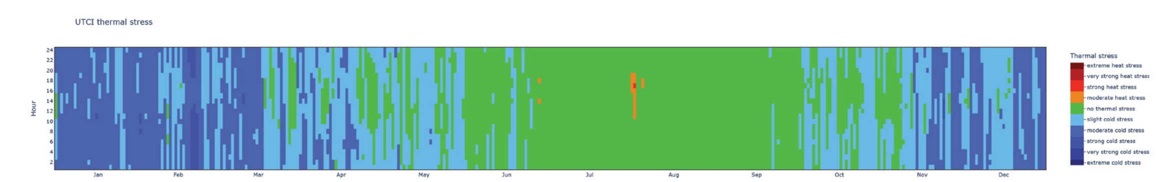
Daily dry bulb temperature



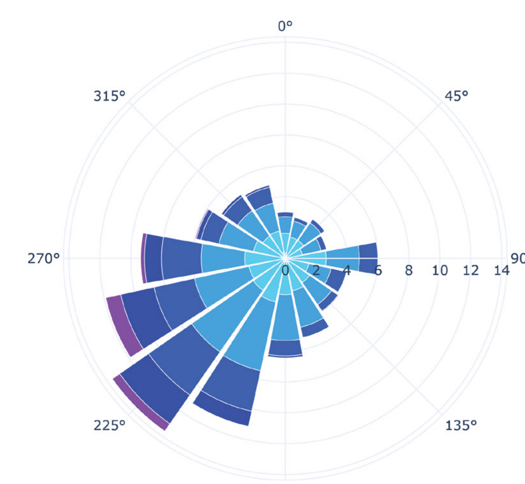
UTCI – Sun and wind



UTCI – Sun and no wind



UTCI – Wind and no sun



Annual wind rose

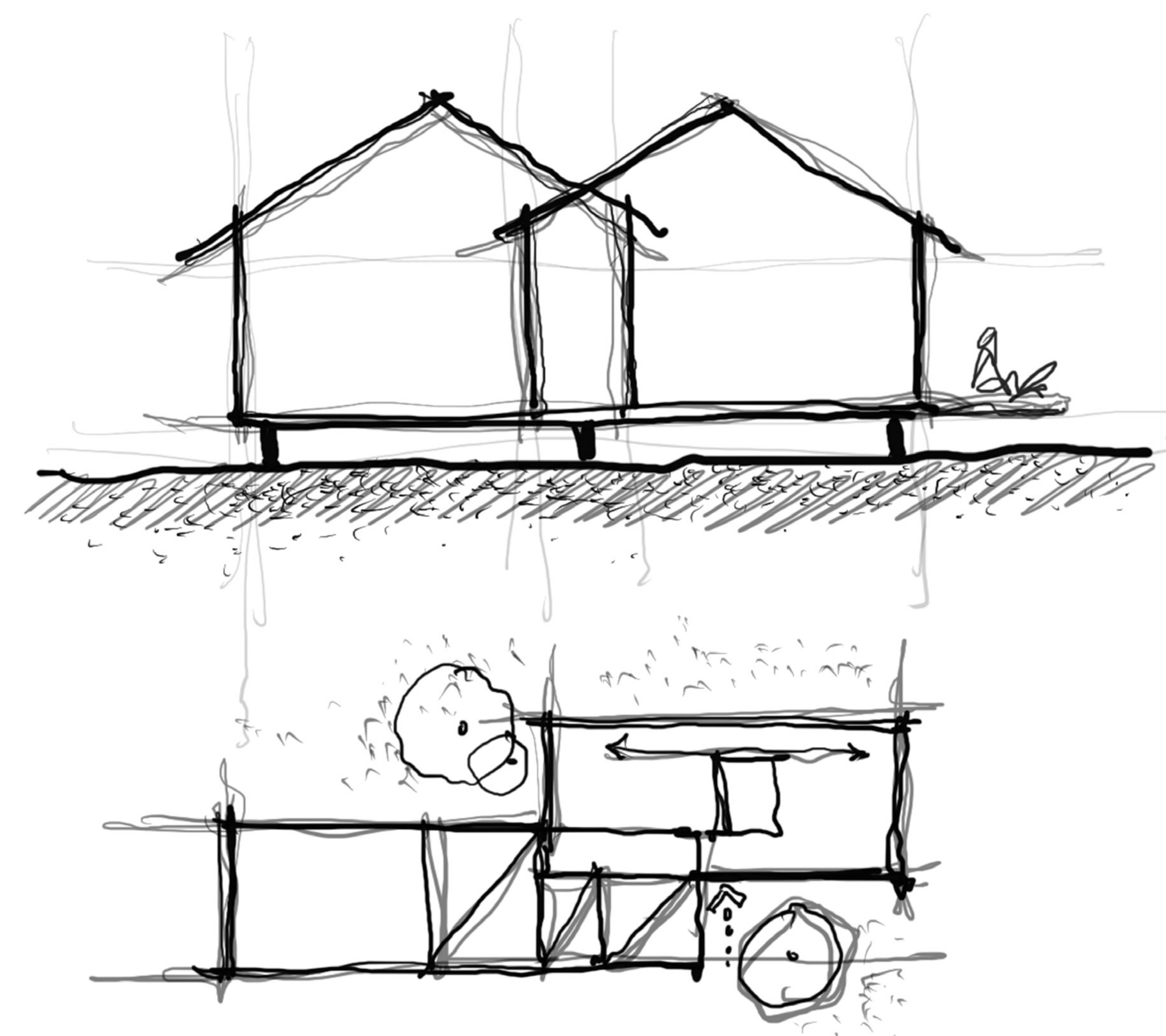
Average yearly temperature: 14.2 °C
Hottest yearly temperature (99%): 27.3 °C
Coldest yearly temperature (1%): 1.0 °C
Observation –
1. The town will still rely heavily on heating but less as compared to 2020 and need slight cooling.
2. The daily dry bulb shows less variable temperature from summer to winter.
3. High outdoor thermal comfort is been achieved in second case where sun is on and no wind.
4. The prevailing winds in the Noordoostpo-lder blow from the southwest and no major change in frequency.

Climate Analysis

The climate analysis is performed using the climate change world weather file generator (CCWorldWeatherGen). Present-day EPW weather file (recent file) is used as input and based on that climate change EPW weather files are generated. The morphed EPW is used to analyse and predict future changes. The graphs are generated by using CBE Clima tool.

The comparison between the climate data for 2020 and 2080 suggests a shift toward a warmer climate in Noordoostpolder. In 2080, the residents may experience slightly warmer summers and milder winters. Despite these changes, the prevailing wind patterns remain consistent. Strategies for adapting to this climate shift and achieving comfort indoors and outdoors include evaluating insulation requirements and implementing passive cooling and heating methods, as well as plantation of crops. Wind needs to be manoeuvred strategically to have more comfort outdoors.

