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RESEARCH PLAN

The potential of biobased installation systems in a passive climate control

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CONTENT

INTRODUCTION

The building industry is a key player of environmental degradation, with material production and energy systems contributing significantly to both waste and carbon emissions. While biobased materials are increasingly used in construction, installation systems— for heating, ventilation, energy generation, and water management—remain a blind spot in these sustainable developments.
This research explores how biobased alternatives can replace conventional installation systems within a passive climate design. By viewing installations not as hidden technical elements, but as visible, architectural components, installations can get a new role in sustainable design.

KEY TERMS

Biobased materials | *Installation systems* | *Passive climate control* | *Embodied carbon* | *Operational carbon*

GLOSSARY OF KEY TERMS

BIOBASED MATERIALS

A (building) material that is wholly or partly derived from biomass (such as plants, animals, enzymes and microorganisms) or agricultural residue that has an equal or shorter renewal period than its rate of consumption. The biobased content of a product is measured by its 14C isotope level, with a higher 14C indicating a greater share of renewable, organic material (Willemse & Van der Zee, 2018).

PASSIVE CLIMATE CONTROL

A design principle that emphasizes on energy efficiency through the combination of thermal-, air-, radiation- and moisture control, using smart design techniques and materials. Making the use of carbon intensive installation systems minimal.

CONVENTIONAL BUILDING INSTALLATIONS

Refers to the standard technical systems integrated into buildings to provide essential functions such as heating, ventilation, cooling, electricity, water supply, and waste management. Conventional building installations typically rely on fossil-based materials, non-renewable resources, and mechanical technologies, and are often concealed within walls, ceilings, or technical spaces.

OPERATIONAL CARBON

The total carbon emission produced during the use of the building, meaning the energy used to operate a building over its lifetime for heating, cooling, lighting and appliances.

EMBODIED CARBON

The total carbon emission produced within the production, transportation, and construction of building materials/the building, including extraction and manufacturing. Also often referred to as cradle to gate.

ARGUMENTATION OF CHOICE OF STUDIO

The choice for the architectural engineering studio lies in my interest of combining architecture with technique. I'm interested in the puzzle of making a building as sustainable as possible, especially focusing on material use, but also including the spatial potential of a building.

I'm fascinated by the effect the form, light, interior, smell and sound of a room can have on your emotions and feelings. I chose architectural engineering to be able to combine the puzzle of sustainability, material use and spatial design.

PROBLEM STATEMENT

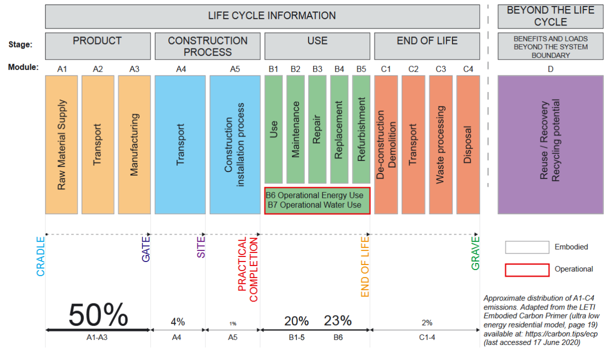
The building sector is a significant contributor to the global environmental degradation, responsible for approximately 37% of the global CO2 emissions and over one-third of the global waste production (UNEP, 2022). Mainstream construction materials, like concrete and steel, produced with fossil based material. Next to the limited supply of these materials, they are often responsible for the high embodied carbon of a building and cause environmental damage when extracted. Once taken from the earth, it takes millions of years for these raw materials to be regenerated.

While in recent years important steps have been made towards the use of more sustainable materials in structural and façade elements, such as timber and biobased insulation, such steps for installation systems remain a critical blind spot. Installation systems like HVAC units, solar panels and heat pumps are considered 'sustainable' for their operational energy efficiency, yet they still heavily rely on harmful, fossil-based materials for their production (Ardente et al., 2008).

Solar panels, for example, require energy-intensive and harmful mining of silicon and rare earth metals, generating 50 to 60 CO2/kWh during their manufacturing process.

Beside this, solar panels are hard to recycle, due to toxic materials like lead and cadmium (Mose Solar, 2025). Also heat pumps, while reducing operational carbon emissions, depend on steel, copper and refrigerants, which contribute to marine ecotoxicity and ozone depletion through material extraction and leakage (Shamoushaki and Koh, 2023).

