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The Kumiki Model House: Building Alternatives in the Dutch Countryside

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Abstract. Given the urgent need to reduce GHG emissions, achieve net cooling impacts while addressing the severe housing crisis in the Netherlands, this paper proposes an alternative way of living in the Dutch countryside by integrating nature, agriculture and housing. This demonstration case study emerged from social and political demands and is being 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 considers the landscape, farming, local development, environmental performance, land health, and lifestyle. The Kumiki Model House aims at implementing the theoretical take on 'Vernacular Architecture of the 21st Century'. This paper retraces the design process and the logic behind it, while attempting to quantify the response to the 'new vernacular' principles, by demonstrating the potential of regionally produced, locally available, natural and fast-growing bio-based materials in the Noordoostpolder. These materials and the related building techniques have a low environmental impact, while still catering to contemporary expectations. The Life Cycle Assessment performed for stages A1-A4 shows that the use of fast-growing, locally sourced bio-based materials like straw, flax, paulownia and willow, along with a limited use of robinia, Douglas fir, Norway spruce, and oak, allows the Kumiki Model House to store significant amounts of biogenic CO2, making it carbon-negative. Moreover, the multi-layered issues in Noordoostpolder are addressed through permaculture principles, emphasising regenerative living, self-reliance, and resource use minimisation.

1. Introduction

Since the 2008 financial crisis, the Netherlands has faced a prolonged period of subdued residential construction (1). This has exacerbated a significant housing shortage in the country. Additional factors driving this challenge include immigration stemming from international conflicts (2), along with escalating housing prices, growing inequality, a lack of affordable housing options, and increased investment from foreign buyers (3). Years of insufficient construction activity have created a significant backlog in housing supply that cannot be fully resolved by transforming and reallocating existing buildings alone. Eight million buildings are in the process of being insulated, and the government wants to build almost a million additional houses before 2030 (4). The target understates the actual building requirements, so shortages may persist even if it is met (1). On the other hand, to limit further global warming, the Dutch government aims at reducing CO_2 emissions by more than half by 2030, and at becoming fully circular and operating within planetary boundaries by 2050 (5). The construction sector is responsible for approximately 50% of national raw material consumption and 11% of national

CO2 emissions (5). The reduction of CO2 and nitrogen emissions conflicts with the production of construction materials. While no specific data or research is available on materials metabolism for rural architecture in the Netherlands, the Circularity Gap Report (6) provides insights into the overall material metabolism, sources of raw materials and their end-of-use. Detached and semi-detached houses can serve as references for analysing the material metabolism of rural architecture. For these building types, when material input is categorised into four groups—metals, non-metallic minerals, biomass, and fossil-based polymers—concrete and brick emerge as the predominant materials by mass. While ores and fossil-based products contribute to some extent, bio-based materials hold a negligible share of the material inputs. Although some materials are recycled, virgin materials continue to dominate new construction.

To meet housing demand while limiting GHG emissions and temperature rise (7), buildings must act as carbon sinks. Biogenic materials typically contain 50% carbon by mass (8). Large Dutch construction companies are establishing timber prefab factories to build about 1,000 homes annually (9) taking advantage of automation, rapid assembly, moderate costs, regulatory compliance, and carbon storage. However, long-term benefits depend on prolonged carbon storage (10), and local timber availability is scarce. Dutch construction timber mainly comes from EU forests (11). Forests play a crucial role in mitigating climate change by sequestering carbon. About 10% of total EU GHG emissions are currently offset by forests (12), but 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 (13). Wildfires have become more frequent, especially in southern Europe, and further increases are predicted (14).