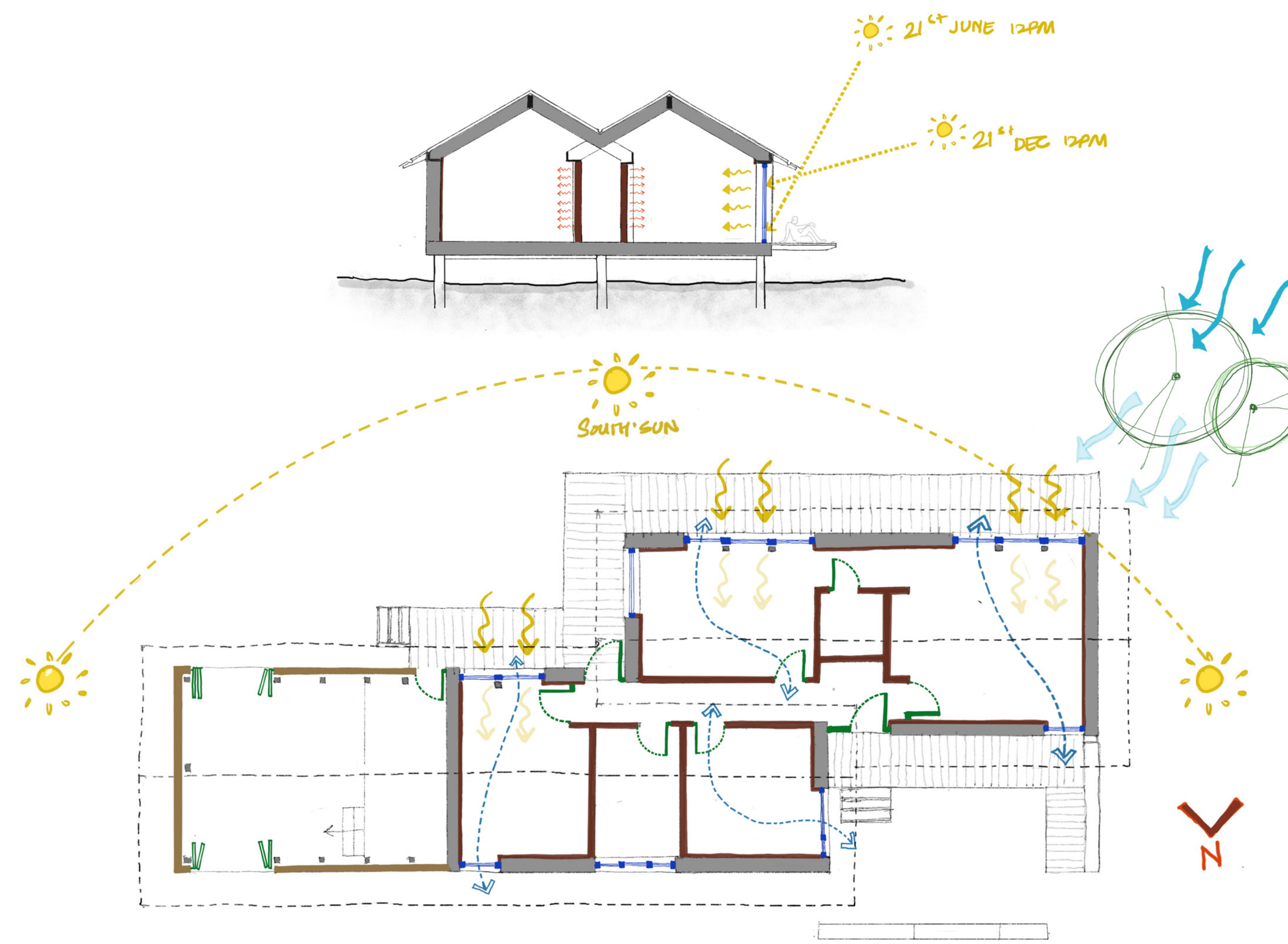
Kumiki Model House Sketch Design

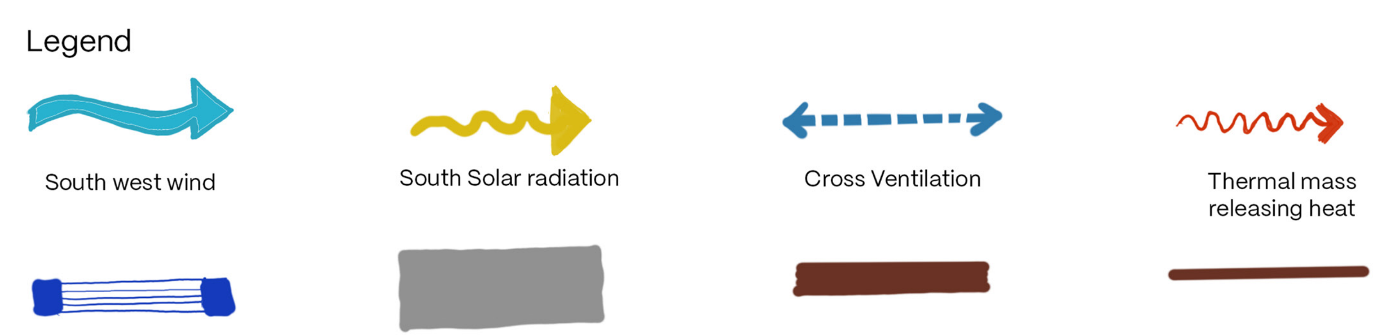


Kumiki Model House Passive Strategies

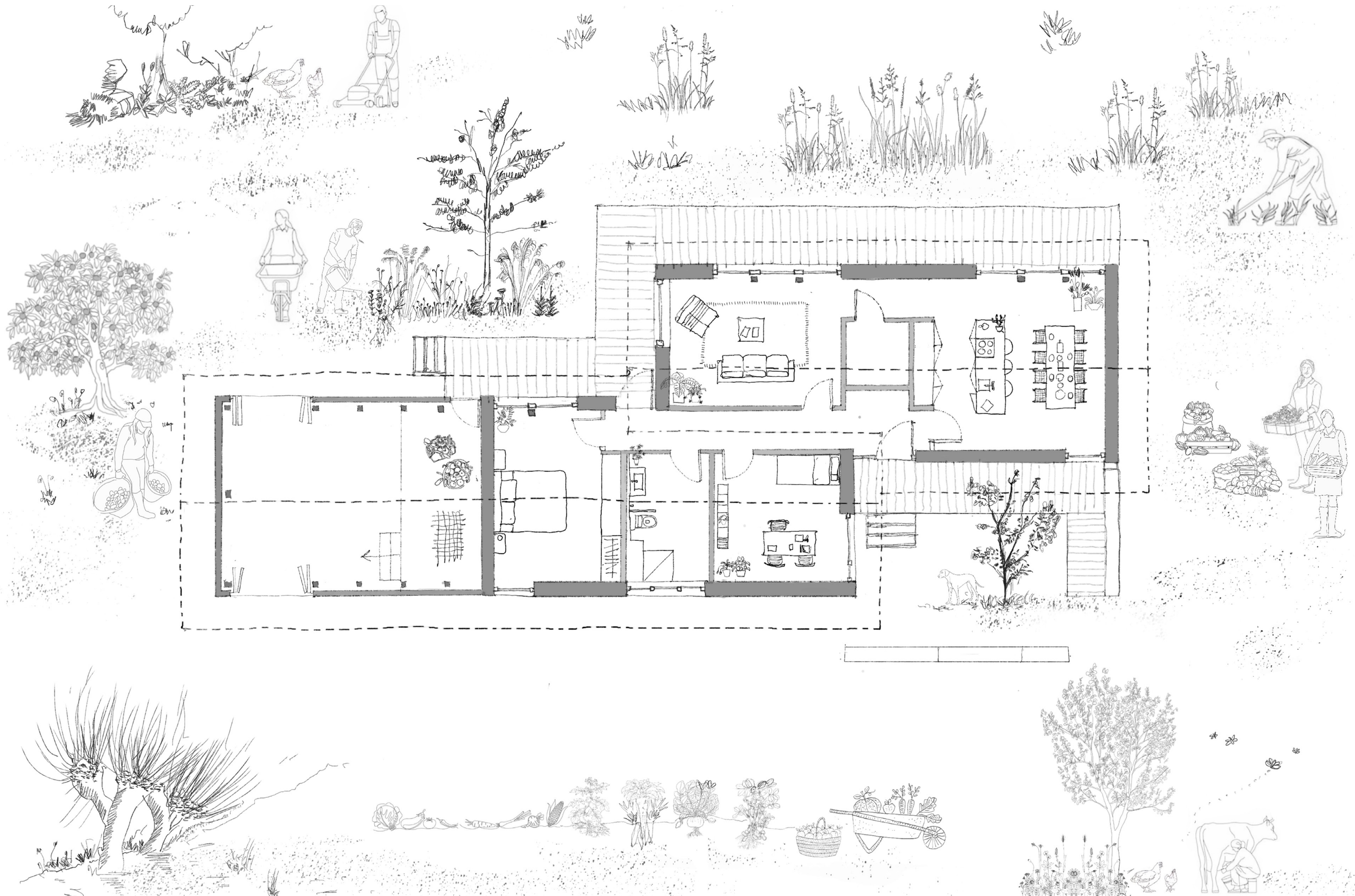
The brief was developed based on basic requirements and a user study. All spaces are universally accessible. At the entrance located on the Northwest side, a patio is designed with a small Stinzen garden. A takkenril or houtwal (branch ridge or wood bank) is placed to frame the patio. This provides hiding and breeding spaces for birds, mammals, and insects. Additionally, the high moisture levels create an ideal environment for mushrooms, mosses, and ferns to thrive. A peek through the kitchen window gives a brief view into the patio while a glimpse through the hobby room's window reveals the quiet patio with the setting sunset.

The intertwining of two volumes minimises circulation passage and maximizes the usability of the end spaces (Kitchen and Bedroom). Spaces like the Kitchen, dining and living room are placed on the south side. Large south-facing triple-glazed windows not only allow abundant light but also provide a panoramic view of the fields. The installation room is centrally located to optimise energy efficiency. A small barn/ storage space is placed after the bedroom. This will help store fresh produce and tools needed for agriculture.