These production related emissions (cradle to gate) can cause up to 50% of a building's total embodied carbon (figure 1), especially in energy-efficient design where the operational carbon emissions are lower (Orr et al., 2020).



Note. From "A brief guide to calculating embodied carbon," by Orr et al., 2020, The structural engineer, p.22.

While structural and façade components have seen innovation, like the use of biobased materials, installations lack behind because they continue to rely on conventional, high-impact materials, creating a gap in the pursuit of fully circular and low-carbon buildings.

Biobased materials could not only present a solution as alternative for fossil-based materials in construction, but also in installation systems, such as algae systems, mycelium filters and wooden ventilation shafts. Biobased materials often have a reproduction rate which is faster than the lifespan of the material, creating the opportunity to use the materials (relatively) endlessly. Not only is the source almost unlimited, biobased materials capture CO2 while they grow, storing it for the duration of their lifespan.

This makes that the materials often have an positive effect of the environment, storing more CO_2 then it produces. Despite their promise, biobased systems are largely absent from mainstream installation systems, highlighting the need to expand the scope of material innovation beyond structure and façade to include building installation systems. A rethinking of installation techniques through biobased solutions could bridge the gap of the material transition and facilitate the shift towards truly regenerative architecture.

OVERALL DESIGN OBJECTIVE

The design aim of this project is to create a building that shows the potential of biobased materials. As shown in the previous chapter, the production of materials used in buildings (the cradle to gate phase) are responsible for at least 50% of the embodied carbon present in a building. Biobased materials could be the solution to reduce this number significantly, as well as posing a solution for the material shortage the building sector is currently facing.
The design will combine the known potential of biobased materials in construction with the in this research developed knowledge of the potential of biobased materials in installation systems, creating a truly regenerative building.

The project shows how design and installation technique can come together, using passive design principles to minimize the needed installation systems while making the present systems part of the architecture. With the use of biobased construction materials and minimal, biobased installation system, a comfortable and healthy climate will be realized in an multistory apartment building.

OVERALL DESIGN QUESTION

The overall design objective of the project is as followed:

"How can biobased installation systems be integrated as part of the architectural design in a passive residential building?"

REFLECTION ON THE RELEVANCE

The project aims to stimulate architects to truly embrace installation systems as an integral part of the design process. Currently, these systems remain a blind spot in sustainable developments— ventilation ducts made of aluminum, plastic piping, and HVAC units packed with toxic and rare earth elements are still the norm. Installations are often treated as only technical necessities, pushed to engineers or subcontractors after the architectural design is finalized. This project challenges that division by viewing installations as both functional and architectural elements. It asks for a shift in mindset where systems for heating, cooling, ventilation, and water are truly part of the design from the start, materially and spatially. The approach is both specific, offering a installation systems framework to design around for passive multistory housing, and broadly usable, offering new perspectives for the architectural field at large. It challenges architects to view installations as a design opportunity rather than a technical afterthought.

THEMATIC RESEARCH OBJECTIVE

The research aim of this project is to develop a catalogue of biobased installation systems that can serve as alternative systems to conventional, resource-intensive building installations. The project looks for innovative biobased systems that fulfill essential building functions like heating, ventilation, energy generation, and water management through nature-based processes and materials.
The research focuses on how these biobased systems can function within a framework for passive climate control, while also investigating their architectural integration, making installations a visible and meaningful part of the building's design.
A residential building complex of four floors will serve as a case study, setting the functional, spatial, and technical requirements for the research. This scale allows for a realistic evaluation of biobased systems in relation to energy needs, spatial constraints, and design opportunities.
The resulting catalogue will serve as an foundation to design a residential building where biobased installation work hand in hand with passive systems, enhancing both the environmental performance and the architectural expression of the building.