Harvested wood products (HWP) help tackle embodied emissions but merely transfer carbon from one pool (forests) to another (built environment) (15). Their low emissions are valid only if harvested areas are replanted, taking decades to compensate. Since HWP is not climate-neutral in the short term (16) and resources are insufficient, it cannot achieve carbon neutrality by 2040 nor limit warming to 1.5°C by 2050. Increased timber harvesting will raise GHG emissions for 30 years (17). Thus, HWP should be used wisely in long-lasting applications, and reused to extend carbon storage time. The Netherlands being the second-largest exporter of agricultural goods in the world (18) generates abundant agricultural residues. Fast-growing plants like straw, hemp, flax, and miscanthus sequester carbon annually: they can achieve net cooling impacts more quickly due to their short rotation periods.

2. Method: Research, design framework, LCA framework and boundaries

The research employed a triangular methodological approach, combining research, fieldwork (qualitative data collection), and quantitative analysis. Building Balance facilitated stakeholder engagement in the model house project, with valuable insights from farmers, foresters, millers, and the Noordoostpolder municipality shaping the research. The material investigation and building technology involved a market study of local suppliers and a literature review to assess construction material procurement.

The framework developed for the Life Cycle Assessment (LCA) of the Kumiki House Model follows the ISO 14040 standard (19). The life cycle stages considered are A1 to A4, as described by the EN 15978 standard (20). The construction phase (A5) and use stages are excluded and will be subject of further investigation using first-hand data as the project develops. End-of-Life (EoL) scenarios are excluded from the boundaries of this study. Building services are also excluded, due to their difficult quantification (21). Reused building components are included in the inventory, but their impacts are assumed to be zero since production impacts are allocated to the first use. The bill of quantities was extracted from the Building Information Modelling (BIM) 3D model, and transport distances were calculated from the provider to the site.

Calculations were performed using the SimaPro software (22), with Ecoinvent 3.9 (23) as the reference database and implementing the evaluation method IPCC2021 (24). The selected impact category is climate change, using a characterisation factor of Global Warming Potential over 100 years (GWP100), with results expressed in kgCO2eq. The datasets selected are either representative of the context or European averages (RER).

The biogenic carbon was calculated by defining specific carbon and water contents for each bio-based source, according to the EN 16449 methodology (25). These values were converted to kgCO2eq by applying a -1 factor, following the -1/+1 approach and excluding EoL stages, in line with the partial (cradle-to-site) analysis. Finally, the results were added to the fossil carbon footprint, yielding the CO2 balance for stages A1-A4. The impact was calculated in absolute values, per square metre of gross internal area (GIA) and per kilogram of building weight.

3. Design Choices

In the Noordoostpolder, part of the Flevoland province, villages and small towns are surrounded by large extents of farmland making up a flat, wide landscape subdivided by ditches, where scattered farmsteads are composed by a few buildings around a yard (26). All of this reclaimed land was destined to agriculture (27). The soil of this young polder consists mainly of mineral-rich marine clays with a peat subsoil: it is therefore ideal for developing bio-based circular construction methods and craftsmanship. The municipality of Noordoostpolder has temporarily allotted agricultural use land around the yard where the Kumiki Model House will be built. This temporary allocation supports the ‘Omgevingsvisie Noordoostpolder’ (Environmental Vision Noordoostpolder), ‘Klimaat en Energie’ (Climate and Energy) program, and Landschappelijke inpassing (Landscape integration) (28).

3.1. Design Principles

The Kumiki Model House aims at implementing the theory of a “Vernacular Architecture of the 21st century” (29). The building is designed to demonstrate the potential of regionally produced locally available, natural, and fast-growing bio-based materials in the Noordoostpolder and to minimise high-tech components, using them only when necessary to enhance overall performance, reflecting Peter Harper’s concept of “low carbon + industrial vitamin” (30).

The project uses fast-growing, locally sourced, diverse bio-based materials such as straw, flax, paulownia, and black locust to sequester CO_2. Low-carbon geo-based materials like clay and compressed earth blocks are also employed. Sourcing is facilitated by Building Balance, prioritising contractors’ skill sets. Douglas fir, Norway spruce, and Eco OSB for beams, pile foundations, and structural webs will come from other parts of the Netherlands and Germany, as the current production forest in Flevoland lacks these species. This highlights the need to plant trees specifically for construction. High-tech components such as triple-glazing timber-framed windows, EPDM sheets, and metal flashings ensure material longevity. Corrugated aluminium roofing will be reclaimed from another building.