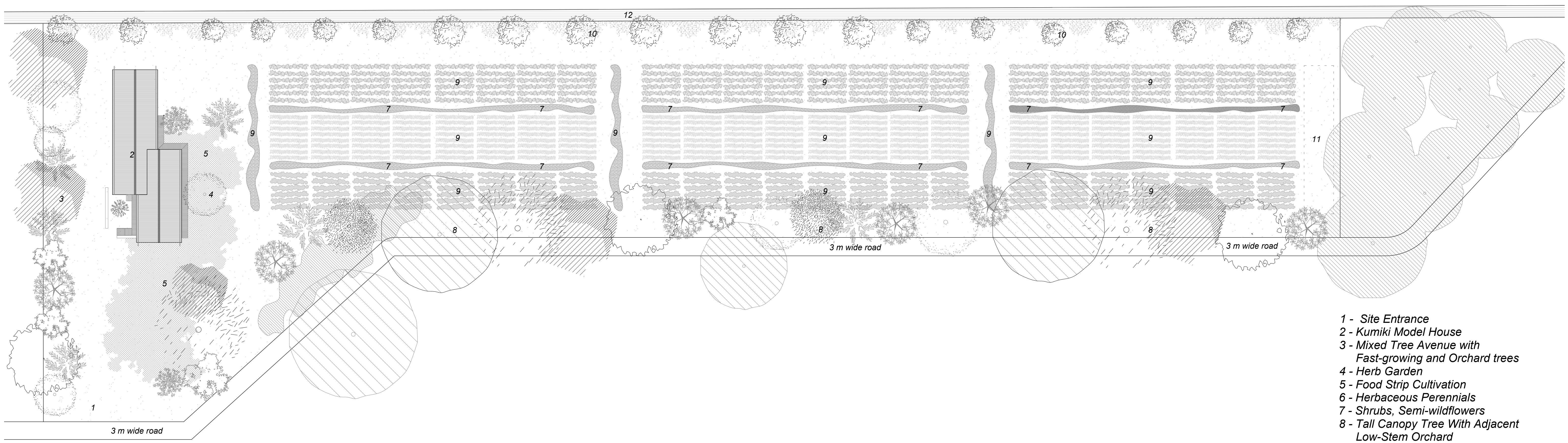




Kumiki Model House Doodle

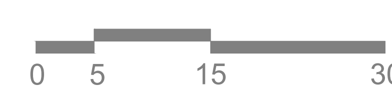


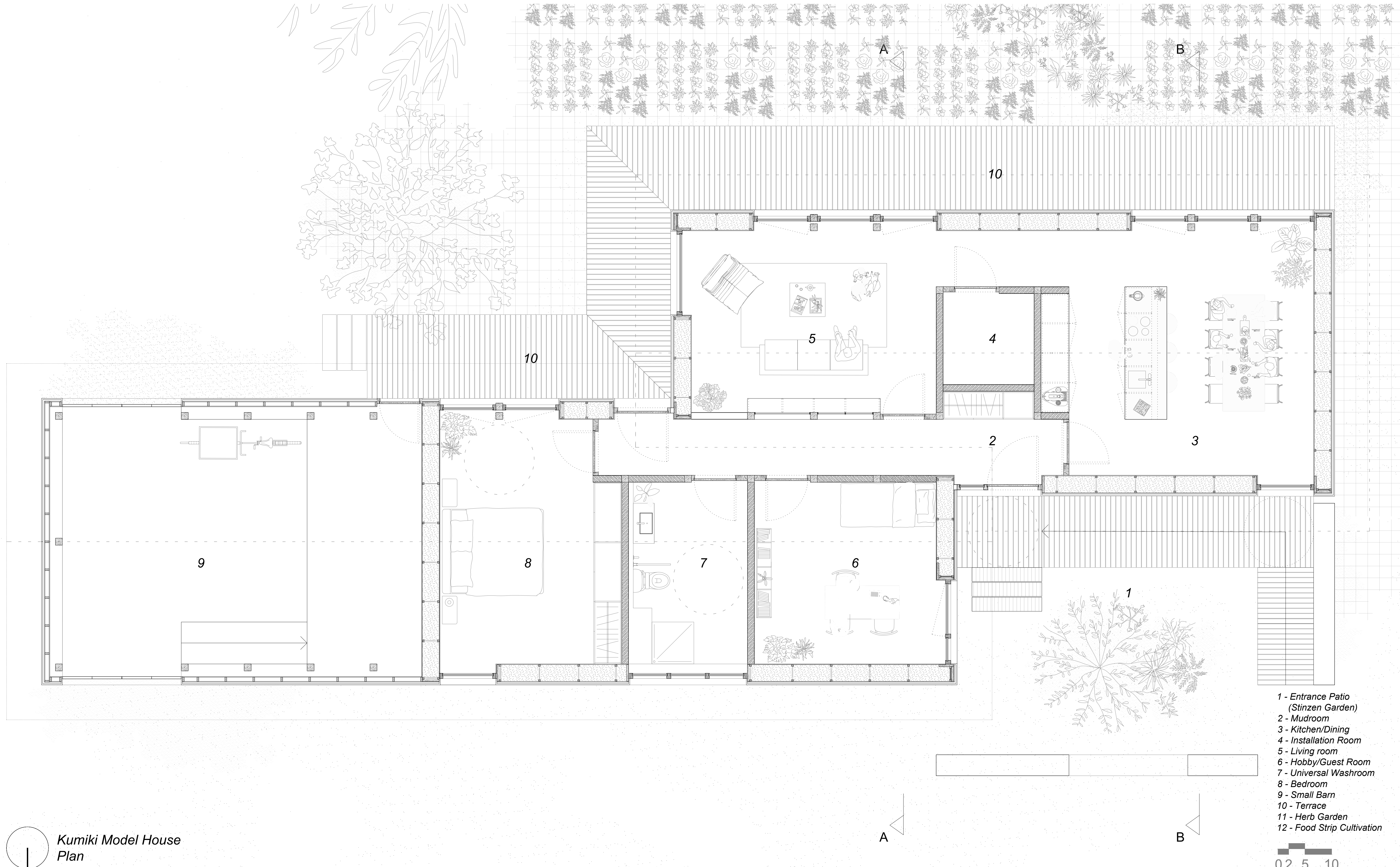
Spatial Framework



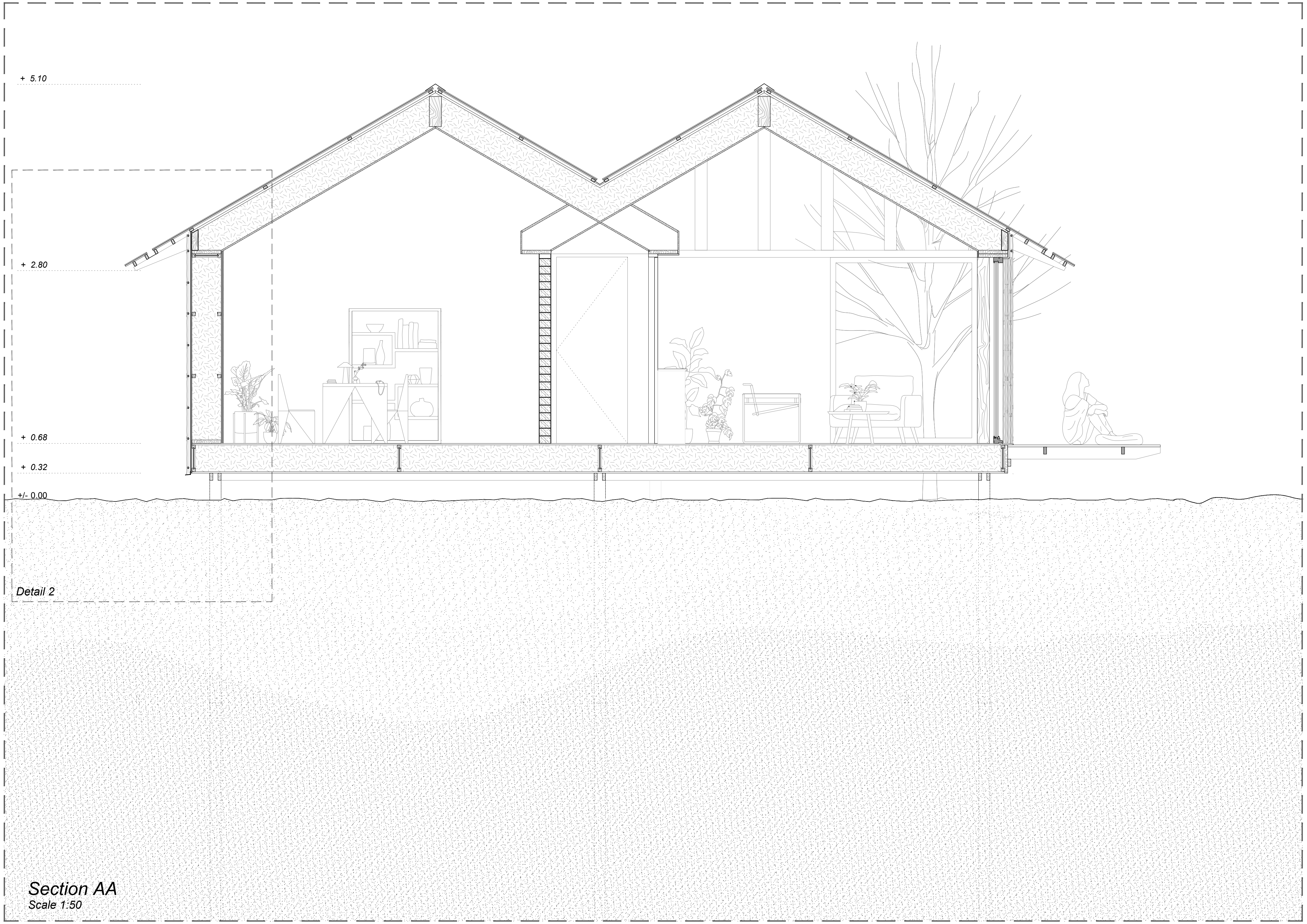
1 - Site Entrance
2 - Kumiki Model House
3 - Mixed Tree Avenue with
Fast-growing and Orchard trees
4 - Herb Garden
5 - Food Strip Cultivation
6 - Herbaceous Perennials
7 - Shrubs, Semi-wildflowers
8 - Tall Canopy Tree With Adjacent
Low-Stem Orchard
8 - Wide Strip Annuals
in rotation with under cover crops
managed with controlled traffic system
10 - Existing Willow plantation
11 - Barn Future Expansion
12 - Polder dike