THEMATIC RESEARCH QUESTION

The thematic research will focus on the main question:

"Which biobased installation systems can be integrated in a passive climate control as an alternative for conventional building installations"

In order to answer this question, several sub-questions are addressed:

1. *What are the passive performance requirements for a four story apartment complex in The Netherlands?*
2. *What is the annual energy demand of the hypothetical passive housing complex?*
3. *What biobased can replace conventional building systems for heating, ventilation, energy generation and water management?*
4. *What biobased systems would be able to best supply the energy demand of the hypothetical passive building?*
5. *How feasible is a biobased installation system in passive design compared to a conventional installation system based on cost and carbon footprint.*

REFLECTION ON THE RELEVANCE

The proposed research aims to fill the knowledge gap of the potential of biobased installation systems within a passive climate control. While biobased materials are increasingly explored in structural and façade applications, their role in technical systems remains underdeveloped. This research addresses that gap by identifying and evaluating biobased installation systems as alternative for conventional installations—such as heating, ventilation, water, and energy systems—that are typically reliant on carbon-intensive and non-renewable materials. The project is both specific and explorative: it uses a concrete case study to define technical parameters for passively controlled apartment buildings, while the outcomes offer broader insights for architects, engineers, and policymakers aiming to design more regenerative buildings.

RESEARCH METHODOLOGY

To answer the main research question, a combination of methods is used to address the sub-questions. The overall approach is 'research by design,' as a hypothetical passive building is developed to set performance parameters that serve as a testing ground for the feasibility of different biobased installation systems.
Literature review and case study analysis are used to answer the first sub-question, focusing on a quantitative approach to define the technical requirements of the building. These results are then combined with fieldwork—such as map analysis and GIS data—to determine the project's context.
For the remaining sub-questions, the hypothetical design functions as a reference framework. The third sub-question involves calculations and takes a quantitative approach. The fourth includes interviews with experts to gain insight into existing and emerging biobased systems, also using a quantitative methodology.
The fifth sub-question applies a comparative analysis to link the in sub-question four established systems with the required energy demand from sub-question three.
The sixth also has a qualitative approach, focusing on a comparative analysis of the chosen biobased systems with conventional systems.

EXPECTED RESULTS

The expected outcome of the thematic research is a comprehensive catalogue of biobased installation systems that can can serve as less impactful alternatives to conventional, fossil-based installations.

This catalogue will explore systems for heating, ventilation, energy generation, and water management, based on natural processes and fast-renewable, low-impact materials. It is expected that the catalogue will show the feasibility of 3-5, well thought-out, systems based on their carbon footprint, cost, material composition and compatibility with passive climate control strategies. The integration potential to use the system both technically and architecturally will also be taken into account, serving as an benchmark and checking how systems can become a meaningful part of the design rather than a hidden component.
The research will be directly implemented in the design of a passive multistory residential complex, where the systems from the catalogue are tested in a real architectural context.

The project is successful when at least one of the researched biobased systems is integrated as an visible, architectural and technical component of the final design.

PLANNING

LITERATURE REFERENCES

Algae might be a secret weapon to combatting climate change. (2019, October 1). Quartz. https://qz.com/1718988/algae-might-be-a-secret-weapon-to-combatting-climate-change

Ardente, F., Beccali, M., Cellura, M., & Lo Brano, V. (2008). Energy performances and life cycle assessment of an Italian wind farm. Renewable and Sustainable Energy Reviews, 12(1), 200–217. https://doi.org/10.1016/j.rser.2006.05.013

Biloria, N., & Thakkar, Y. (2020). Integrating algae building technology in the built environment: A cost and benefit perspective. Frontiers of Architectural Research, 9(2), 370–384. https://doi.org/10.1016/j.foar.2019.12.004

Bio-based Building. (n.d.). ONCRA. Retrieved March 19, 2025, from https://biobased.oncra.org/www.oncra.org

Bit.Bio.Bot exhibition shows how algae can be used as air purifiers and protein source. (2021, May 24). Dezeen. https://www.dezeen.com/2021/05/24/ecologicstudio-algae-bit-bio-bot-exhibition-venice-architecture-biennale/

Chayaamor-Heil, N., Perricone, V., Gruber, P., & Guéna, F. (2023). Bioinspired, biobased and living material designs: A review of recent research in architecture and construction. Bioinspiration & Biomimetics, 18(4), 041001. https://doi.org/10.1088/1748-3190/acd82e

Ghimire, U., & Gude, V. G. (2019). Accomplishing a N-E-W (nutrient-energy-water) synergy in a bioelectrochemical nitritation-anammox process. Scientific Reports, 9(1), 9201. https://doi.org/10.1038/s41598-019-45620-2

Innovative materials with carbon fibres made from algae. (2018, November 13). https://www.tum.de/en/news-and-events/all-news/press-releases/details/35547