3.2. Reviving Tradition: Exploring the Possibility of Composite Wooden Pile Foundations

Due to the weak load-carrying capacity of the clay topsoil and peat subsoil, pile foundations transfer loads to deeper bearing ground. The current Dutch built environment heavily relies on concrete piles due to their ease of installation, structural reliability, and assumed durability. This choice comes with significant environmental ramifications such as high GHG emissions, ecological impacts on soil, and loss of soil organic matter. Thiel et al. (31) highlighted that materials such as concrete and structural steel contribute substantially to the environmental footprint of buildings in net-zero energy structures. Foundations, structural components, and electrical equipment were identified as major contributors to environmental impacts (32). For instance, in the Ugakei Circles Centre House, where carbon-negative biogenic materials were used in the superstructure, the reinforced concrete strip foundation alone accounted for 66% of the building's embodied carbon (33).

A key principle of the Kumiki Model House is embracing biogenic materials. Wooden piles align with this approach, acting as a carbon sink, supporting traditional building culture, and highlighting the importance of planting trees locally. In composite timber piles, spruce, with its low-permeability sapwood, is ideal for submerged sections as it resists bacterial decay (35), while the top section is critical, as exposure to oxygen and fluctuating moisture accelerates decay. This is why the part above the groundwater table is usually treated with preservatives to reduce the wood's degradation (34). In this project, Robinia pseudoacacia, a fast-growing, invasive species in Europe (36), was chosen due to its high density; it is naturally pest-resistant and is the only European wood whose durability class is 1-2 (DIN EN 350-2) (37). Its high carbon storage, adaptability to poor soils, short harvesting time (30-40 years), and nitrogen-fixing ability align with the project's philosophy. Impregnation with chemicals that diffuse into wood cells is the most common treatment in similar situations (38); it reduces timber permeability in unsaturated environments. Kebony, a Nordic company with a unit in Belgium, uses a patented process (39), applying biobased furfuryl alcohol from agricultural waste like sugarcane, sunflower, and birch chips (40). The industrial process has not yet been performed with robinia nor with foundation piles. Our proposal aims to test bio-based impregnation methods, which do not involve added chemicals or glues. The two timber sections will be joined to form a fully bio-based pile. Norway spruce piles will be rammed into the ground, then connected to robinia upper sections. The House will be detached from the ground, leaving minimal traces if disassembled.

3.3. Exploring Local Fast-Growing Biobased Materials for the Superstructure

The superstructure predominantly comprises three main elements: the load-bearing structure; the envelope; and the cladding (Figure 1).

The Dutch timber frame tradition predates the brick culture it is known for today (41). However, timber construction declined in the 19th century due to urban fires, stricter regulations (42), and wood scarcity. Modern timber frame construction (HSB), using thin timber elements with bracing sheets, was introduced in the 1970s. Noordoostpolder limited forests are mainly nature reserves (43, 44), making alternative structural materials necessary.

The alternative material explored is fast-growing timber. Paulownia, one of the world's fastest-growing tree species (45) is native to China and now widely cultivated across Australia, Asia, the USA and Europe (46). With physical and mechanical properties similar to poplar and willow (45), its high strength and low density make it ideal for lightweight structures (47). Small sections from locally sourced paulownia are specified in this project due to its fast growth, reducing reliance on imported timber and supporting carbon emission reduction targets.

Furthermore, the thick bio-based insulation in low-energy buildings are advantageously coupled with timber I-beams made of small sections (48).