Kumiki Model House
Site Plan

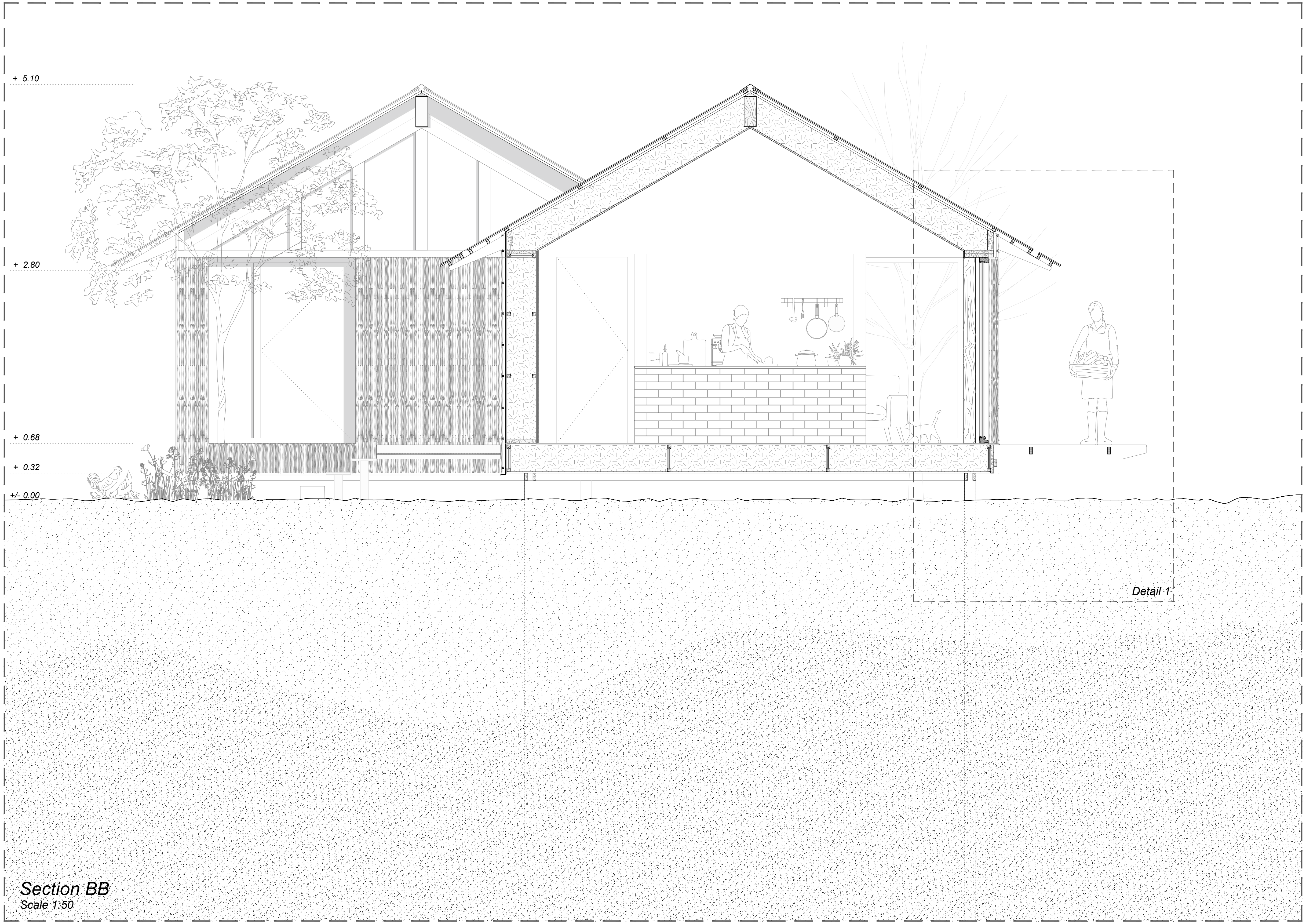




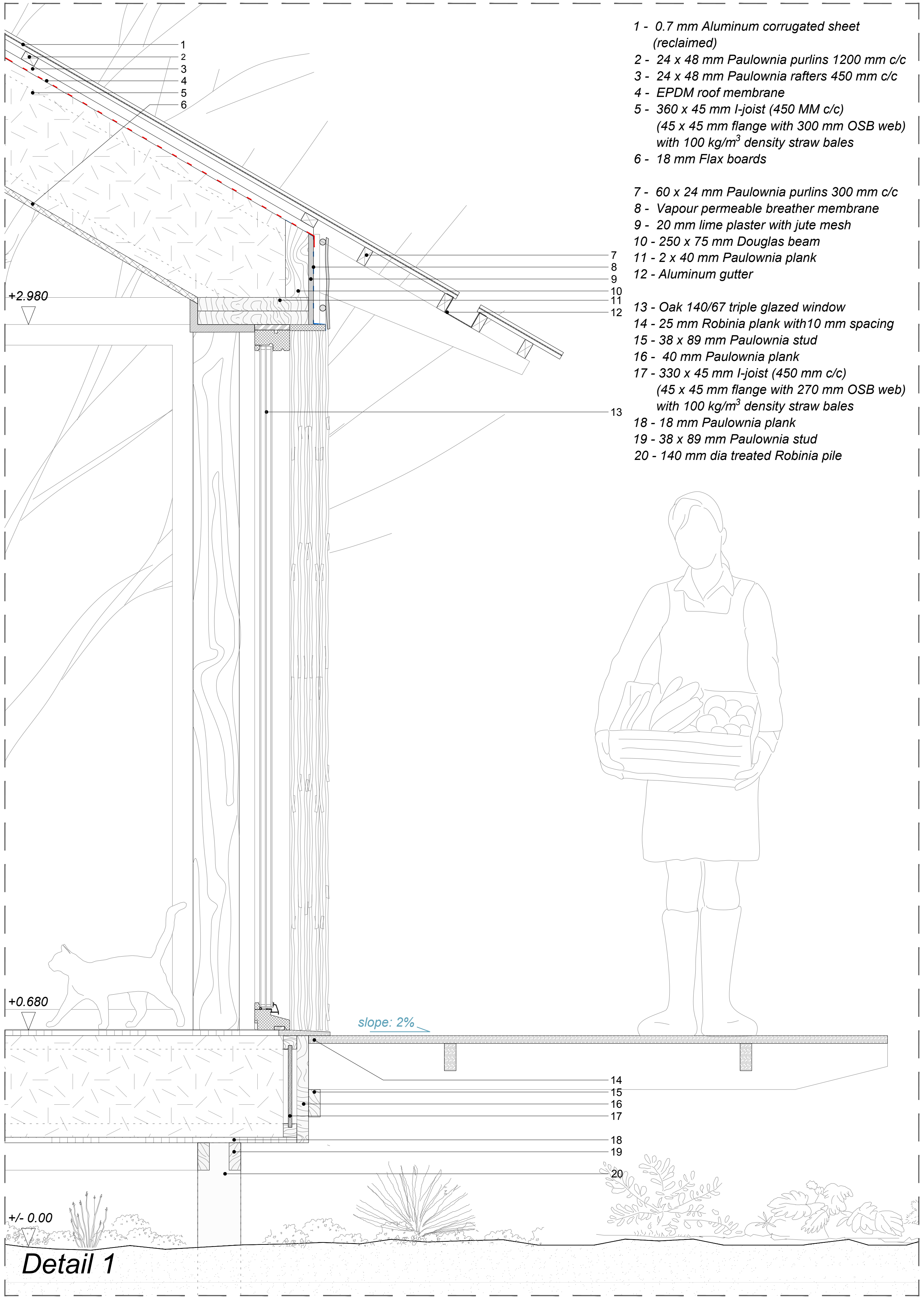
Kumiki Model House
Plan



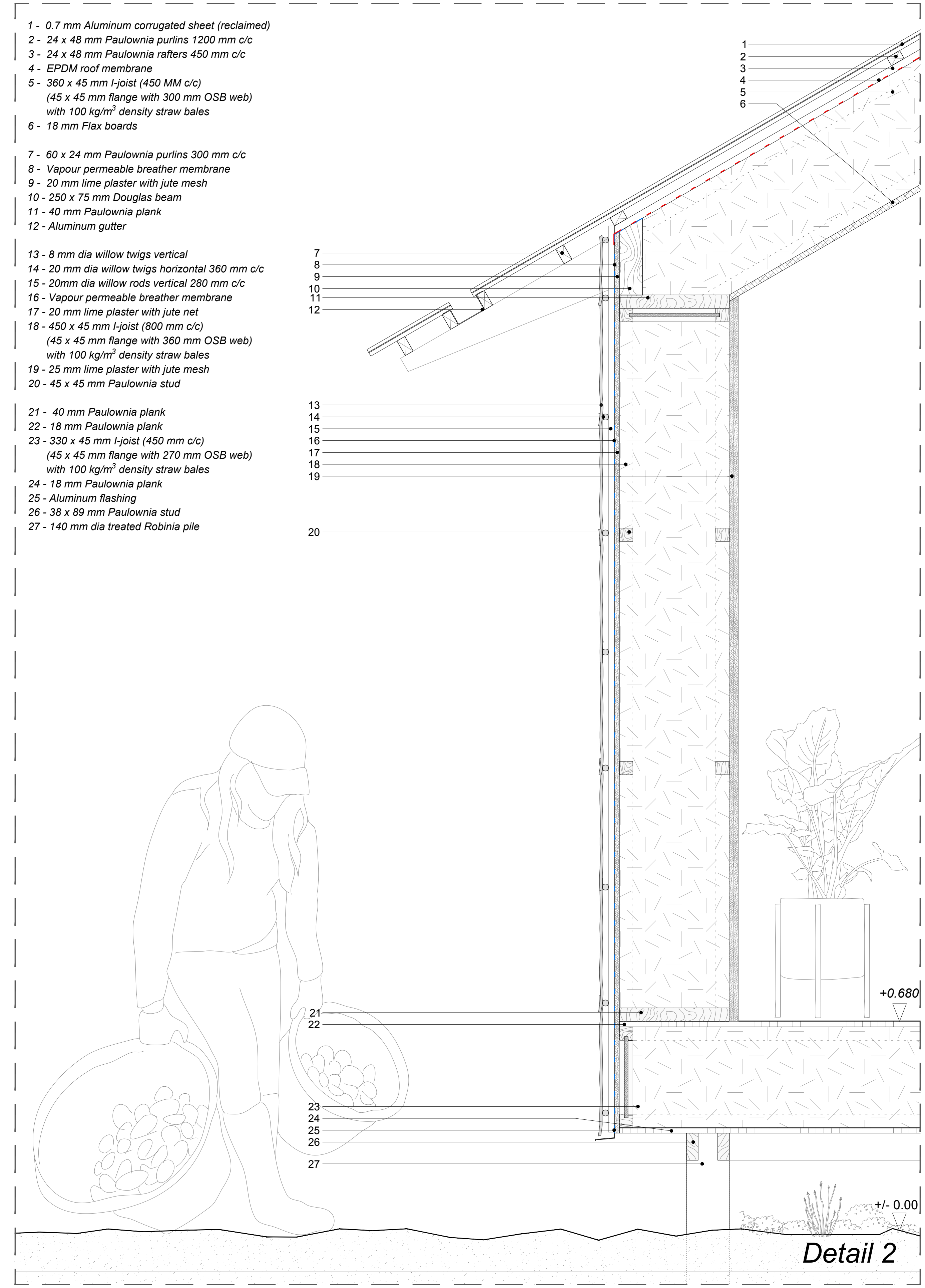
Section AA
Scale 1:50



Section BB
Scale 1:50



1 - 0.7 mm Aluminum corrugated sheet (reclaimed)
2 - 24 x 48 mm Paulownia purlins 1200 mm c/c
3 - 24 x 48 mm Paulownia rafters 450 mm c/c
4 - EPDM roof membrane
5 - 360 x 45 mm I-joist (450 MM c/c) (45 x 45 mm flange with 300 mm OSB web) with 100 kg/m3 density straw bales
6 - 18 mm Flax boards
7 - 60 x 24 mm Paulownia purlins 300 mm c/c
8 - Vapour permeable breather membrane
9 - 20 mm lime plaster with jute mesh
10 - 250 x 75 mm Douglas beam
11 - 2 x 40 mm Paulownia plank
12 - Aluminum gutter
13 - Oak 140/67 triple glazed window
14 - 25 mm Robinia plank with10 mm spacing
15 - 38 x 89 mm Paulownia stud
16 - 40 mm Paulownia plank
17 - 330 x 45 mm I-joist (450 mm c/c) (45 x 45 mm flange with 270 mm OSB web) with 100 kg/m3 density straw bales
18 - 18 mm Paulownia plank
19 - 38 x 89 mm Paulownia stud
20 - 140 mm dia treated Robinia pile
+2.980
+0.680
slope: 2%
+/- 0.00
Detail 1



1 - 0.7 mm Aluminum corrugated sheet (reclaimed)
2 - 24 x 48 mm Paulownia purlins 1200 mm c/c
3 - 24 x 48 mm Paulownia rafters 450 mm c/c
4 - EPDM roof membrane
5 - 360 x 45 mm I-joist (450 MM c/c) (45 x 45 mm flange with 300 mm OSB web) with 100 kg/m3 density straw bales
6 - 18 mm Flax boards
7 - 60 x 24 mm Paulownia purlins 300 mm c/c
8 - Vapour permeable breather membrane
9 - 20 mm lime plaster with jute mesh
10 - 250 x 75 mm Douglas beam
11 - 40 mm Paulownia plank
12 - Aluminum gutter
13 - 8 mm dia willow twigs vertical
14 - 20 mm dia willow twigs horizontal 360 mm c/c
15 - 20mm dia willow rods vertical 280 mm c/c
16 - Vapour permeable breather membrane
17 - 20 mm lime plaster with jute net
18 - 450 x 45 mm I-joist (800 mm c/c) (45 x 45 mm flange with 360 mm OSB web) with 100 kg/m3 density straw bales
19 - 25 mm lime plaster with jute mesh
20 - 45 x 45 mm Paulownia stud
21 - 40 mm Paulownia plank
22 - 18 mm Paulownia plank
23 - 330 x 45 mm I-joist (450 mm c/c) (45 x 45 mm flange with 270 mm OSB web) with 100 kg/m3 density straw bales
24 - 18 mm Paulownia plank
25 - Aluminum flashing
26 - 38 x 89 mm Paulownia stud
27 - 140 mm dia treated Robinia pile
+0.680
+/- 0.00
Detail 2

Elevation

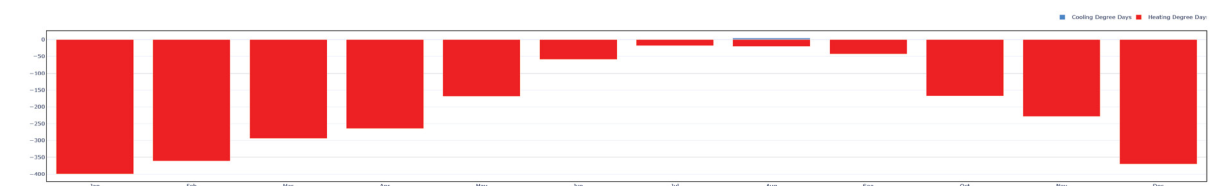
Designing for Efficiency: Energy Systems of the Kumiki Model House

The wind farms, consisting of 86 wind turbines located on the west side of the Noordoostpolder, generate approximately 1.4 billion kWh of clean, renewable electricity each year (Windpark Noordoostpolder, n.d.). This amount of electricity is sufficient to meet the energy needs of around 400,000 households. Additionally, a solar park is in the final stages of development. This solar park will be installed in the fragmented areas surrounding the existing wind turbines along the Noordermeerdijk in the Noordoostpolder, where the land is less feasible for agricultural purposes. The anticipated energy output from the solar park is expected to cover the electricity consumption of roughly 26,000 households (Lankhorst, 2021). Moreover, the potential for cable pooling, by connecting the existing wind farm grid to the solar park is being explored. This could facilitate continuous energy generation throughout the year.

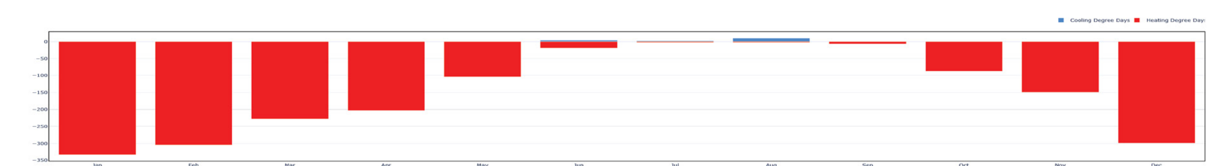
The Kumiki model house will obtain operational electrical energy from the wind and solar parks. Due to the high embodied carbon footprint of solar panels and the requirement for a tilt angle of 44° South for optimal energy generation, the proposed design does not include solar panels on the roof.

Rainwater from the roof is channelled through gutters and either percolated into the ground or used for farming and gardening. Storing and filtering this water for domestic use is neither ecologically nor financially feasible in this case, as it would require the construction of an underground storage tank, ideally made of concrete, which would disturb the topsoil and contribute to carbon emissions. Additionally, the current water rates are very low in the Noordoostpolder, further reducing the incentive to implement such a system.

Fig 95 – Zuidwester onshore wind farm, Noordoostpolder. Source – RWE AG.