Jack. (2025, January 31). Solar Panel Manufacturing's Environmental Impact: The Truth Behind Green Production. Mose Solar. https://www.moserbaersolar.com/uncategorized/solar-panel-manufacturings-environmental-impact-the-truth-behind-green-production/

Kravchenko, I., Kosonen, R., Jokisalo, J., & Kilpeläinen, S. (2022). Performance of Modern Passive Stack Ventilation in a Retrofitted Nordic Apartment Building. Buildings, 12(2), Article 2. https://doi.org/10.3390/buildings12020096

Mazzoni, F., & Losacker, S. (2024). What hinders the transition towards a bio-based construction sector? A global innovation system perspective on its value chain. Progress in Economic Geography, 2(2), 100023. https://doi.org/10.1016/j.peg.2024.100023

Miettunen, K., Hadadian, M., García, J. V., Lawrynowicz, A., Akulenko, E., Rojas, O. J., Hummel, M., & Vapaavuori, J. (2024). Bio-based materials for solar cells. WIREs Energy and Environment, 13(1), e508. https://doi.org/10.1002/wene.508

Mihai, M., Tanasiev, V., Dinca, C., Badea, A., & Vidu, R. (2017). Passive house analysis in terms of energy performance. Energy and Buildings, 144, 74–86. https://doi.org/10.1016/j.enbuild.2017.03.025

Milieu-impact van Bouwmaterialen. (n.d.). Groene Bouwmaterialen. Retrieved March 19, 2025, from https://www.groenebouwmaterialen.nl/biobased-bouwen/milieu-impact-van-bouwmaterialen/?source=facebook

Mlecnik, E. (2012). Defining nearly zero-energy housing in Belgium and the Netherlands. Energy Efficiency, 5(3), 411–431. https://doi.org/10.1007/s12053-011-9138-2

Orr, J., Gibbons, O., & Arnold, W. (2020). A brief guide to calculating embodied carbon. The Structural Engineer, 98(7), 22–27. https://doi.org/10.56330/JZNX5709

Pomponi, F., & Moncaster, A. (2017). Circular economy for the built environment: A research framework. Journal of Cleaner Production, 143, 710–718. https://doi.org/10.1016/j.jclepro.2016.12.055

Quist, Z. (2021, July 2). Does 'biobased' always mean 'more sustainable'? Ecochain LCA Software. https://ecochain.com/blog/is-biobased-always-sustainable/

Ranganath, S., McCord, S., & Sick, V. (2024). Assessing the maturity of alternative construction materials and their potential impact on embodied carbon for single-family homes in the American Midwest. Frontiers in Built Environment, 10. https://doi.org/10.3389/fbuil.2024.1384191

Shamoushaki, M., & Koh, S. C. L. (2023). Heat pump supply chain environmental impact reduction to improve the UK energy sustainability, resiliency and security. Scientific Reports, 13(1), 20633. https://doi.org/10.1038/s41598-023-47850-x

The little book of Bio-Based Fibre Materials in Passivhaus Construction in Latin America. (n.d.).

Thieblesson, L. M., Collet, F., Prétot, S., Lanos, C., Kouakou, H., & Boffoue, O. (2017). Elaboration and Characterization Of Eco-Materials Made From Recycled Or Bio-Based Raw Materials. Energy Procedia, 139, 468–474. https://doi.org/10.1016/j.egypro.2017.11.239

Van Den Oever, M., Melchers, R., Van Westerlaak, M., Bakker, B., Engelbrecht, E., Drissen, J., Weterings, H., De Munck, E., Van Der Burgh, F., & Verspeek, S. (2024). Bio-based building products in the Dutch Environmental Database (NMD): Part 3: Example calculations on the environmental impact of A) building products and B) reference buildings to show the effects of: 1) bio-based vs. conventional building products, 2) crediting biogenic carbon storage. Wageningen Food & Biobased Research. https://doi.org/10.18174/683389

Wilkinson, S., Stoller, P., Ralph, P., Hamdorf, B., Catana, L. N., & Kuzava, G. S. (2017). Exploring the Feasibility of Algae Building Technology in NSW. Procedia Engineering, 180, 1121–1130. https://doi.org/10.1016/j.proeng.2017.04.272

Zhao, J., & Carter, K. (2020). Do passive houses need passive people? Evaluating the active occupancy of Passivhaus homes in the United Kingdom. Energy Research & Social Science, 64, 101448. https://doi.org/10.1016/j.erss.2020.101448