Sawn paulownia is specified for I-joists, roof battens, purlins, and floor planks. In I-beams, flanges will be solid paulownia, webs OSB boards. Eco OSB made of Dutch timber, formaldehyde free, is specified. I-beams will be used in walls, floors, and the roof, which offer comparable strength to solid timber with less material and are lightweight for easy handling. Solid 150x150 mm lumber will be used for columns where I-joists are not needed.

Straw is specified for insulation (50): it is abundant in Noordoostpolder and ideal for construction. It has a low impact (51) and, in suitable thicknesses, provides higher thermal insulation than most framed wall systems. Thermal resistance can be optimised by adjusting

superstructure predominantly comprises three main elements: the load-bearing structure; the envelope; and the cladding density (49). Straw shows a remarkable heat storage capacity and therefore is conducive to balanced indoor temperatures. It sequesters 60 times more carbon than it emits during the cradle-to-gate phase (52). Building with straw requires no additives, though toxic substances may be present due to the cultivation methods. To prevent rot and fire risks, straw bale walls need thick plaster, roof overhangs, and rainscreens in temperate maritime climates (53). In the Kumiki Model House, straw bales will be used as infill because current building regulations rule out any load-bearing role. Blow-in insulation and prefabrication were excluded because they involve a degree of technology that is unnecessary for the scale of the House. The bales will be sourced from Loonbedrijf Witkop (an arable farm and contracting company located in Noordoostpolder) and will measure 800x450x360 mm with a 100 kg/m^3 density.

Sheathing, lining boards, and plasters are key elements in floor, wall, and roof build-ups. Conventional options include plasterboard, OSB, and softwood sarking boards. Gypsum plasterboard traps moisture, affecting air quality, and requires significant energy to recycle (54). OSB contains chemical adhesives, and regional softwood sarking board production is limited. Fast-growing flax panels from Linum Nagele farm, made from discarded flax loams, will be tested. These residual flax shives require no additional chipping and are sheet-pressed with bio-based resin. The Compost Board company in Liessel, the Netherlands, follows a similar process using hemp, flax, and paprika fibres (55). Such breathable, fire-resistant boards are 100% recyclable and biodegradable. In the barn, flax boards will be used for wall linings.

Bio-based materials are vulnerable to excess moisture, risking structural failure, especially in a temperate maritime climate. Indoor heating increases moisture content, while low outdoor temperatures create high vapour pressure. A permeable, hygroscopic render (clay or lime plaster) allows moisture to move through straw bales to the exterior, preventing condensation. A thick internal render may improve indoor air quality and protects straw and timber from moisture damage (56). However, lime-based renders absorb moisture; while rainwater evaporates, persistent rainfall and strong winds can lead to excessive moisture build-up in straw. Research conducted in Liskeard, whose climate is also temperate maritime, shows that screening effectively mitigates water ingress (53). In the Model House fast-growing, woven, untreated, and unpeeled willow twigs will be used for rainscreen cladding. This choice moves away from conventional, often imported cladding products. Sourced from the site’s willow trees, the ventilated screens form an impervious outer layer, requiring only one lime render coat for fire and vermin protection. Vertical and horizontal wattle constitute the structure while ensuring airflow behind the screen.

Compressed earth blocks, made from Dutch clay soil with low energy input, will be used for internal walls, offering thermal mass to this otherwise relatively lightweight, framed building thanks to their density of 2080 kg/m^3, specific heat capacity of 0.837 kJ/kg·K, and volumetric heat capacity of 1740 kJ/m^3·K (57). The blocks will help regulate moisture, and will be laid with lime mortar and rendered with lime plaster for reusability. Large south-facing glazing and clerestory windows will enhance passive heating, while recessed openings and roof overhangs will minimise summer heat gain.

The small plot surrounding the House will be tended according to Permaculture, mimicking natural ecosystems and designing from patterns to details (58). It is envisaged that techniques such as wide-strip cultivation, agroecological succession, and cover cropping will be demonstrated so to restore the land, enhance biodiversity, improve soil health, and build ecological resilience, aligning with the ethics of Earth Care, People Care, and Fair Share. Thus, the Kumiki Model House will serve both symbolic and functional roles, connecting people to the land and food systems through local, low-impact construction, and embodying principles of regenerative living.