The set points taken into consideration are 18^{0} for HDD and 26^{0} for CDD



The set points taken into consideration are 18^{0} for HDD and 26^{0} for CDD

Fig 96 (above) – The Heating Degree Days (HDD) and Cooling Degree Days (CDD), calculated with set points considered, are 18^{0} for HDD and 26^{0} for CDD. These values are derived from the EPW file of the Noordoostpolder for the year 2020.

Fig 97 (below) – The Heating Degree Days (HDD) and Cooling Degree Days (CDD), calculated with set points considered, are 18^{0} for HDD and 26^{0} for CDD. Estimated HDD and CDD for the year 2080 have been generated by morphing the 2020 EPW file.

The comparison between the HDD and CDD for 2020 and 2080 suggests a shift toward a warmer climate in Noordoostpolder. By 2080, residents may experience slightly warmer summers and milder winters. However, heating will still be the dominant energy requirement. The use of thick straw bales for high insulation, along with high-tech triple-glazed windows and passive strategies such as roof overhangs, recessed windows, thermal mass from compressed earth blocks, a high percentage of glazing on the south façade and limited openings on the east and west side, will significantly reduce the heating demand. In addition, a wood pellet boiler is proposed to ensure comfort. This system uses pelletised cylindrical pieces 10–20 mm long, with 5 to 10 mm dia. Energy is consumed to produce wood pellets in comparison to chipping wood but the uniform compact size, low moisture content and high calorific value (Selkimäki et al., 2010) make them ideal for burning in relatively small residential stoves. This system offers nearly neutral CO_2 emissions with a high energy output, and wood pellets are readily available as they are commonly used for biopower generation in the Netherlands (Guo et al., 2015). A small number of pellets are fed into the combustion chamber for burning, with the feed rate controlled by a thermostat. The heat generated from combustion is transferred to water within a closed system, which is then circulated through radiators in the habitable spaces. In the Kumiki House Model, the installation room is centrally located to optimise energy efficiency.

Operational Framework

A mechanical ventilation system is proposed for the kitchen and bathroom, where excess moisture is generated. All other habitable spaces will be ventilated naturally. Detailed planning and selection of all installations will be carried out during the technical phase, along with the engineering of the structural components. Due to time constraints, the scope of this research is limited to material research and the design phase.

The Kumiki Model House will be constructed by students from the Allround Timmerman carpentry course under supervision. This hands-on experience will allow students to build a tiny house using biobased and natural materials.

The construction site will be open to the public on certain days, fostering community development initiatives, landscape restoration, and collective farming. Lastly, after the construction of the Model House, Kumiki also aims to monitor the hygrothermal performance to analyse the energy savings.

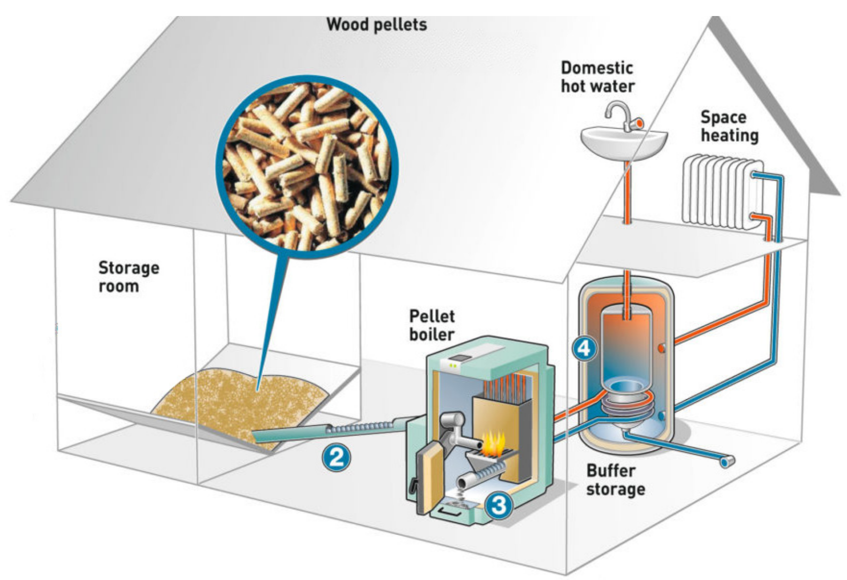


Fig 98 – Edited by author, Wood pellet furnace. Source – https://www.sustainableheating.org/wood-pellet-furnace/

Operational Framework

Environmental Impact – LCA (Cradle-to-Gate)

As the global population grows, the fair share of services and resources our global ecosystems provide diminishes, leading to a widening disconnect between society's resource consumption and ecological replenishment (Vale & Vale, 2013). If resource consumption continues as usual in the building sector embodied emissions will contribute nearly half of all emissions by mid-century (United Nations Environment Programme & Yale Centre for Ecosystems + Architecture, 2023).

The final chapter elaborates on one of the objectives of the research, to demonstrate potential environmental savings by selecting locally sourced biobased materials and implementing low-impact technology in the Kumiki Model House. By quantifying the potential environmental impact (PEI) and global warming potential (GWP)—which measures the mass of CO_2 released into the atmosphere per unit mass of material—alongside biogenic CO_2 storage, this approach underscores the significance of selecting resources cautiously. The Kumiki Model House is currently in the engineering phase, so the life cycle assessment (LCA) is limited to a cradle-to-gate analysis (A1-A3). This assessment methodology considers the energy, materials, processes, and land-use inputs required to produce a unit of a specific product.

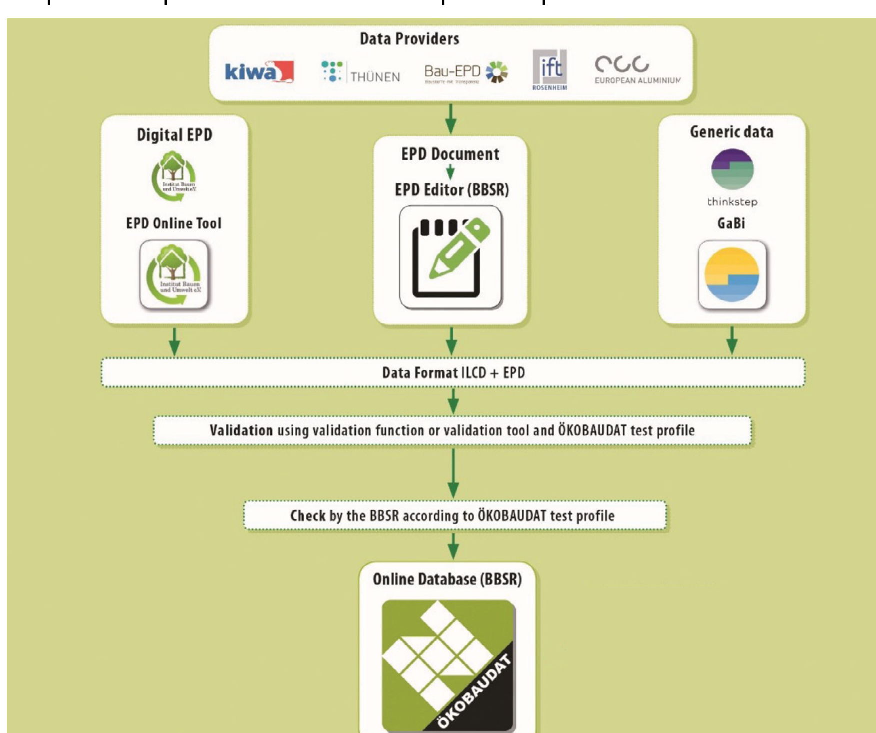


Fig 99 – Edited by author, standardised processes – data generation of Ökobaudat online database. Source: ÖKOBAUDAT Manual Technical and formal information and rules for the ÖKOBAUDAT database. https://www.bbsr.bund.de/BBSR/EN/Research-Programmes/References/_Node/OekoManual.pdf

The analysis will be performed using database Ökobaudat due to its open access and Intuitive interface. In cases when selected materials do not have attributed EPDs in the database, product-specified EPDs by suppliers are referred. This database provides standardised data for ecological evaluations of buildings by the Federal Ministry for Housing, Urban Development and Building (BBSR, 2021). The Ökobaudat online database includes LCA and EPDs of building materials, energy, transport, and construction processes, all in compliance with DIN EN 15804. The database is updated annually with new EPDs added regularly (BBSR, 2021). The recent version – 2023-I from June 15, 2023, was referred to.

Assumptions and Method of Calculation

The inventory of the materials used in the design of the Kumiki Model House was extracted from BIM (ArchiCAD). Thereafter reference unit, density, PEI-Primary Energy Intensity both renewable and non-renewable (PERT + PENRT), GWP total and GWP biogenic were extracted from the Ökobaudat database.

Assumptions need to be embraced as the data extracted is based on a standardised conventional process, but processes may vary especially when adapting low-impact technology as some processes are skipped. The geographic location might also showcase some variation. This can most certainly result in an overestimation of environmental impact.

The database does not include all the species of timber that are used in the Kumiki Model House therefore similar data based on the wood type or density were considered. For instance, Paulownia is the lightest hardwood, with a density of 260 kg/m³. This lower density significantly impacts the total weight of the structure, especially when compared to the standard density of hardwood in the Ökobaudat database, which is 761.6 kg/m³. In this analysis, we use the PEI (Primary Energy Intensity) and GWP (Global Warming Potential) values from the hardwood data in the Ökobaudat database while considering the specific density of Paulownia wood provided by the supplier.

Straw bale data was extracted from the previous version of EN

15804 +A1. Since GWP biogenic was not available in that version, a conversion was performed by hypothesizing a sequestration of 1.8 kg of CO_2 per kilogram of dry vegetal material.

Elements such as willow twigs and rods, which will not be processed and will be sourced directly from the site and surrounding area, are only considered under A1 (raw material supply) for the analysis.

As aluminium corrugated sheets and gutters will be procured from old barns and repurposed the environmental impact is considered zero.

Installations, fasteners, wall finishes, sanitary fittings and kitchen fittings are not considered in this phase as no adequate information is available. Including these elements would inevitably increase the overall impact.

Environmental Impact

ELEMENT	MATERIAL CLASS	VEGETAL	NATURAL	tot length (l*n)	area (l*w*n)	volume (l*w*h*n)	density			WEIGHT
				[m]	[m2]	[m3]	[kg/m]	[kg/m2]	[kg/m3]	[kg]
Window frame	timber	YES	YES	128.41			2.11			270.95
Wheat Straw	other vegetal	YES	YES			150.40			100.00	15,040.00
lime plaster Outside	Concrete	NO	NO		91.97	1.85			1,800.00	3,330.00
lime plaster Inside	Concrete	NO	NO		91.97	2.26			1,800.00	4,068.00
Treated hardwood (Robinia)	timber	YES	YES			2.66			761.60	2,025.86
Soft wood (Norway Spruce)	timber	YES	YES			3.15			481.60	1,517.04
Douglas sawn beam	timber	YES	YES			2.98			459.00	1,367.82
Paulownia structural element	timber	YES	YES			15.44			260.00	4,014.40
Flax boards	other vegetal	YES	YES		245.00	4.41			400.00	1,764.00
OSB	timber	YES	YES			3.36			600.00	2,016.00
Compressed earth blocks	earth	NO	YES			11.72			2,200.00	25,784.00
Linoleum flooring	other vegetal	YES	YES		102.00			2.90		295.80
Window glass	glass	NO	NO		180.56			30.00		5,416.80
Door frame and shutter	timber	YES	YES		121.38			53.95		6,548.45
Willow cladding	timber	YES	YES		131.35	1.01			485.31	490.16
Water and airtight membrane	plastic	NO	NO		131.35			0.07		8.67
Foil (EPDM)	plastic	NO	NO		239.37			2.00		478.74
Aluminium corrugated sheet	metal	NO	NO		313.34	0.62			2,700.00	1,674.00

Fig 100 – Kumiki Model House material inventory extracted from BIM model.

Fig 101 – Kumiki Model House weight chart illustrating reference unit, PEI-Primary Energy Intensity both renewable and non-renewable (PERT + PENRT), GWP total and GWP biogenic extracted from the Ökobaudat database and product-specified EPDs.

ELEMENT	tot length (l*n)	area (l*w*n)	volume (l*w*h*n)	WEIGHT	Ref unit	PEI renewable	PEI non-renewable	PEI (TOT)	$GWP_{biogenetic}$	GWP (TOT)	PEI non-renewable	PEI (TOT)	$GWP_{biogenetic}$	GWP (TOT)
	[m]	[m2]	[m3]	[kg]	[-]	[MJ/unit]	[MJ/unit]	[MJ/unit]	[kg CO2eq/uni	[kg CO2eq/uni	[MJ]	[MJ]	[kg CO2eq]	[kg CO2eq]
Window frame	128.41			270.95	1m	91.40	53.12	144.52	- 3.86	- 0.37	6,821.14	18,557.81	- 495.28	- 47.46
Wheat Straw	0.00	0.00	150.40	15040.00	1m3	1,650.00	62.80	1,712.80	- 1.80	- 127.00	9,445.12	257,605.12	- 27,072.00	- 19,100.80
lime plaster Outside	0.00	91.97	1.85	3330.00	1m3	1,209.00	2,621.00	3,830.00	-	397.70	4,848.85	7,085.50	-	735.75
lime plaster Inside	0.00	91.97	2.26	4068.00	1m3	1,209.00	2,621.00	3,830.00	-	397.70	5,923.46	8,655.80	-	898.80
Treated hardwood (Robinia)	0.00	0.00	2.66	2025.86	1m3	23,260.00	1,377.00	24,637.00	- 1,252.00	- 1,136.00	3,662.82	65,534.42	- 3,330.32	- 3,021.76
Soft wood (Norway Spruce)	0.00	0.00	3.15	1517.04	1m3	8,971.00	1,344.00	10,315.00	- 793.70	- 693.20	4,233.60	32,492.25	- 2,500.16	- 2,183.58
Douglas sawn beam	0.00	0.00	2.98	1367.82	1m3	1,106.00	1,787.00	2,893.00	- 814.70	- 693.50	5,325.26	8,621.14	- 2,427.81	- 2,066.63
Paulownia structural element	0.00	0.00	15.44	4014.40	1m3	10,420.00	717.20	11,137.20	- 796.30	- 741.30	11,073.57	171,958.37	- 12,294.87	- 11,445.67
Flax boards	0.00	245.00		1764.00	1m2	20.50	111.00	131.50	- 6.83	8.00	27,195.00	32,217.50	- 1,673.35	1,960.00
OSB	0.00	0.00	3.36	2016.00	1m3	1,340.00	8,209.00	9,549.00	- 986.70	- 639.30	27,582.24	32,084.64	- 3,315.31	- 2,148.05
Compressed earth blocks	0.00	0.00	11.72	25784.00	1m3	103.50	1,542.00	1,645.50	-	91.76	18,072.24	19,285.26	-	1,075.43
Linoleum flooring	0.00	102.00	0.00	295.80	1m2	70.40	46.50	116.90	- 4.26	- 0.66	4,743.00	11,923.80	- 434.52	- 67.32
Window glass	0.00	180.56	0.00	5416.80	1m2	82.15	719.90	802.05	-	57.14	129,985.14	144,818.15	-	10,317.20
Door frame and shutter	0.00	121.38	0.00	6548.45	1m2	1,077.00	584.00	1,661.00	- 62.00	- 24.70	70,885.92	201,612.18	- 7,525.56	- 2,998.09
Willow cladding	0.00	131.35	1.01	490.16	1m3	8,544.00	217.30	8,761.30	- 794.40	- 777.20	219.47	8,848.91	- 802.34	- 784.97
Water and airtight membrane	0.00	131.35	0.00	8.67	1m2	0.88	8.24	9.12	-	0.35	1,082.85	1,197.90	-	45.50
Foil (EPDM)	0.00	239.37	0.00	478.74	1m2	12.96	230.30	243.26	-	8.35	55,126.91	58,229.15	-	1,998.74
Aluminium corrugated sheet	0.00	313.34	0.62	1674.00	1kg	46.79	-	-	-	-	-	-	-	-

	Ökobaudat					
	WEIGHT	PEI non-renewable	PEI	GWPbiogenet	GWPpositive	GWP (TOT)
	[kg]	[MJ]	[MJ]	[kg CO2eq]	[kg CO2eq]	[kg CO2eq]
timber	18250.68	129804.02	539709.72	-32691.65	-57387.85	-24696.21
other vegetal	17099.80	41383.12	301746.42	-29179.87	-46387.99	-17208.12
earth	25784.00	18072.24	19285.26	0.00	1075.43	1075.43
aggregates	0.00	0.00	0.00	0.00	0.00	0.00
stone	0.00	0.00	0.00	0.00	0.00	0.00
concrete	7398.00	10772.31	15741.30	0.00	1634.55	1634.55
HP clay	0.00	0.00	0.00	0.00	0.00	0.00
glass	5416.80	129985.14	144818.15	0.00	10317.20	10317.20
metal	1674.00	0.00	0.00	0.00	0.00	0.00
plastic	487.41	56209.76	59427.05	0.00	2044.24	2044.24
others	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	**76110.68**	**386226.59**	**1080727.90**	**-61871.52**	**-88704.43**	**-26832.92**
VEGETAL	35350.48	171187.14	841456.14	-61871.52	-103775.84	-41904.33
total natural	61134.48	189259.38	860741.40		-40828.90	-40828.90
OTHER NATURAL	25784.00	18072.24	19285.26		62946.94	1075.43
HUMAN-MADE MATERIALS	14976.21	196967.21	219986.49		-47875.53	13995.98

Fig 102 – Kumiki Model House LCA results

Results

The area of the Kumiki Model House is 201.1 m², including 50 m² outhouse storage area. The total weight of the house is 761.10 tons, which equals 3.78 tons per m².

Biobased and natural materials together account for **80.32%** of the total weight. The remaining **19.68%** consists of human-made materials. Within the biobased and natural materials category:

- **Biobased materials** (such as straw, flax, and various timber species) make up **46.44%** of the total weight.
- **Natural materials** (like compressed earth blocks) account for **33.88%** of the total weight.

This breakdown indicates that, even though the volume of biobased materials is relatively high, these materials have lower densities compared to natural materials like compressed earth blocks, which have a density of **2200 kg/m³**. This explains why biobased materials, despite their larger volume, do not dominate the total weight.

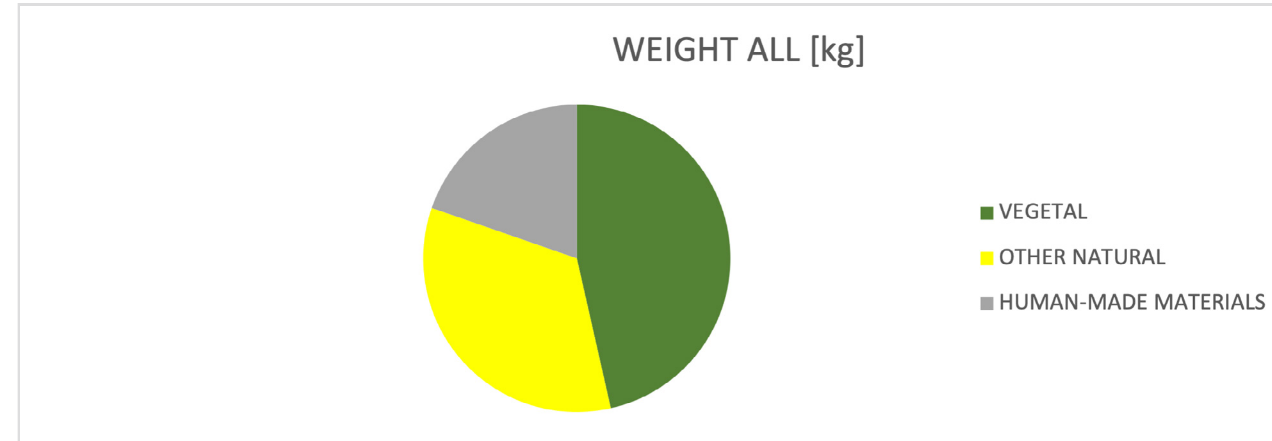


Fig 103 – Kumiki Model House weight contribution by macro material category. The building materials used were aggregated into three macro-categories: bio-based, other natural and human-made materials.

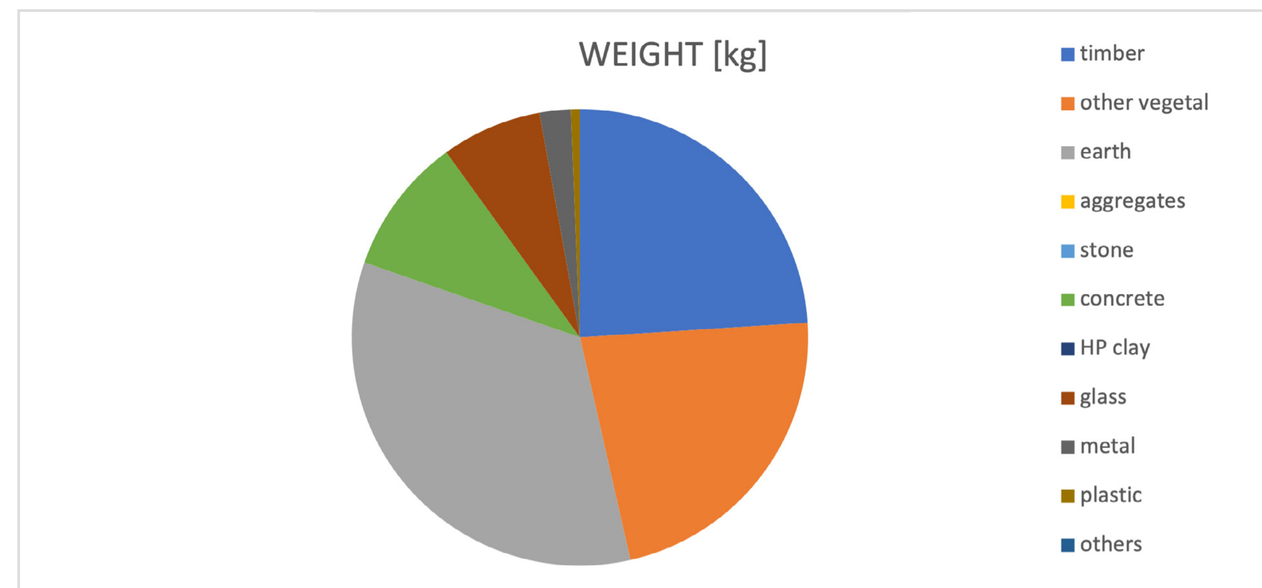


Fig 104 – Kumiki Model House weight contribution by material category. The building materials used were aggregated into eleven categories.