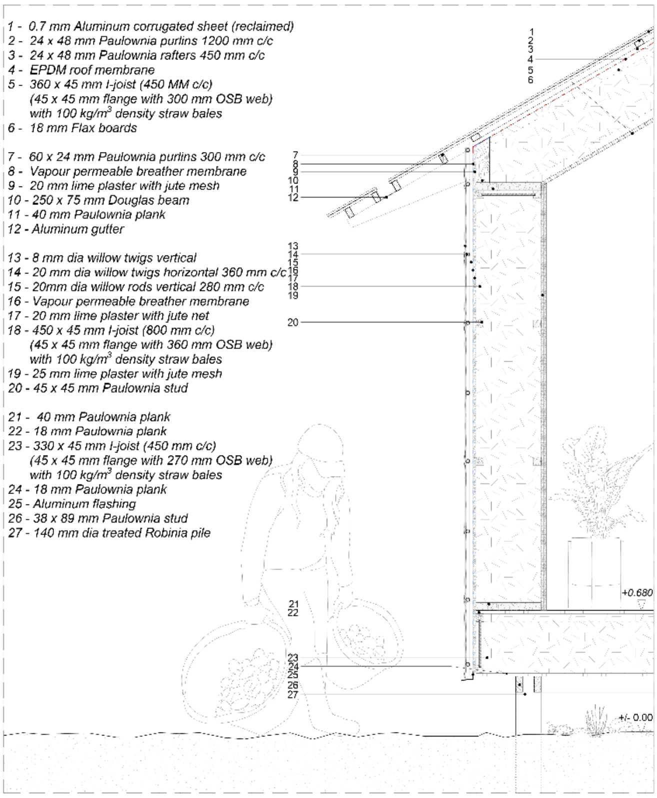

Figure 1. Wall section of Kumiki Model House

4. Environmental assessment of the proposed model

4.1. LCA for stages A1 - A4

The results of the partial LCA are presented below (Figure 2). The building shows a low environmental impact compared with previous studies (59,60). When accounting for biogenic carbon in stages A1-A4, the Model House shows a regenerative potential, storing around 50 tonnes of CO2 – around four times the amount emitted by the production of construction materials and their transport to the site. It should be highlighted that fully attributing the biogenic carbon to phases A1-A4 in the present analysis, may lead to misconceptions derived from still fragmented and unresolved methodologies regarding the approach to accounting for biogenic carbon in LCA studies (61,62)

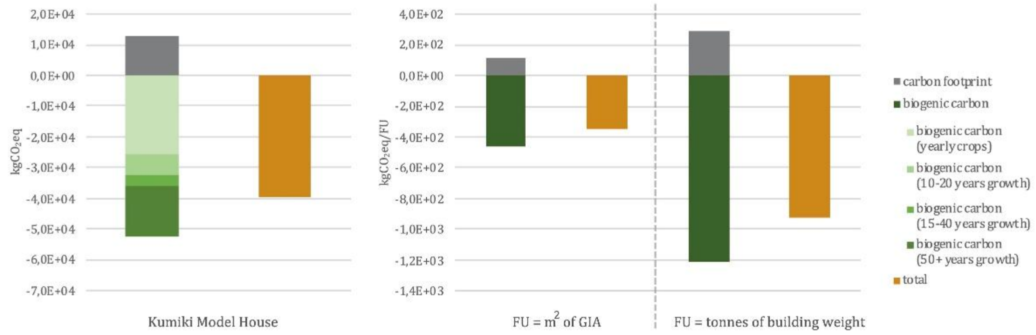

Figure 2. Results of the LCA for stages A1-A4: for the entire building on the left and per unit GIA (m^2) and per unit weight (kg) on the right.