Environmental Impact

The weight of the material is one of the key factors that significantly contributes to the Global Warming Potential (GWP). A lower percentage of human-made materials is due to the cautious use of 'Industrial vitamin'. When comparing materials, man-made materials like aluminium corrugated sheets and gutters, glass, lime plaster and foils have a higher weight relative to their volume. For instance, only 0.62 m^3 of the volume of aluminium sheets accounts for 2 per cent of weight. Aluminium has one of the highest embodied emissions hence in this project sheets will be reclaimed from surrounding barns and repurposed. The selection of this material was mainly to protect all the biobased materials in the superstructure.

The total PEI value of the building is 1080727.90 MJ of which 386226.59 MJ is non-renewable PEI. 1080.72 GJ gives a PEI of 5.37 GJ/m^2. The categories with the highest incidence in this result are timber elements with 50% (539.70 GJ), other vegetal, including straw and flax with 28% (301.7 GJ), glass with 13% (144.8 GJ), and plastic, i.e. foils and EPDM with 5% (59.4 GJ).

OTHER VEGETAL and TIMBER materials have a significantly higher total PEI than non-renewable PEI, suggesting a substantial contribution from renewable energy sources. While HUMAN-MADE MATERIALS (GLASS, PLASTIC, CONCRETE) show a high reliance on non-renewable energy sources as indicated by the close numbers between the total and non-renewable PEI.

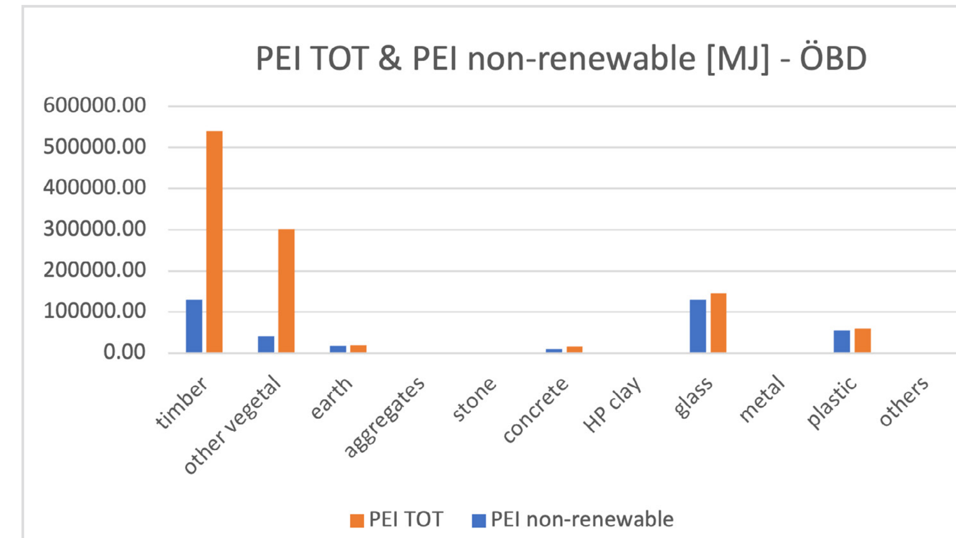


Fig 105 – Kumiki Model House primary energy intensity (PEI) both PEI TOT and PEI non-renewable by material category. The building materials used were aggregated into eleven categories.

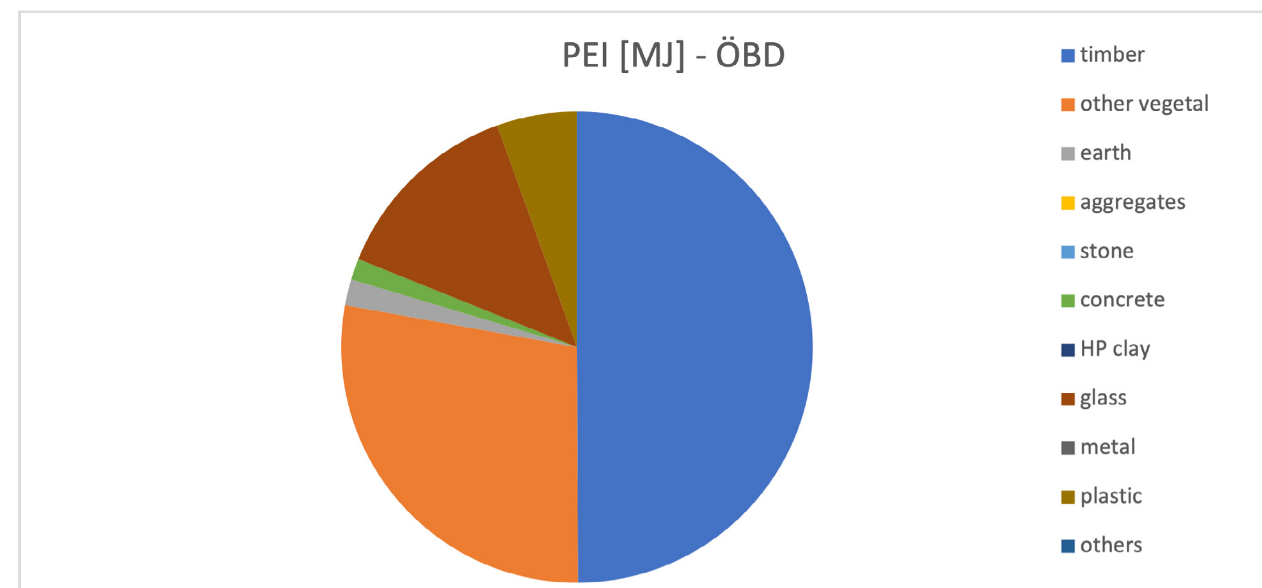


Fig 106 – Kumiki Model House primary energy intensity (PEI) by material category. The building materials used were aggregated into eleven categories.

Environmental Impact

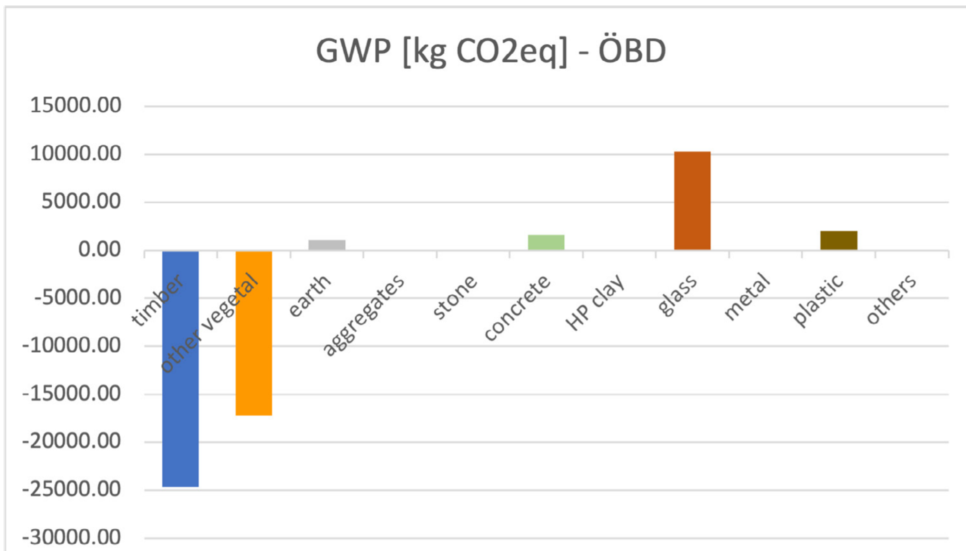


Fig 107 – Kumiki Model House Global Warming Potential by material category. The building materials used were aggregated into eleven categories.

The negative values of the total Global Warming Potential (GWP) reflect the CO_2 plants capture during their growth phase through photosynthesis. In the analysis of the Kumiki Model House, negative GWP values were recorded for all timber species used, including paulownia, impregnated robinia, Norway spruce, Douglas fir, oak, and willow (–24,696.21 kg CO2eq). Annually harvested bio-based materials like straw and flax showed negative GWP values (–17,208.12 kg CO2eq). In contrast, the primary contributors to positive GWP are energy-intensive products such as glass, lime plaster, and plastic foils. Reclaimed aluminium corrugated sheets and gutters were excluded from this analysis. The high negative GWP values for vegetal materials are mainly due to the use of straw as insulation in the roof, slab, and walls.

The low environmental impact of the Kumiki Model House is achieved through specific design choices for the foundation, including a raised slab and a composite timber pile foundation. Previous research has shown that foundations and below-grade insulation significantly affect a building's overall environmental impact, even when low-impact materials are primarily used (Bocco & Bocci, 2022). In the case of the Kumiki Model House, a timber pile foundation is proposed because the superstructure is single-storey and primarily constructed from lightweight biobased materials.

Environmental Impact

Conclusion

This research sought to explore integrating nature, agriculture, and housing into the Dutch countryside through a restorative and regenerative lens. This approach was investigated by proposing the development of a real-world demonstrative case study in the Noordoostpolder. The use of biobased materials and permaculture principles formed the core of the project's approach. By developing the Kumiki Model House, a demonstrative case study, the research has highlighted how regional architecture and landscape development can embrace sustainability, aligning with the urgent need for climate-responsive solutions.

The key achievement of the study is demonstrating how the use of local, low-processed bio-based materials in large quantities for the Kumiki Model House can contribute to achieving carbon-negative or near-zero-carbon buildings. This is partly attributed to the composite timber pile foundation with a raised floor, which eliminates the need for concrete and steel. Additionally, the small floor area of the proposal helps reduce overall (embodied) resource consumption. The simultaneous application of both strategies results in the most significant carbon savings.

The findings from the preliminary Life Cycle Assessment (LCA) underscored the critical role of early design choices in minimising carbon intensity, offering valuable insights for future sustainable construction practices.

In the Noordoostpolder, current farming practices are not immediately threatened; however, the continued reliance on monoculture farming and increasing demand could lead to severe environmental issues in the long term, with significant consequences for the agricultural sector. The proposal to integrate permaculture principles into a small section of arable land is ambitious. While it may not initially yield comparable results to conventional methods, it aims to demonstrate alternative farming practices by introducing diverse biodiversity and incorporating biobased fibre cultivation for material purposes. The core objective is to avoid simply replacing one form of monoculture with another or substituting toxic, emission-intensive materials with industrialised, global, and mass-produced biobased materials. Instead, the goal is to develop more sustainable and environmentally friendly farming practices.

This highlights a limitation encountered during the fieldwork: the current Dutch market for local and minimally processed materials is niche and overshadowed by conventional, highly processed materials and imported processed timber for construction. Coordinating an interdepartmental policy strategy across nature, agriculture, and housing could accelerate the transition to a low-carbon society by promoting the use of local and minimally processed biobased materials.

In regions like the Noordoostpolder, where timber as a biobased structural material is scarce, there is potential to use abundantly available straw as a load bearing. Current building regulations do not permit this, but adopting straw as a load bearing could reduce the pressure on timber and help accelerate the transformation of the global building stock into a carbon sink (Göswein et al., 2022).