The climate benefit associated with biogenic carbon storage could continue under optimistic end-of-life scenarios which avoid re-emission of biogenic carbon (63), but these stages are not considered for the purposes of this study. Moreover, such climate benefit is achieved through replanting and regrowth of harvested bio-based materials (63): in the case of the Kumiki Model House, one of the main foci of the design process was the greatest possible employment of fast-growing crops and timber from relatively short growth harvesting periods. This is reflected in 49% of the mass of biogenic carbon deriving from yearly crops; 19% is timber with short harvesting cycles (shorter than the nominal building life, that is conventionally set at 50 years). The remaining 32% is timber and processed timber elements ordinarily used in construction.

4.2. *Contribution analysis*

The main contributors to the environmental impact are energy-intensive products like glass and EPDM, despite their low contribution to the building weight (Figure 3). On the contrary, the contribution to the overall impact of low-processed materials like straw and timber, despite their significant amounts, is small. The contribution of transport (phase A4) is around 5%.

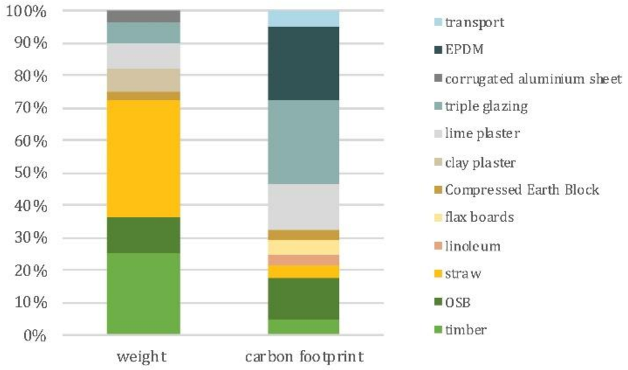

Figure 3. Contribution analysis of each material in the total weight and in the carbon footprint of the building. Contributions smaller than 2% are not shown for clarity.

4.3. *Transport distances and material sources*

The main contributors to the environmental impact are energy-intensive products like glass and EPDM, despite their low contribution to the building weight (Figure 3). On the contrary, the contribution to the overall impact of low-processed materials like straw and timber, despite their significant amounts, is small. The contribution of transport (phase A4) is around 5%.

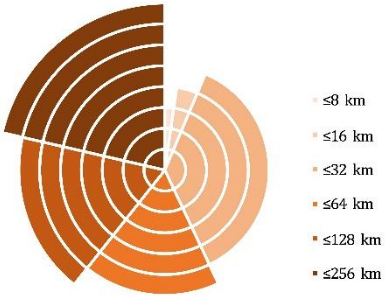

Figure 4. Concentric chart representing the transport distances from the manufacturer to the construction site and the corresponding quantities of material used. The actual maximum distance is 160 km. Distance classes use a logarithmic scale for clarity and comparability with previous studies (60).

Unsurprisingly, we observed that bio-based and minimally processed geo-based materials are relatively straightforward to trace back to the extraction/production of raw materials, while highly processed products pose greater challenges. The significant amount of the first in Kumiki House, allows to trace back 79% of the materials: of these, 49% are sourced at the same location (or the surroundings) of the providers and 30% have a Dutch origin. Of the remaining products, 12% are imported, and 9% have mixed or unknown origin. The latter are highly processed products which also contribute the most to the overall emissions, such as glass and EPDM.

5. Conclusion

The research substantiates the design choices beyond carbon accounting, demonstrating how this experimental community-built project offers an alternative to conventional buildings and aligns regional architecture with climate-responsive solutions – particularly in the countryside. A key achievement is proving that using local, low-processed, fast-growing bio-based materials in significant quantities can achieve a low carbon footprint and even regenerative potential. While natural materials may require more frequent inspection, monitoring the Model House could explore low-impact, self-maintaining strategies supported by long-term stewardship. Future studies could address market and regulatory challenges to support a widespread adoption of such strategies.

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