Going forward, the next steps will involve the engineering and implementation phases of the Kumiki Model House and associated farming practices. Engaging the community and stakeholders, such as the Allround Timmerman carpentry students, will be essential in transforming this project into a social experiment that not only tests the practicality of the model but also fosters local involvement in sustainable development. Moreover, monitoring the hygrothermal performance of the house will provide further data on its energy efficiency.

On an overarching level of analysis, this research contributes to the broader discourse on sustainable development by proposing a holistic, place-based approach that integrates architecture, agriculture, and ecological regeneration. By advancing the use of local biobased materials and promoting permaculture, the project provides a blueprint for building more resilient, low-carbon communities. Future studies could expand on these findings, focusing on overcoming market and regulatory challenges to facilitate the widespread adoption of such practices.

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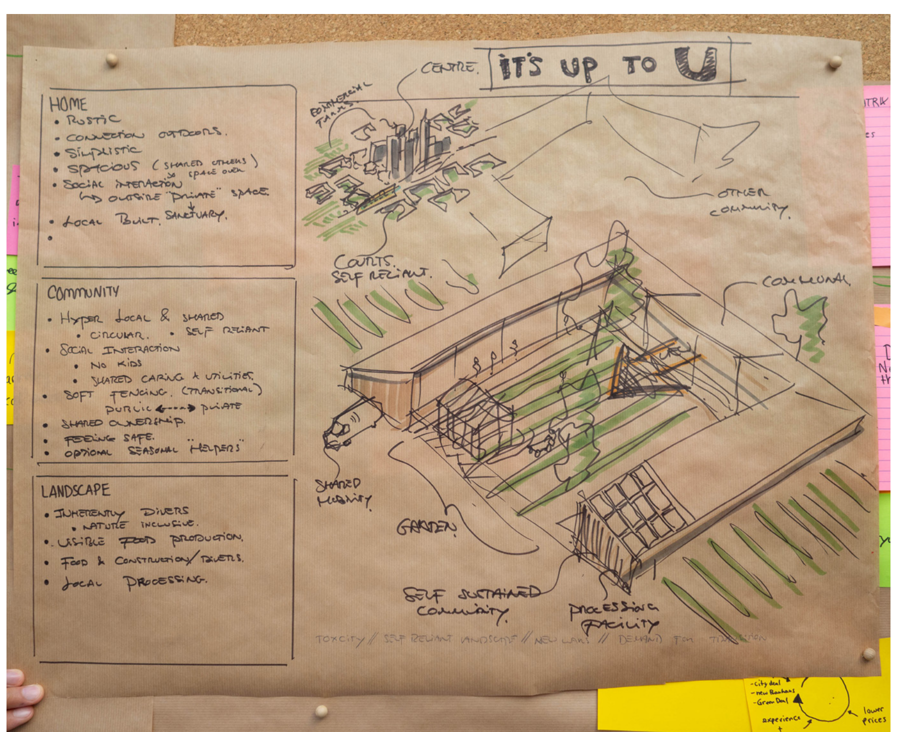
Appendix



Brainstorming sessions at Kumiki for Kumiki House vision organised by Studio Futurall

Brainstorming sessions at Kumiki for Model house design, team – Kevin, Mees, Priyank

Families with kids, couples who are or are not planning to have kids. Those who are researching the possibilities of living outside of the defined 'urban' areas.

Family life

Motivations

> Affordability
> Low energy bill
> Better air quality
> Easy access to healthy food
> Space for hobbies
> Space for storage
> Space for guests
> Space around the home for recreation
  i.e. Outdoor activities
> Environment with similar minded people
  i.e. Friendly neighbours
> Sense of community
> Self sufficient
> Isolated from future pandemics
> Healthy indoor climate
> Good work from home space
> Safer streets for kids to be outside
> Less (perceived) crime
> Good lifestyle image

"Less maintainance as/or both are full-time working."

"Products or services should be carefully choosen so that it can be fixed with DIY approach for minor defects. "

"Community around the house/site for development of kids."

"Outdoor learning with The Community Classroom"

"Multi-purpose hobby space/ guest room. "

Barriers

x Reliant on private automobiles
x Unsafe roads for kids to go to school
x Lack of social life besided work and kids
x Leaving social circle
x Schools to choose from
x Lack of culture
x Missing out on global food
x Access to medical care
x Lack of cultural exposure for kids
x Unconventional design and way of living
x Value increase of home unproven
x Access to public transport

Farmers who are already tiptoeing into regenerative agriculture, organisations working with regenerative goals.

Regenerative and agricultural entrepeneurs

Motivations

> Grow and sell hyper local
> Diversifying the business model
  i.e. Renting out houses, selling land, renting out land.
> Always someone taking care of the land
  i.e.: Have residents help out, protection by presence
> A viable financial model that helps regenerate
> Option for it to be hassle free
> Steady income throughout the year
> Good image of agricultural sector
> Financial donars can experience the effect
> Forming healthy farmer communities
> Storage space can be allocated per dwelling
> Sharing the good rural life
> Regenerating barren agricultural land
> Crops processing can be done locally

"Generate income from unused areas of existing land and also continue to use the land without disrupting the business."

"Maintain profitable healthy farming and production practice."

"Success in farming isn't measured solely in the size of your yield; it's about cultivating a balance between profit and the well-being of the land, the people, and the future."

"Showcasing a small sneak peak into their life."

Barriers

x Urbanites complaining about noises and smells
x New residents are just a nuissance
x Diversifying just makes it more complex
x Infrastructure will harm the land
x More work, also taking care of residents / guests
x Long process to have municipality approve

User Analysis for the Kumiki house design, team – Kevin, Mees, Priyank.

Those who create for a living, artists, small farmers, food producers.

Small creators

Motivations

> Space to work remotely
> Space to create
> Space to host friends and family
> Space to host parties
> Temporary
> Help sustainable process
> Option to rent
> Healthy environment
> Support digital nomad lifestyle
> Help build your own home
> Proximity to outdoor activities
> Outdoor gym, physical activities
> Pioneer
> Compact house
> Affordability
> Sense of community
> Ample storage
> Space for parking
> Proximity to raw natural materials
> Inspiring environment
> Instagram-able lifestyle

"In a favorable environment, the seeds of creativity take root and flourish. It's where ideas are nurtured, workshops bloom, and artistic visions find their stage to exhibit the beauty they hold."

"Small spaces with big potential."

"Loading and unloading facilities connected to site."

Barriers

x Loneliness
x Lack of connectivity to parties
x Lack of night life
x Uncertainty of work
x Far from culture
x I only go if y'all are going too
x Lack of social life vibrancy
x Depended on automobiles
x FOMO
x Leaving social circle
x Un-affordable
x Boring

Those who's kids are out of the house. Currently still living in a family house that is not matching their current dwelling requierments.

Empty nesters / retirees

Motivations

> Nice views
> Healthy indoor and outdoor environtment
> Nearby typically religious areas
> Safer surroundings to walk and recreate
> Safer space to host grand children
> Space to host guests
> Going back to roots
> Space to house caregiver
> Happy to create space in housing market
> Option for Airbnb / B&B
> Option to rent, spend money on fun things
> Community living and sharing
> Space for hobbies
  i.e.: Farming, gardening
> Sizing down, quality up
> Space to park campervan

"Comfort is key."

"A home tailored as a suit, with usuable hobby spaces that are an integral part of the house."

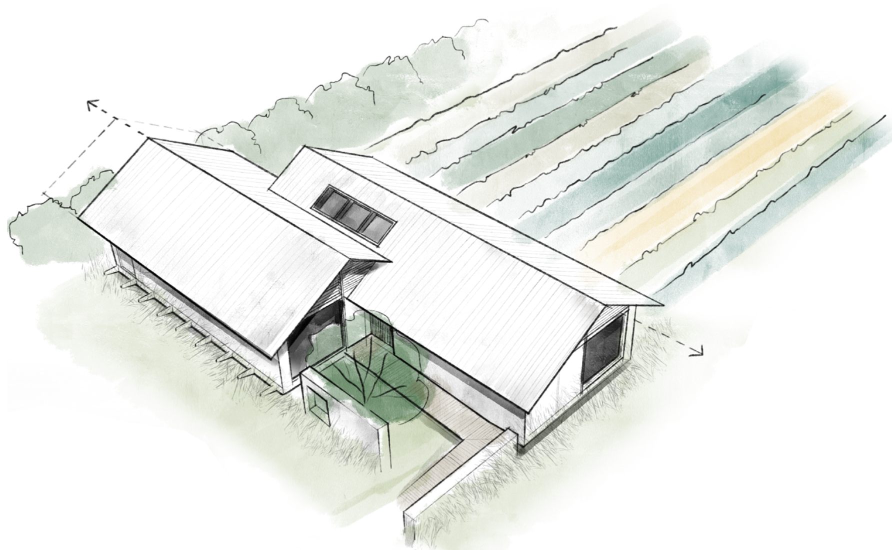
"Clever solutions to adapt the house to different situations, like a fold out bed for guests."

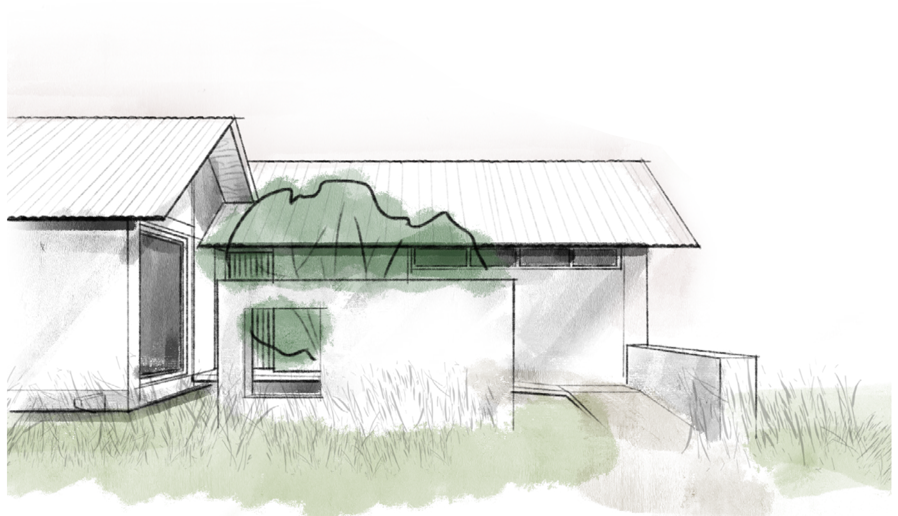
"Conviniences like low maintanance, parking your car in a carport an being able to easily charge it, space to comfortable store and charge a bicycle."

Barriers

x Leaving social circle
x Medical / healthcare far away
x Loneliness
x Maintainance of house and garden
x Smaller house means less quality

User Analysis for the Kumiki house design, team – Kevin, Mees, Priyank.





Mass study for the Kumiki house design, team – Kevin, Mees, Priyank.

Material palette for the Kumiki house design, team – Kevin, Mees, Priyank.

Discussion Session organised by Building Balance Organisation involving Flevoland farmers, inspirators, builders, municipalities and schools on Flevoland straw as a building material.

Blow-in straw instalation demo organised by Building Balance Organisation.

Discussion Session organised by Building Balance Organisation involving Flevoland farmers, inspirators, builders, municipalities and schools on Flevoland flax as a building material.

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